The association between cardiorespiratory fitness and performance in a submaximal stepping test standardised for external workload.

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Abstract

Submaximal step tests are used to predict maximal oxygen consumption and work capacity. However, if the external workload is not controlled the interpretation of the test results may be inaccurate. The purpose of the research was to develop a submaximal test of cardiorespiratory fitness using a novel step test designed specifically to overcome the weaknesses of the previously published step tests.

A series of studies contributed to the theoretical development of the submaximal step protocol, piloting the protocol, reliability studies, validation of the protocol and finally a cross-validation of the protocol. The first study tested the hypothesis that stepping tests configured for the same external workload, but varying in stepping frequency, elicit the same physiological stress. Participants ($n = 31$) performed three step tests at 16, 20 and 24 steps per minutes in random order. External workload was standardised at 45 kJ. Energy expenditure, heart rate recovery, rating of perceived exertion, maximum heart rate and total heart beats were significantly different between tests ($p < 0.05$) with the biggest differences occurring between 16 and 24 steps per minute. Maximum heart rate as a percentage of age predicted heart rate increased from 70% at 16 steps per minute to 81% at 24 steps per minute. The study concluded that standardisation of external workload with different exercise intensities does not result in the same physiological responses. The second study tested the reliability of the step test. Participants ($n = 34$) performed a step test three times in a week at a cadence of their choice (16, 20 or 24 steps per minute). The study showed that the step test is repeatable for most variables measured and therefore is a reliable test of fitness.

The third study used the outcome variables measured during the step test to develop equations which predicted VO_2max measured directly in a maximal test on a treadmill. A diverse sample of participants ($n = 273$), differing in sex, level of habitual physical activity and age were recruited for the study. Several models for predicting VO_2max were determined. The most parsimonious equation was:

$$VO_2max\ (ml.kg^{-1}.min^{-1}) = -0.10911\ (age) - 0.06178\ (body\ mass) - 0.75481\ (body\ fat\ \%) +0.00208\ (METS) + 0.11636\ (HRR) - 0.019551\ (MHR) + 0.07955\ (Av\ HR) + 83.34846$$

(R^2 = 0.75, standard error of estimate = 5.51 ml.kg.min^{-1}) where METS is metabolic equivalent, HRR is heart rate recovery, MHR is maximum heart rate and Av HR is average heart rate.

Cross validation was done (n = 50) to test the accuracy of the prediction equation. The relationship between the predicted VO_2max and the measured VO_2max was r = 0.87. In conclusion the standardised step test can predict VO_2max in a heterogeneous population of males and females, varied ages (20 to 60 years), physical activity levels and fitness levels.

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Dedication

I dedicate the thesis to my dad who departed when I was finalising and my late maternal grandmother who made me embark on the journey.

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CHAPTER 1

LITERATURE REVIEW

1.1 Introduction

Cardiorespiratory fitness, which represents the effectiveness of the body's respiratory and circulatory system to supply adequate oxygen to working muscles, is generally regarded as a marker for general fitness status. In addition to cardiorespiratory fitness the other components of fitness are muscular endurance, flexibility, balance, speed, muscular strength, power, agility, coordination, reaction time and body composition. The assessment of cardiorespiratory fitness provides a measure of fitness status and changes in cardiorespiratory fitness provide a measure of the effectiveness of a training programme. Also, an individualised exercise-training programme can be prescribed based on cardiorespiratory fitness measured at the start of training.

As a consequence, cardiorespiratory fitness, also known as aerobic capacity, has often been assessed in studies on physical activity and health. The first well documented test of aerobic capacity was the Astrand and Ryhming test, developed in 1954 [1]. This was a submaximal test that used a cycle ergometer to control the workload. The test gained popularity and in the 1960s many other walking, running and stepping tests were developed to cater for different purposes and needs. These tests required either a maximal effort, or were submaximal and predicted the aerobic capacity from measurements during the test.

1.2 Measures of Cardiorespiratory Fitness

1.2.1 Maximal Tests

Maximum oxygen uptake (VO_2max), the classical measurement of cardiorespiratory fitness is a function of the maximum rate of oxygen consumption. The magnitude of VO_2max is dependent on the transport of oxygen by the cardiorespiratory system from the atmosphere to the exercising muscles, followed by the utilisation of oxygen by the metabolically active tissue [2]. To accurately determine VO_2max a participant performs a maximal test to exhaustion and oxygen consumption is measured via indirect calorimetry. The test is usually performed either on a treadmill or cycle ergometer in a laboratory; however tests can also be performed on other ergometers (e.g. swimming flume, kayak ergometer). The VO_2max test is regarded as the "gold standard" measurement of aerobic capacity [3]. A VO_2max measurement is not an assessment of a participant's athletic performance *per se*, but rather it reflects the participant's maximal ability to consume oxygen during high intensity exercise. The accuracy of the measurement is dependent on the measurement technique, which involves calibration of equipment for measuring oxygen, carbon dioxide and volume of expired air. The participant also has to be fully motivated to exert maximal effort. The VO_2max also varies depending on the mode of exercise, with the highest VO_2max values recorded for exercise recruiting the most muscle mass [3]. For example, VO_2max tests involving running on a treadmill elicit the highest VO_2max values, while VO_2max tests conducted on a cycle ergometer, or kayak ergometer are lower because of the smaller muscle mass used in the activity. Due to the specificity of metabolic responses to an exercise mode, it is preferable to measure VO_2max using a mode of exercise the participant is accustomed to. Intra-individual day-to-day variation in VO_2max is 4 to 6% in individuals with no cardiopulmonary pathology or impairment [4].

The end of a VO_2max test is defined by volitional exhaustion. If the participant does not exert him/herself maximally the VO_2max will be lower than the individual physiological capacity value [3].

Maximal tests also have practical limitations. For example, measurement of VO_2max is expensive, requires a high level of technical expertise and supervision, is time consuming and impractical in non-laboratory and field-test situations. Furthermore a VO_2max test is exhausting for the participant and therefore not recommended for individuals with health problems, injuries or low fitness levels [5]. In such cases the test needs to be monitored by a physician. This has resulted in a proliferation of submaximal tests to predict cardiorespiratory fitness [6], which have overcome these limitations to some extent.

1.2.2 Submaximal Tests

Submaximal exercise refers to non-exhaustive exercise that disturbs homeostasis by increasing the basal metabolic rate. An exercise intensity below 85 percent of age-predicted maximum heart rate is considered to be submaximal [7]. Submaximal tests in the laboratory usually involve one of three modes of exercise: running, cycling or stepping and are conducted on a treadmill or cycle ergometer or involve stepping up-and-down off a bench. The tests are either single stage or multistage protocols. Worth mentioning is the nomogram for the prediction of aerobic capacity from submaximal work which was developed by Astrand and Ryhming [1]. The nomogram can be used with a cycling, running or stepping protocol and considers the relationship between heart rate during exercise and workload to predict VO_2max. Balke [8] developed a 15 minute field performance test involving running to assess the aerobic fitness of military personnel. The average energy cost or oxygen consumption for the test was calculated using time and distance measurements. Cooper also developed a shortened 12 minute running test in which participants had to cover as much distance as possible [9]. The distance covered was then used to predict VO_2max. A variety of other submaximal exercise tests have been developed since these early aerobic capacity tests. The tests involving stepping will be discussed in detail later in this chapter.

The prediction formula of VO_2max for submaximal exercise tests manipulates the linear relationship between heart rate and oxygen consumption or the equivalent work rate. The extrapolation of data from a measured submaximal performance to a predicted maximal value makes the following assumptions: (1) linearity of the heart rate versus oxygen consumption relationship, (2) a known maximum heart rate, and (3) if oxygen consumption is not measured there is consistent mechanical efficiency of exercise [10]. This principle has been applied in a number of tests including the Astrand-Ryhming nomogram [1], the Canadian Home Fitness Test based on a double bench stepping [11] and a simple step test for estimating VO_2max [12]. Some of the tests are based on the assumption that the recovery of heart rate after exercise is related to cardiorespiratory fitness. Cardiorespiratory fitness can therefore be predicted with reasonable accuracy by applying these principles.

Exercise duration and the choice of protocol, steady state versus progressive/ incremental exercise have an effect on physiological responses [13]. When a submaximal test is used to predict VO_2max the test duration should be such that the participant assumes a steady state. Donald et al [14] suggest that steady metabolic state can be attained within one minute of exercise. However Shephard [15] refutes the one minute proposal suggesting that it leads to serious errors and under-predicts

VO_2max by 5 to 15% at higher workloads. Fitchett [13] found that heart rates from progressive protocols were consistently lower than those from steady state protocols.

1.3 Heart Rate as a Physiological Determinant of Cardiorespiratory Fitness

Two of the most widely used variables to predict cardiorespiratory fitness are heart rate during steady-state submaximal exercise and heart rate during recovery from steady state submaximal exercise. Tests are based on the principle that the lower the heart rate during exercise or the faster the heart rate recovers after exercise the fitter the individual. The relationship between heart rate and other exercise-related parameters is influenced by physiological and environmental factors.

Although the heart initiates its own electrical impulse (intrinsic control) for contraction in the sinoatrial node, the timing and effects can be altered through extrinsic systems, namely the autonomic nervous system and the endocrine system (hormones) [16]. The heart has a rich supply of sympathetic and parasympathetic nerve fibres which regulate heart rate.

At rest the parasympathetic system activity predominates in a state referred to as vagal tone. The parasympathetic innervation runs in the paired vagus (10^{th} cranial) nerve. The vagus contains preganglionic axons that synapse on postganglionic neurons in a ganglionic plexus that lies among the cardiac muscle cells. Both the preganglionic and postganglionic neurons release the transmitter acetylcholine. Postganglionic cells possess nicotinic receptors while cardiac cells possess muscarinic receptors. Most of the parasympathetic postganglionic neurons synapse on cells of the atria and conducting system, the sinoatrial and atrioventricular nodes and not on the ventricular myocardium [17]. The vagus nerve has a depressant effect on the heart. It slows the impulse conduction and thus decreases heart rate. Maximal vagal stimulation can lower the heart rate to between 20 and 30 beats per minute. The vagus nerve also decreases the force of cardiac contraction [16].

The sympathetic nervous system has opposite effects. Sympathetic postganglionic cells connect to the heart from the thoracic sympathetic chain ganglia. Sympathetic neurons make adrenergic synapses both on the pace makers in the nodes and on the ventricular myocardium. Sympathetic activation of the adrenal medulla delivers the hormone adrenaline to all parts of the heart by way of the coronary circulation. As a result, the sympathetic nervous system can influence both the heart rate and the strength of ventricular contraction in systole [17]. Sympathetic stimulation increases impulse conduction speed and thus heart rate. Maximal sympathetic stimulation allows the heart rate to increase to about 200 beats per minute. Sympathetic input also increases the contraction force. The sympathetic system predominates during times of physical or emotional stress when the body's demands are higher. After the stress subsides the parasympathetic system again predominates [16].

The endocrine system exerts its effects through the hormones released by the adrenal medulla, adrenaline and noradrenaline; these hormones (adrenaline and noradrenaline) are referred to collectively as catecholamines. Similar to the effect of the sympathetic nervous system, these hormones stimulate the heart, increasing its rate. In fact, release of these hormones is triggered by sympathetic stimulation during times of stress, and their actions prolong the sympathetic response [16]. Postganglionic sympathetic fibres that release noradrenaline are distributed in the entire myocardium. A sympathetic activation of the adrenal medulla releases adrenaline and some noradrenaline. The effect of transmitter substances are determined by the membrane receptors of the target cells [18]. There are two main groups of receptors, alpha (α) and beta (β) adrenergic receptors with subgroups α_1 and α_2 and β_1 and β_2. Alpha-receptors are found mainly in the cell membranes of vascular smooth muscle cells and α- adrenergic activity causes vasoconstriction. In the heart α-receptors are sparse so adrenaline and noradrenaline activate mainly β receptors. This increases the heart rate by increasing the firing pattern of the sinoatrial node and increases the conduction velocity of the atria, the atrioventricular node and the Purkinje system. The effect is the opposite of stimulation of the parasympathetic nerve and is called chronotropic action. β_1 adrenergic activity increases the activity of myocardial contractility, that is, the strength of contraction at any given end-diastolic volume. This increases stroke volume at the expense of a reduced end-systolic volume. This effect exerted by catecholamines is called positive inotropic action [18].

A chronotropic effect is an alteration of the heart rate. The bradycardia caused by the parasympathetic input is a negative chronotropic effect, while the tachycardia caused by sympathetic input is a positive chronotropic effect. Chronotropic effects are a result of changes in the rate of diastolic depolarisation, the process by which the pacemakers of the sinoatrial SA node automatically return to threshold after an action potential. An inotropic effect is an alteration of the contractile properties of myocardial cells. Activation of the β_1-adrenergic receptors of myocardial cells by adrenaline or noradrenaline results in a positive inotropic effect, or increase in the force of contraction during systole [17].

The venous filling of the heart determines the size of the stroke volume. An increased sympathetic drive elevates the heart rate and the heart beat becomes more forceful. This increases the myocardial oxygen uptake and coronary blood flow. The net effect is a dilation of the coronary vessels. The inherent rate of the heart beat can be highly modified and can range from about 40 beats per minute at rest to about 200 beats per minute during heavy exercise in a young individual [18].

At rest in a supine position, cardiac output is 4 to 6 $L.min^{-1}$ depending on body size. In a passive feet down position cardiac output decreases due to venous pooling. The stroke volume is reduced and the heart rate increases. The oxygen uptake is unchanged and hence the arteriovenous oxygen difference (a-v) O_2) is increased. Activation of the skeletal muscle pump propels the blood towards the heart and heart rate may decrease as stroke volume increases. During exercise cardiac output increases with increasing oxygen uptake. Blood flow is redistributed so that skeletal muscles receive 80% to 85% of the cardiac output compared to about 15% at rest [18]. Cardiac output (Q) is the product of heart rate (HR) and stroke volume (SV). (Q = HR X SV) [16]. Therefore the relationship between heart rate, oxygen uptake and exercise intensity can be used to assess cardiorespiratory fitness.

1.3.1 Resting Heart Rate

Resting heart rate decreases after endurance training [19,20,21]. Wilmore at al [20] found small but significant decreases in resting heart (2.7 to 4.6 $beats.min^{-1}$ at 72 hours post training) after a 20 week endurance training programme. Smith et al [22] investigated the mechanism behind bradycardia. They suggested that the decrease in resting heart rate after training was due to changes in the intrinsic rhythmicity of the heart and an increase in the predominance of parasympathetic control. The sympathetic contribution to heart rate decreases slightly [22].

1.3.2 Heart Rate during Exercise

The time between each heart beat varies at rest or during low intensity exercise; this is referred to as heart rate variability. Heart rate variability decreases with increasing exercise intensity [23,24]. This is due to the different firing patterns of the autonomic nervous system as exercise intensity increases [25]. During rest and low intensity exercise the parasympathetic nervous system is dominant and fires infrequently to cause variations in the time interval between heart beats [26]. As the exercise intensity increases the firing of the parasympathetic nervous system reduces [25] and there is activation of the sympathetic nervous system [26,27,28], resulting in decreases in heart rate variability.

1.3.3 Effect of Endurance Training on Submaximal and Maximal Heart Rate

Heart rate at the same submaximal exercise intensity under controlled conditions decreases after endurance training. The decrease is due to a decrease in sympathetic activity [29,30,31,31], enhanced intrinsic heart rate regulation, increased baroreceptor and metaboreceptor sensitivity and improved autonomic balance after endurance training [32].

Maximal heart rate decreases with endurance training [33,34,35] and increases with detraining [36,37]. Maximum heart rate decreases by between 5 and 13 beats per minute with aerobic training and increases by 4 to 10 beats with reduced training or detraining [38]. Proposed mechanisms for the decrease in maximal heart rate after endurance training include plasma volume expansion [34], enhanced baroreflex function [39] and decreased β-adrenergic receptor number and density [40,41].

1.3.4 Factors Affecting Heart Rate during Exercise

Heart rate during exercise is affected by environmental conditions. When exercising in hot conditions (i.e. temperatures above 30 ºC), heat loss mechanisms such as evaporation, conduction, convection and radiation are less efficient. As a consequence heart rate is about 10 beats per minute higher at submaximal exercise intensities in the heat than it would be during cool conditions [42,43]. Therefore under these conditions heart rate overestimates the intensity of exercise [44]. These findings show that it is unreliable to use heart rate to monitor exercise intensity under such conditions, although it remains a good general marker of physiological stress.

The time of day and altitude are other factors that affect heart rate during exercise and should be controlled when heart rate is measured. Measurement of heart rate should be done at same time of day to cater for circadian changes in heart rate and minimise circadian effect on heart rate [45]. When exercising at altitude the heart rate/VO_2 relationship remains linear, however submaximal heart rate is elevated at a given VO_2. Another factor that can affect the heart rate/workload relationship is the duration of exercise. After prolonged exercise, particularly exercise in the heat, blood volume decreases. This results in an increase in submaximal heart rate at the same submaximal workload [23,46].

In summary, submaximal heart rate can represent the exercise intensity and can also be monitored at regular intervals and used as a marker of changes in training status. While a decrease in submaximal heart rate at a controlled absolute workload indicates a positive adaptation to training, an increase in submaximal heart rate indicates either overtraining [44,47], dehydration [46] or a decreased training status.

1.3.5 Heart Rate after Exercise

Heart rate recovery is the rate at which heart rate decreases towards resting levels after moderate to heavy exercise. Heart rate recovery is a measure of the regulation of the autonomic nervous system [48]. Following the cessation of exercise, heart rate decreases almost immediately, with the initial decrease being almost linear. The rate of reduction of heart rate is dependent on the withdrawal of input from the sympathetic nervous system and the reactivation of the input of the parasympathetic nervous system [24,49,50,51]. Many researchers describe a coordinated interaction between parasympathetic reactivation and sympathetic withdrawal with sympathetic withdrawal occurring faster and therefore playing an important role in the early decrease in heart rate recovery [50,32,52,51]. The parasympathetic drive is higher during recovery [50] than during the preceding workload. Hence heart rate variability is also higher during recovery than during the preceding exercise [24].

Heart rate recovery is an indicator of cardiorespiratory fitness; a general principle is that the faster the rate of heart rate recovery, the higher the fitness level of participants [53,54]. Indeed, the heart rate of well-conditioned, trained, physically active participants recovers faster than untrained participants [23,54,55,56,57,58]. Cardiorespiratory fitness can be predicted with a reasonable accuracy by applying the relationship between the rate of heart rate recovery and fitness [54,56,58]. A heart rate recovery of 12 beats or less in the first minute is a strong predictor of subsequent mortality [59,60].

The heart rate at the end of exercise influences the decrease in heart rate during recovery [27]. Heart rate recovery is slower after maximal exercise than after submaximal exercise. This is due to the sympathetic nervous system, which is stimulated significantly more during maximal exercise [49] and continues to dominate into the recovery phase, contributing to sustained tachycardia despite parasympathetic nervous system reactivation [27]. After high intensity exercise sympathetic withdrawal contributes to heart rate deceleration whereas after submaximal exercise heart rate recovery is mainly controlled by parasympathetic reactivation. Exercise intensities ranging between 86 and 93% of maximum heart rate have the most stable heart rate recovery, therefore the highest sensitivity to detect meaningful changes on a day-to-day basis [61].

1.3.6 Application of the Heart Rate Data

Heart rate and VO_2 increase linearly with increasing exercise intensity up to near maximal exercise. An individual's aerobic fitness is reflected in the slope of the heart rate-VO_2 curve. Heart rate during exercise can therefore be used to estimate VO_2. Astrand and Ryhming [1] used the heart rate-VO_2 relationship in a nomogram designed to predict VO_2max. The method is based on the assumption that the relationship between heart rate and VO_2 is linear over the entire range of exercise intensities. In fact the relationship is curvilinear at very low exercise intensities and towards maximal exercise. Therefore the accuracy of the prediction diminishes at these extreme ends of the relationship. Also, the prediction of VO_2max from submaximal heart rate has limitations if the factors that affect heart rate during submaximal exercise are not controlled.

In summary, heart rate can be used as a marker of exercise intensity. Furthermore, both resting and submaximal heart rates decrease with endurance training, whilst heart rate recovery after exercise increases with endurance training. All these measurements are affected by external factors that need to be controlled to improve sensitivity. Heart rate recovery after exercise can be used to predict cardiorespiratory fitness using the relationship between heart rate recovery and fitness. If the heart rate/VO_2 relationship is known, VO_2max can be predicted from heart rate. This relationship has practical application and has been used with several different exercise modalities [4,62,63,64,65,66,67,68,69,70,71,72,73,74,75,76]. Step tests have been the most popular mode of exercise to assess cardiorespiratory fitness and have received the most attention from a validation perspective. The explanation for this is that most people are accustomed to stepping and therefore do not have to be familiarised with the mode of exercise, and the step test does not require expensive equipment. For these reasons step tests have the potential to have a useful practical application for the assessment of cardiorespiratory fitness.

The next section will discuss the various step tests that have been developed to predict VO_2max using the principles of measuring heart rate either during or after exercise.

1.4 Step Tests

1.4.1 Introduction

Step tests are amongst the earliest submaximal tests designed to predict VO_2max [1], possibly because the protocols can be easily controlled. Step testing is an inexpensive form of a submaximal test and is appealing because it does not involve laboratory equipment. The first step tests were used in the early part of the 20th century. Many of the step tests that are used today are derived from these early tests. As a result there are a multitude of tests that are currently in use, some which have been validated and others which have not. Unfortunately it has become difficult to differentiate the validated tests from those that have been developed without undergoing any form of systematic analysis. The following section is a review of all known step tests. The aim of the review is to describe each of the tests, in particular the information that describes the accuracy and validity of each test. The review describes the required protocol when performing step tests and also analyses the manner in which the step tests were validated. A brief description of each step test is given in Table 1.

Table 1 Brief description of step tests

Year	Test	Brief description	Publication
1920	Cardiovascular efficiency test	Cardiovascular rating based on changes in cardiovascular system following six different interventions, including 15 seconds step test	Schneider, E.C. [77]
1931	Pulse-Ratio test	The ratio of the resting heart rate to heart rate after exercise (obtained by dividing two minutes heart rate after a known amount of exercise by one minute resting heart rate).	Tuttle,W.W. [78]
1942	Harvard step test	Five minute step test, the score is obtained by dividing the duration of exercise by the total of the heart beats during the different phases of recovery	Johnson,R.E. Brouha, L. Darling,R.C. [79]
1954	Astrand-Ryhming nomogram	Submaximal step test, treadmill test or cycle test. Oxygen at 50% and 70% of VO_2max is plotted against heart rate and nomogram worked out with scales of work levels (cycle test) and body weight (step test). Oxygen intake from the scales and heart rate were used to calculate VO_2max.	Astrand, P.O., Ryhming, I. [1]
1961	YMCA 3-Minute step test	Three minute step test, 30.5 cm step at 24 steps per minute. One minute sitting recovery heart rate determines fitness category	Kasch, F.W. [80]
1965	Balke step test	Adjustable platform from 2 to 50 cm, 24 or 30 steps per minute for 20 minutes or to exhaustion respectively. Total oxygen intake obtained using the equation: Total VO_2 = standing VO_2 + 1.33 × horizontal VO_2 + 2.4 × vertical ascent	Nagle, F.J., Balke, B., Naughton, J.P. [81]
1972	Queen's college step test	Three minutes step test, 15 s recovery heart rate, regression line used to predict VO_2max	McArdle, W. et al. [82]
1975	Canadian home fitness test	Multistage step test, each stage three minutes long, double step used, 10 s recovery heart rate	Shephard, R.J. et al [11]
1995	Chester step test	Five stage step test each stage two minutes long, heart rate and RPE are continuously measured throughout the test	Sykes, K. Roberts, A. [83]

2003	Cambridge step test	Eight minutes step test, gradual increase in stepping rate, resting, exercise and recovery heart rate used to predict VO_2max	HSE [84,85]

1.4.2 Cardiovascular Efficiency Test

The Cardiovascular efficiency test was developed during the First World War in response to the need to measure physical efficiency, fatigue, physical fitness and health of aviators [77]. A cardiovascular rating based on six sets of observations of cardiovascular changes was developed for the test: (1) reclining heart rate (2) standing heart rate, (3) heart rate increase from reclining to standing, (4) heart rate increase due to exercise, (5) time taken for heart rate to return to resting heart rate from a standing posture and (6) rise or fall in systolic blood pressure on standing.

The participant reclines for five minutes and heart beats are counted for 20 seconds, multiplied by three to get heart rate in beats per minutes and recorded. Systolic blood pressure is recorded when the participant is still reclining. From a standing position heart beats are counted for 20 seconds, multiplied by three and heart rate recorded. The difference between the standing and reclining heart rate is recorded. Standing systolic blood pressure is recorded and the difference between standing and reclining systolic blood pressure is determined. The stepping exercise follows. This involves stepping on a chair about 45.7 cm high five times in 15 seconds. This is equivalent to a stepping rate of 20 steps per minute. Immediately after the 15 seconds of exercise the heart beat is counted for fifteen seconds, multiplied by four and recorded. Counting continues in fifteen seconds intervals for two minutes, with the counts being recorded at 60, 90 and 120 seconds. The difference between exercise heart rate and standing heart rate is determined. The time taken for the heart rate to return to standing heart rate is also recorded. The scores for each of the six items range from +3 to -3. When all items are added together the perfect score is 18. A score of 9 or less is considered a low score that requires further investigation by a medical examiner.

The results obtained from the cardiovascular efficiency test were compared with medical examination results [77]. Aviators underwent a thorough medical examination and 54 were found to be physically unfit. The Cardiovascular efficiency test was administered on the 54 aviators and 89% had scores ranging from -1 to 9. Only 11% scored above 9. The results indicated that a score of 9 or less is characteristic of unfit men.

To verify the results obtained from the cardiovascular efficiency test, 150 men were tested and 46 men scored 9 or less. Medical examination results of the 46 men indicated that 65% were “unfit”.

The Cardiovascular efficiency test scored men as either “fit” or “unfit” according to cardiovascular responses. Whilst the test gives some indication of an individual’s fitness, questions concerning the aerobic capacity of the participant remain unanswered. The test does not provide precise individual measurements of fitness and has not undergone a systematic evaluation.

1.4.3 Pulse-ratio Test

The next recorded step test was the pulse-ratio [78]. This test was designed to measure physical efficiency based on various tests that had been done at State University of Iowa. The objective was to develop a test for coaches for rating physical efficiency with a high degree of accuracy. The pulse-ratio represents the ratio of the resting heart rate to heart rate after exercise and is obtained by dividing total number of heart beats for two minutes after a known amount of exercise by the heart beats in one minute during rest. For example, if the total number of heart beats for two minutes after exercise is 210 beats and the resting heart rate for one minute is 70 beats, then the pulse ratio is three.

This protocol requires a standard exercise that has the same relative demands on all participants, for a comparison of heart rate response between individuals or the same individual under different conditions. In earlier research Hambly and his workmates [86,87] investigated various types of exercise such as walking, stair-climbing and running and recommended using a stepping or stool climbing exercise as this could be standardised and the protocol is convenient, flexible, and does not require skill. The amount of work performed can be varied to suit the experiment under consideration by varying the rate of stepping or by increasing the duration at a uniform rate. A 33 cm stool is used with stepping rates ranging from 15 steps per minute to 60 steps per minute. Uniformity in technique execution is emphasised. A calibrated metronome is used to control the stepping rate. The participant steps for one minute at a determined stepping rate. Immediately after the exercise, heart beats are counted for two minutes.

An empirical standard pulse-ratio of 2.5 was adopted to compare the efficient ratings of different individuals or those of the same individual under different conditions. According to the procedure the standard pulse ratio remains constant while the amount of standard exercise required to produce it is the variable factor. The amount of work required to produce a pulse-ratio of 2.5 is determined as number of steps per minute and is the basis of rating an individual's efficiency. This value is derived from a graphic calculation where two ratios are given, one below and the other above the 2.5 ratio. A certain amount of work is selected, for example 18 steps per minute, which gives a pulse-ratio below 2.5. Then a second one is employed, 30 or 40 steps per minute, which gives a ratio above 2.5. Two data points are plotted and connected by a straight line on a graph, with number of steps on the X axis plotted against pulse ratio on the Y axis. A line is dropped from the point where the line crosses the 2.5 pulse-ratio to the base-line (X axis) representing the number of steps per minute.

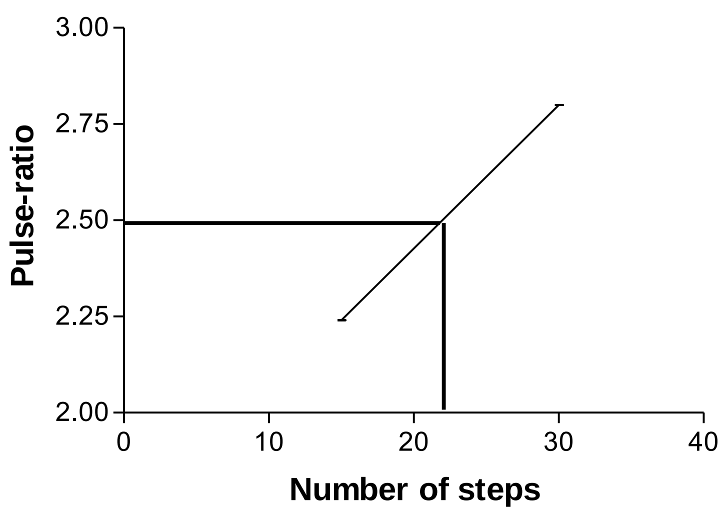

Figure 1 The graphic calculation of the number of steps that produce a pulse-ratio of 2.5

For comparison purposes the number of steps required to produce a 2.5 pulse-ratio is converted into percent efficiency. The amount of exercise required to produce a pulse-ratio of 2.5 is assumed to be 50 steps and the value 100% is assigned. The following formula is used to reduce the data to an arbitrary percent.

$$\textit{Efficiency rating} = \frac{\underline{100\ (\textit{Number of steps required for 2.5 pulse-ratio})}}{50} \qquad \text{(Equation i)}$$

The basis of the pulse-ratio test is to measure the cardiac response to exercise. It shows physiological changes that are reflected by the compensatory mechanism of the heart. The test has been used to investigate the effect of athletic performance [88,89], physical efficiency [90,91], fatigue [78] and smoking [78] on cardiac response to exercise.

Physical efficiency of athletes (n = 80) was compared with the physical efficiency of sedentary people (n = 90) [78]. Athletes had a mean efficiency rating 6% higher than non-athletes. However, the study does not provide measurement error data making it impossible to determine whether the 6% was outside the margin of error. Data also indicated a 95% chance that athletes have a higher efficiency than non-athletes. An investigation on the effects of fatigue data showed that fatigue induced by 250 deep knee-bends decreased efficiency by 22%.

An investigation on the effect of smoking on high school boys (n = 15) showed that the mean efficiency of smokers was 5% less than that for non-smokers [78]. The authors acknowledge that the sample is small but the results agree with the general accepted view regarding smoking. In another study the physical efficiency of university women who were habitual smokers (n = 10) was determined by the pulse-ratio test [78]. Smokers were 13% less efficient than non-smokers.

The concept of standardising work for a test of physical fitness was considered by Tuttle in the pulse ratio test [88]. It occurred to him that a step test presented as a simple physical activity that could be standardised for participants for comparison purposes. The pulse-ratio test rates physical efficiency. However, assumptions were made when designing the test, making the results only good for comparison purposes, and not as a measure of an individual's fitness level. For example, the use of 2.5 as a standard pulse ratio was done so that efficiency ratings of different individuals could be compared. Another assumption made was that 50 steps was the number of steps that result in 100% efficiency. Tuttle also observed that when the calculated number of steps required for a 2.5 ratio was performed, the resulting pulse-ratio was not 2.5 [78]. Due to the development of later tests that could either predict or measure physical fitness, the pulse-ratio test was relegated as a fitness test and has not been adopted as a protocol in research.

1.4.4 Harvard Step Test

The Harvard step test, first described in 1942, was developed in the Harvard Fatigue Laboratories during World War II and has since been used in research [79]. During the test the participant steps up and down, 30 times a minute for five minutes off a 50.8 cm platform. The test may end before five minutes if the participant gets exhausted before that. With the original version of the test the tester counted the pace *up - 2 - 3 - 4*, every two seconds, however more recently a metronome has been used to control the pacing. At the end of the test the participant sits down. The tester records the duration of exercise and the number of heart beats from 1 to1 ½, 2 to 2½ and 3 to 3½ minutes after the end of the exercise. The score is obtained by dividing the duration of exercise in seconds by the total of the heart beats during the different phases of recovery, according to the following formula.

$$\textit{Index*} = \frac{\textit{Duration of exercise (seconds) x 100}}{\textit{2 x total heart beats in recovery**}} \qquad \text{(Equation ii)}$$

*The index has no units, it is just a numerical value

**Sum of beats from 1 to1 ½, 2 to 2½ and 3 to 3½ minutes

The interpretation of the test was simplified by the compilation of a table for participants who managed to complete five minutes of the test. The heart beats for the three recovery periods are added and the scores compared to normative data. The score is interpreted as follows: below 55 = poor; from 55 to 64 = low average; from 65 to 79 = high average; from 80 to 89 = good; above 90

= excellent [92]. The fitness categories were derived from the results of many tests that were done in the Harvard Laboratories. There are differences in the fitness categories that were used when the test was first described for different forms of exercise such as running uphill on a treadmill, pulling a stone boat with a load one-third of the participant's body mass, rowing against a heavy load, cycling on a bicycle ergometer against a load proportional to the body mass [79] and the fitness categories when stepping was the mode of exercise [92]. The average score for the Harvard College population irrespective of training was 75 with a range from 15 to 120 [92].

The original Harvard step test was designed for adult men. Reedy, Saiger and Hosler conducted a study on army trainees to determine if height and weight influenced an individual's performance in the Harvard step test [93]. They showed that a combination of height and weight factors had no significant influence on the scoring of the Harvard step test. When height was analysed independently it did not influence the Harvard test score significantly. However, when weight was analysed independently, lighter men achieved significantly higher scores than heavier men regardless of the fitness of the participants. Sloan [94] modified the Harvard step test to accommodate women by lowering the height of the step to 43.2 cm. Bandyopadhyay [95] concurred with Sloan [94] that the original Harvard step test was very strenuous and unsuitable for children, short, untrained and aged people.

However, Ricci et al [96] showed that it was not necessary to lower the step height to cater for shorter people. They investigated the energy cost and efficiency of the Harvard step test performance with two male and two female graduate students in the same work categories using a 50.8 cm bench. Females were 159 cm and 163 cm stature whereas the males were 175 cm and 185 cm tall. Females also had shorter leg lengths and weighed less than the males. Participants performed the Harvard step test on alternate class days during a six-week period. The test scores of all participants improved with females achieving the "excellent" category of the Harvard step test and the males achieved "good" and "high average" scores. Open-circuit indirect calorimetry was used and exhaled gases were collected in Douglas bags. A similar pattern in oxygen uptake during the Harvard step test and recovery was observed in males and females with female values slightly lower than males. The energy cost for males was also slightly higher than females.

However female participants had higher net efficiency ratings than males. Participants reported discomfort in the quadriceps and none reported discomfort in the knee joint due to fatigue. Contrary to the findings of Sloan [94], Ricci et al [96] found no justification for lowering the step height for women as they achieved high Harvard step test score, high net efficiency ratings and low oxygen debt values. They suggested that the unsuccessful completion of the test, especially by women, might be a reflection of motivation levels and discomfort tolerance levels rather than cardiorespiratory response to exercise. However it should be pointed out that the sample size of the study of Ricci et al [96] was too small to represent all women, and therefore their conclusions are inconclusive.

Many single stage step tests have been developed from the original Harvard step test by modifying work variables (step height, step frequency, stepping duration) and the scoring method. For example of such tests are the Queen's college step test [82] and the YMCA three minute test [80].

1.4.5 Astrand-Ryhming Nomogram

Astrand and Ryhming [1] developed a nomogram for calculating aerobic capacity based on a series of studies on healthy men and women aged 20-30 years. Participants did submaximal work adjusted so the workload demanded oxygen intake of approximately 50% of VO_2max. This elicited a mean heart rate of about 128 beats per minute in men and 138 beats per minute in women after about six minutes. Participants then exercised at an oxygen intake 70% of VO_2max. The heart rates at this workload were about 154 and 164 beats per minute in men and women respectively. The relationship between heart rate and oxygen intake expressed as a percentage of VO_2max was plotted on a graph using the two data points. A nomogram to calculate aerobic capacity was determined based on these relationships.

Astrand [97] found that oxygen intake could be calculated from work level within a range of ± 6% in two thirds of the participants. A similar range was obtained when oxygen intake was calculated from work done on a step test [98]. The step height was 40 cm for men and 33 cm for women and the stepping rate was 22.5 steps per minute. The work done was calculated from body mass, step height and a constant mechanical efficiency.

Based on the findings of the experiments by Astrand and Ryhming [97,98] scales for work levels (cycle test) and body mass (step test) were added to the nomogram. A conception of energy output can be obtained by reading horizontally from these scales to the 'oxygen intake' scale.

A study examined the validity of the predicted measurement of VO_2max against measured VO_2max determined in maximal treadmill or cycle ergometer tests [97]. Well trained participants (27 males and 31 females) aged between 20 and 30 years performed a submaximal cycle test at 900 kg $m.min^{-1}$ (women) and 1200 kg $m.min^{-1}$(men). The difference between measured and calculated VO_2max was 0.55% in men and 0.34% in women [1]. The coefficient of variation was less than 7% for men and 9% for women. However, with a lower work rate, (600 kg $m.min^{-1}$ for women and 900 kg $m.min^{-1}$for men), the coefficient of variation was higher, 14% and 10% respectively.

In another study designed to validate the nomogram 18 well trained male participants aged 18-19 years did a VO_2max test [99]. It is not clear if the VO_2max test was done on a treadmill or cycle ergometer. Participants also did two submaximal tests; a step test with a step height of 40 cm at 22.5 steps per minute and a treadmill test with the treadmill set at 1º elevation and at 10 $km.h^{-1}$. Oxygen intake and heart rate data measured during these submaximal tests were used to predict VO_2max. The difference between predicted and measured VO_2max was 0.15% in the step test and 0.49% in the treadmill test. The coefficient of variation was less than 7% [1].

VO_2max for 31 female and 28 male participants aged 20-30 years was calculated from heart rate and oxygen intake obtained from a cycle test of 600 kg $m.min^{-1}$ (women), 900 kg $m.min^{-1}$ (men) and a step test and the results were compared. The difference between the means was 0.61% for women and 0.10% for men. The standard deviation was 9.5% for men and 7.3% for women. Both the cycle test and step test had similar VO_2max predictions.

The Astrand-Ryhming nomogram does have limitations. For example, comparisons of predicted and measured VO_2max have consistently shown that the Astrand-Ryhming nomogram under predicts VO_2max [100,101,102,103,104]. However, many of the studies attempting to validate the nomogram have had methodical concerns, which have militated against the interpretation of the results. Also some of the experiments compared VO_2max predicted from a cycle ergometer protocol with that measured from a treadmill protocol [100,105].

Another limitation of the Astrand-Ryhming nomogram is the assumption of the linearity between VO_2 and heart rate over the whole range of effort [105]. It is understood that at near maximal levels the relationship is non-linear, exponential and asymptotic [101,106,107].

The nomogram was developed on healthy participants aged 18 - 30 and subsequently adapted for use over a wide range of age groups and physical fitness levels. Individual variations in fitness affect the accuracy of construction and predictive ability of the nomogram and limit its applicability to groups of different ages and fitness. The authors were aware of this limitation and advised that caution should be taken when using the nomogram for different age groups. They developed an age correction factor [108].

In summary, the Astrand-Ryhming nomogram was developed on a group of young men and women and the prediction equation was adjusted for older people. The test is based on submaximal work; up to 70% of an individual's age predicted maximum heart rate that engages large groups of muscles (i.e. bench stepping, cycling on a cycle ergometer and running on treadmill). The test duration is five to six minutes, a duration that allows circulation and ventilation adjustments to the level of exercise. VO_2max is calculated from heart rate and oxygen intake or work level reached during the test. Although the precision of the prediction equation has been established, some of the validation studies had methodological limitations and therefore these results should be interpreted with caution.

1.4.6 YMCA 3-Minute Step Test

The 3-minute step test was developed by Kasch and first documented in 1961 [80]. The step test involves stepping on a 30.5 cm step at 24 steps per minute for three minutes. Within five seconds of completing the test the participant sits on a bench and heart beats are counted for one minute. In its original form the step test used one minute heart beat count as the score to determine a participant's fitness category [109]. Now the test uses heart rate after one minute of recovery to categorise participants according to age and sex. The categories are: very poor, poor, below average, average, above average, good and excellent. A low heart rate at the end of the one minute of recovery is rated highly. In 1970 the Young Men's Christian Association (YMCA) adopted the 3-minute step test as a simple and fast method of assessing cardiorespiratory fitness and this became known as the YMCA 3-minute step test [109].

The YMCA 3-minute step test categorised cardiorespiratory fitness but did not estimate VO_2max. Therefore it could not be used to design individualised training programmes based on VO_2max data.

Santo and Golding [109] investigated the effect of adjusting step height on the relationship between heart beat count in the YMCA 3-minute step test and VO_2max. They also investigated whether a shorter recovery heart beat count of 15 seconds resulted in a better correlation between VO_2max and heart beat count than a longer period of one minute. Sixty participants (27 women and 33 men) aged 18 to 55 years performed the YMCA 3-minute step test followed by a VO_2max test. Step height was adjusted according to participant stature using the equation $H_f = (0.187)\ (I_h)$ for women and $H_f = (0.190)\ (I_h)$ for men, where H_f represents bench height in cm, and I_h represents the participant's height in cm [53,110]. Heart beat count was recorded by an electrocardiogram (ECG) and the printout was used to determine heart beat count at 15 seconds and one minute after the step test.

Forty-four participants (22 women and 22 men) satisfied the VO_2max test criteria and had their results analysed. There were significant correlations between both the 15 seconds recovery heart beat count and one minute recovery heart beat count with VO_2max, ($r = 0.58$) and ($r = 0.61$) respectively. The standard error of estimate (SEE) for predicting VO_2max from 15 seconds and one minute heart beat count were 8.8 and 8.5 $ml.kg^{-1}.min^{-1}$ respectively. SEE values were higher than desirable, 15 to 20% of the measured mean, probably due to the use of heart beat count and not heart rate. Heart beat count gives the total number of heart beats in a minute whereas heart rate gives the rate at which the heart beats which may vary from beat to beat. During recovery from exercise, heart rate decreases markedly in the first minute. Heart beat count cannot be used to represent heart rate recovery. Contrary to earlier studies [2,82] which suggested that the first 20 seconds recovery heart beat count yielded greater reliability than one minute recovery heart beat count, Santo and Golding [109] found no statistical significance in the 15 seconds and one minute heart beat count prediction of VO_2max. Santo and Golding [109] used sitting recovery heart beat count as opposed to standing recovery heart beat count used in previous studies [2,82]. This could be the source of the difference in findings.

One limitation of the study by Santo and Golding [109] was that they assumed a discrepancy in heart beat count from the original 3-Minute Step test which did not adjust step height according to participant height. Since the participants of this study did not perform the original YMCA 3-Minute Step test, the validity of this assumption could not be ascertained. Also, the YMCA Step test did not predict VO_2max, so no comparison could be made between the original test and the modified test.

The step test was popularised by its adoption by the YMCA. It is part of their fitness test battery and is used as a fast and convenient way of testing cardiorespiratory fitness. Since the test does not predict VO_2max it could not be validated.

1.4.7 Balke Step Test

The Balke step test is a maximal effort graded step test that differs from other step tests in that it has a gradual increase in step height and continues until the participant is exhausted [81]. Nagle et al [81] investigated the feasibility of a progressive step test for the assessment of work capacity. They evaluated two stepping procedures with an adjustable platform that could be elevated or lowered from 2 to 50 cm as the participant stepped. They used the data from the test to derive equations for the prediction of oxygen costs of stepping at various stepping rates and step heights.

Thirty-eight men aged 18 to 49 years and weighing 62 to 98 kg performed a step test at 30 steps per minute [81]. The platform was set at two centimetres and raised two centimetres every minute. Heart rate, blood pressure, respiratory exchange ratio and ventilation were measured and recorded. The test was stopped when the participant could not maintain the stepping rhythm or when pulse pressure began declining at near maximum heart rates.

To cater for participants of low physical working capacity a slower stepping rate was used. Twenty-two man aged 29 to 68 years and weighing 61 to 109 kg performed a similar test procedure at 24 steps per minute [81]. The initial platform height was 3.3 centimetres and was raised 1.7 centimetres every minute. The test was terminated after 20 minutes. Some participants did not attain their aerobic capacity when the test was terminated.

The work done when stepping was a summation of the positive work of lifting the body onto a raised platform and the negative work of lowering the body down. Experiments were done to determine the metabolic costs of each phase of a stepping cycle, standing, stepping forward, stepping down and normal stepping. To determine negative work a gradational stepping device with a windlass mechanism was used which lifted the participant rapidly to a certain height from which they stepped down. The energy cost of the negative work was obtained by subtracting the costs of standing and stepping forward horizontally from the total energy expenditure of the exercise procedure. This was done at 12 and 18 steps per minute due to mechanical limitations of the windlass mechanism. Oxygen cost for positive work was calculated by subtracting the cost of standing and negative work from the oxygen cost of the normal stepping procedure.

The oxygen intake at varying step heights at the rate of 30 steps per minute ranged from 12.0 ± 1.2 to 40.8 ± 3.5 $ml.kg^{-1}.min^{-1}$. At 24 steps per minute oxygen intake ranged from 10.7 ± 1.1 to 28.8 ± 1.3 $ml.kg^{-1}.min^{-1}$.

Negative work was about a third of positive work. Assuming that the same distribution of energy costs occurs for any combination of stepping rate and step height, an equation was derived for predicting the energy cost for stepping, where VO_2 is in $ml.kg^{-1}.min^{-1}$, vertical ascent in metres per minute and 1.8 is the approximate oxygen requirement in millilitres for 1 kg per metre of work:

Total VO_2 = standing VO_2 + horizontal VO_2 + vertical ascent × 1.8 + 0.33 (horizontal VO_2 + (vertical ascent × 1.8)) (Equation iii)

or simplified:

Total VO_2 = standing VO_2 + (1.33 X horizontal VO_2) + (2.394 × vertical ascent) (Equation iv)

The total energy cost for stepping is the sum of oxygen requirements for standing, stepping forward, stepping upward and the negative work of stepping down. The applicability of the formula was tested by comparing the predicted metabolic cost of stepping with the measured values. When stepping at 30 steps per minute the predicted oxygen intake values were approximately the same as the measured values. At 24 steps per minute the predicted values were slightly higher than the measured values but within one standard deviation of the measured, except for the last minute of work which had identical values. Therefore the energy costs of stepping at reasonable rates and heights can be predicted closely [81].

With a resting metabolic rate of 3.5 $ml.kg^{-1}.min^{-1}$ the step tests may be used to evaluate individuals with energy expenditure ranging from 2.5 to 12 times resting metabolic rate. The 30 steps per minute test ranged from 3 to 12 times and the 24 steps per minute test ranged from 2.5 to 8 times resting metabolic rate. The work intensity of the step test progresses gradually allowing for monitoring, thus conforming to the general guidelines of maximal exercise testing. The tests however could not accommodate highly trained participants who exceeded metabolic levels of 12 times resting metabolic rate at approximately 40 centimetre step height in the 20th minute of the test.

1.4.8 Queen's College Step Test

McArdle et al developed the Queen's College Step Test (QCST) at Queens College of the City University of New York in 1972 to assess VO_2max in female students [82]. The QCST protocol requires that the participant steps on and off a 41.3 cm step for three minutes at the rate of 22 steps per minute. After the test the participant stands motionless. With the original version of the test heart rate was measured by counting the pulse of the carotid artery for 15 seconds (5 - 20 seconds) and for another 15 seconds after one minute recovery (60 - 75 seconds). However, this is now done more accurately using a heart rate monitor. A regression line is used to predict VO_2max from the first 15 seconds recovery heart rate using the equation;

$$Y = 65.81 - 0.1847X \qquad \text{(Equation v)}$$

where X is recovery heart rate in beats per minute [82].

McArdle et al [82] evaluated VO_2max predicted from the QCST in 41 female students at Queens College and related VO_2max to physical work capacity (PWC). PWC was defined as the time in seconds the participant ran before the heart rate reached 150 beats.min^{-1} (PWC_{150}), 170 beats.min^{-1} (PWC_{170}), and the point at which the participant could no longer continue running (PWC_{max}). Participants performed a Balke treadmill test on two separate occasions within 3-5 days to determine VO_2max test-retest reliability. After the treadmill test participants performed the QCST twice in one week to determine the reliability of the recovery heart rate scores.

The VO_2max test-retest reliability coefficient was r = 0.95, indicating that the treadmill test is highly reliable for the assessment of aerobic capacity in women. The highest validity coefficient r = -0.76 was obtained when VO_2max was correlated with the first 15 seconds recovery heart rate of the QCST. Therefore approximately 58% of the variability in aerobic capacity can be explained by the recovery heart rate from the QCST. The coefficients r = 0.62, r = 0.68 and r = 0.75 were obtained when VO_2max was correlated with PWC_{150}, PWC_{170} and PWC_{max} respectively.

Chatterjee et al [111] investigated the suitability of the QCST in predicting VO_2max in 30 young, sedentary male students. Participants performed the QCST for the prediction of VO_2max and a bicycle ergometer test for direct measurement of VO_2max four days later. The 15 seconds heart rate was converted into beats per minute. It should be pointed out that heart rate from heart beats at the end of the 15 seconds recovery is different from heart rate measured by a heart rate monitor. Maximum oxygen uptake was predicted from the following equation:

$$VO_2max\ (ml.kg^{-1}min^{-1}) = 111.33 - (0.42 \times \text{heart rate in beats per minute}) \qquad \text{(Equation vi)}$$

There were no significant differences between VO_2max measured directly (39.8 $ml.kg^{-1}.min^{-1}$) and VO_2max predicted from QCT (39.3 $ml.kg^{-1}.min^{-1}$). The mean difference between measured VO_2max and QCT predicted VO_2max was 0.46 $ml.kg^{-1}.min^{-1}$ with 95% confidence interval of -0.09 to 1.01 $ml.kg^{-1}.min^{-1}$. There was a significant correlation ($r = -0.96$,) between QCST recovery heart rate and VO_2max. Chatterjee et al (2004) recommended the QCST as a valid test of aerobic capacity in young Indian men.

Chatterjee, Chatterjee and Bandyopadhyay [112] assessed the applicability of the QCST in predicting VO_2max in 40 sedentary female university students. VO_2max was measured after the participants cycled to exhaustion on a cycle ergometer and indirectly by QCST at a four day interval in a random cross-over design. The equation developed by McArdle et al [82] was used to predict maximum oxygen capacity. There was a significant difference between predicted VO_2max (35.5 ± 4.4 $ml.kg^{-1}.min^{-1}$) and VO_2max (32.8 ± 3.8 $ml.kg^{-1}.min^{-1}$) measured directly. The limits of agreement between predicted VO_2max and directly measured VO_2max were rather large (0.4 to 6.0 $ml.kg^{-1}min^{-1}$) indicating that the protocol was inappropriate for this population. However QCST recovery heart rate was negatively correlated ($r = -0.83$, $p < 0.0001$) with directly measured VO_2max.

A prediction equation (equation iii) was computed from the data for accurate assessment of VO_2max in young women.

$$Y = 54.12 - 0.13X \qquad \text{(Equation vii)}$$

where X was recovery heart rate in beats per minute

Results from the new equation showed a variation from VO_2max measured directly of less than 5% in 24 participants, 5 to 9% in 10 participants, 10 to 14% in two participants, and 15 to 19% in four participants. Chatterjee et al [112] recommended using the new equation for valid prediction of VO_2max from the QCST in sedentary Indian female students.

Sedentary Indian men experienced premature fatigue in the lower limbs when performing the Harvard step test due the high step (50.8 cm, which was not adjusted for stature) and fast stepping cadence (30 steps per minute) that compelled them to stop [113]. This has limited the use of the Harvard step test in this population. As a consequence Bandyopadhyay [113] assessed the suitability of the QCST in determining physical fitness index in 155 sedentary male Indian students. Participants were randomly divided into a study group (n = 100) and confirmatory group (n = 55). The QCST and the Harvard step test were performed at an interval of four days by random cross-over design in which half the study sample performed the QCST first and the other half performed the Harvard step test first. All participants performed the QCST test properly but 20 and 15 participants from the study group and confirmatory group respectively failed to complete the Harvard step test.

There was a significant correlation (r = -0.91) between QCST heart rate and physical fitness index in the study group. The following regression equation was computed from the correlation for the prediction of physical fitness index from QCST and was validated in the confirmatory group.

Physical fitness index= 130.907 – 1.503 x QCST heart rate* (Equation viii)
*The index has no units, just a numerical value.

There was no significant variation between the physical fitness index measured using the Harvard step test (68.3 ±0.5) and the physical fitness index predicted from QCST (69.9 ± 0.6) in the confirmatory group. The mean difference between physical fitness index scores obtained from Harvard step test and QCST equation was 0.1. The limits of agreement (-2.6 and 2.9) were sufficiently small for QCST to be used confidently for prediction of physical fitness index in sedentary Indian men.

Bandyopadhyay [95] assessed the suitability of the QCST in determining physical fitness index in 155 young sedentary females in India. Participants were randomly divided into study group (n = 100) and confirmatory group (n = 55). The QCST and the Harvard step test were performed at an interval of four days by random cross-over design in which the Harvard step test was followed by the QCST in half the sample and the QCST was followed by the Harvard step test in the other half. All participants completed the QCST but 20 participants from the study group and 15 participants from the confirmatory group could not complete the Harvard step test due to premature fatigue in lower limbs.

There was a significant correlation (r = -0.90) in the study group between QCST heart rate and physical fitness index that resulted in the following norm for prediction of physical fitness index using the QCST.

Physical fitness index = 195.09 – 3.09 x QCST heart rate (Equation ix)

The norm was applied in the confirmatory group and there was no significant variation between physical fitness index obtained from the Harvard step test (63.4 ± 5.7) and that obtained using the QCST norm (63.5 ± 6.3). The mean difference between physical fitness index scores obtained in the Harvard step test and QCST norm was 0.1. The QCST norm predicted physical fitness index by between 1.3 and -1.1. The limits of agreement (-2.3 and 2.5) were sufficiently small for the QCST to be used as an alternative to the Harvard step test for prediction of physical fitness index in sedentary females in India. A different equation was derived for the female sample from that for the males.

In summary, prediction of VO_2max from the QCST depends largely on the prediction equation used. McArdle et al [82] found a low prediction validity as depicted by the moderate validity coefficient r = -0.76. Using a different prediction equation Chatterjee et al [111] found no significant variation between VO_2max measured directly and VO_2max predicted from the QCST in young Indian males. When Chatterjee, Chatterjee and Bandyopadhyay [112] used the McArdle [82] equation on young Indian females, there was a significant difference between VO_2max measured directly and VO_2max predicted from the QCST. When a prediction equation based on the correlation between recovery pulse rate and directly measured VO_2max was used, there was little variation between predicted and measured VO_2max. Bandyopadhyay [111,113] demonstrated the capability of the QCST to predict the physical fitness index. The QCST is a valid test for the prediction of physical fitness index and VO_2max provided the appropriate prediction equation is used.

1.4.9 The Canadian Home Fitness Test

The Canadian home fitness test (CHFT) was developed to motivate Canadians to increase their physical activity to improve their physical fitness [11]. It was designed to be a self-administered test that comprises seven stages for males and six stages for females. The test begins with the participant stepping on a 20 cm double step at 65% to 70% of anticipated aerobic power (Table 2) of a person in the next 10-year age group. This phase serves as a warm up. The participant then counts his/her pulse from 5 to 15 seconds after exercise. If the participant has not reached a predetermined heart rate (Table 3) he/she proceeds to the next level where stepping occurs for three minutes at 65% to 70% of anticipated aerobic power of a sedentary person. Pulse count is taken from 5 to 15 seconds.

The test is stopped after six minutes. However data and music allow a further three minutes at a rate 65% to 70% of the average aerobic power for a person ten years younger than the participant. Stepping is performed to a musical rhythm with a six pace cycle: one foot on the middle step, the other foot on the top step, both feet on the top step, one foot on the middle step, the other foot on the ground and both feet on the ground.

The stepping rate and cadence were based on the average fitness of a sedentary Canadian (0). The data were obtained from a sample drawn from Toronto. The data were comparable with a sample from another region in Canada, Saskatoon. Submaximal tests demand 75% to 85% of aerobic power. Shephard et al [11] calculated stepping rates that yield 75% of aerobic capacity on the double 22.5 cm laboratory step and 65% to 70 % of aerobic power using lowest two steps of the 20 cm domestic staircase. The cadence was determined by assuming a basal oxygen consumption of 3 $ml.kg^{-1}.min^{-1}$, a climbing mechanical efficiency of 16% and an energy yield of approximately 21 joules per litre of oxygen.

Table 2 Basis of the Canadian home fitness test [11]

	Anticipated gross VO_2 max ($ml.kg^{-1}.min^{-1}$)		Required rate of climbing ($ascents.min^{-1}$)		Corresponding 6-beat cadence ($beats.min^{-1}$)	
Age (years)	M	F	M	F	M	F
Spare music bands					156	132
15 - 19					156	120
20 - 29	47	38	24.2	19.1	144	114
30 - 39	43	39	21.9	19.7	132	114
40 - 49	38	35	19.1	17.4	114	102
50 - 59	33	30	16.3	14.6	96	84
60 - 69	27	24	12.9	11.2	78	66
Warm up for oldest age group					60	60

Where M = male, F = female

Bailey [114] tested 1544 people in Saskatoon. Fitness was divided into six categories ranging from *very poor* to *very good*. These categories were combined into three categories for the Canadian Home Fitness Test (Table 3), according to the fitness characteristics of *undesirable*, *minimum* or *recommended*. The categories were defined by the number of test stages the subject completed and the 10 second recovery heart rate. The test was stopped after three minutes if the participant had *undesirable fitness*. After six minutes a participant is described as having achieved either *minimum* fitness or *recommended* fitness according to the 10 seconds heart beats as shown in Table 3.

Table 3 Physical fitness evaluation chart for the Canadian home fitness test [11]

	10 seconds heart beats		
Age (years)	Undesirable fitness after 3 min	Minimum fitness after 6 min	Recommended fitness after 6 min
15 - 19	≥ 30stop exercise	≥ 27	≤ 26
20 - 29	≥ 29 stop exercise	≥ 26	≤ 25
30 - 39	≥ 28 stop exercise	≥ 25	≤ 24
40 - 49	≥ 26 stop exercise	≥ 24	≤ 23
50 - 59	≥ 25 stop exercise	≥ 23	≤ 22
60 - 69	≥ 24 stop exercise	≥ 23	≤ 22

Shephard, Bailey and Mirwald [11] compared VO_2max predicted from CHFT recovery heart rates recorded with an ECG with VO_2max predicted from a submaximal bicycle ergometer test [108]. The two sets of data were correlated ($r = 0.72$, $n = 1152$), but predictions of VO_2max on the cycle ergometer were lower than predictions of VO_2max from recovery heart rates after the CHFT. This difference can possibly be attributed to the quadriceps weakness that would have caused the participants to underperform in the cycle test.

Two studies, Jette et al [115] and Shephard, Bailey and Mirwald [11] reported inaccuracies in palpated heart beats. The relationship between heart rate measured with ECG and palpated heart rats were $r = 0.50$ [115] and 0.59 [11]. Shephard, Bailey and Mirwald [11] argued that the low correlation was due to the participants' lack of experience in pulse counting. In an earlier study of children speed skaters Bailey and Mirwald demonstrated that with experience actual (135 beats/min) and palpated (127 beats/min) heart rates were slightly different. This translated in a correlation coefficient of $r = 0.94$ for experienced children as compared to $r = 0.76$ when pulse was counted by a friend and $r = 0.37$ when pulse rate was recorded by inexperienced children [11].

Jette at al [115] investigated whether VO_2max could be predicted from Canadian Home Fitness Test variables. In particular they investigated whether the limitations of using just heart rate as a predictor of VO_2max could be overcome by using many variables. Fifty-nine participants (15 – 74 years) completed the Canadian Home Fitness Test and 30 minutes later did a progressive exercise treadmill test to fatigue to directly determine VO_2max. The participant's oxygen consumption in the last stage, weight, post exercise heart rate, age, body surface area, standing heart rate, sitting heart rate and age adjusted maximum heart rate were the predictor variables used. The multiple regression equation was as follows:

$$VO_2max = 42.5 + 16.6(VO_2) - 0.12(W) - 0.12(HR) - 0.24(A) \qquad \text{(Equation x)}$$

where, VO_2max is the aerobic power in $ml.kg^{-1}.min^{-1}$, VO_2 is the energy cost or average oxygen cost of the last completed exercise stage in $l.min^{-1}$ (0), W is the body mass or weight in kg, HR is the post exercise heart rate in beats per minute and A is the subject's age in years.

The observed VO_2max was plotted against the predicted VO_2max in $ml.kg^{-1}.min^{-1}$ and the line of best fit was determined ($r = 0.91$). The standard error of estimate was 4.1 $ml.kg^{-1}.min^{-1}$. There was no significant difference between the mean predicted VO_2max (35.9 ± 9.3 $ml.kg^{-1}.min^{-1}$) and the mean observed VO_2max (36.0 ± 10.4 $ml.kg^{-1}.min^{-1}$) ($P < 0.01$; paired t test).

Table 4 Energy requirements in $l.min^{-1}$ of the CHFT stages [115]

Stage	Males	Females
1	1.1391	0.939
2	1.3466	1.0484
3	1.6250	1.3213
4	1.8255	1.4925
5	2.0066	1.6267
6	2.3453	1.7867
7	2.7653	

Cumming and Glenn [116] evaluated the Canadian Home Fitness Test in 230 men aged 45 to 69 years. Fifteen minutes after completing the CHFT participants performed the Bruce treadmill test [117] to fatigue and VO_2max was estimated. Heart rates were obtained using ECG for the last 10 seconds of the CHFT and by pulse counting and ECG from 5 to 15 seconds after the CHFT. Participants underestimated heart rate by as much as 13 beats per minute when counting compared to when heart rate was measured with ECG. VO_2max predicted from CHFT ECG heart rates and from treadmill test were very close but lower than VO_2max predicted from CHFT subjects' pulse counts by as much as 26%.

Fifty participants rated the intensity of the Canadian Home Fitness Test and the treadmill test using Borg's numerical scale. There was a correlation between RPE and heart rate in the second stage of the CHFT ($r = 0.76$). Cumming and Glenn [116] observed that participants failed to maintain the correct stepping cadence and made heart rate counting errors regardless of training. This was a different observation from Jette at al [115] and Shephard, Bailey and Mirwald [11] who indicated that counting improved with training. Cumming and Glenn [116] concluded that the Canadian Home Fitness Test was unsuitable for home measurement of fitness because of the pulse counting errors that impacted on VO_2max predictions. They suggested the use of Borg's RPE with the CHFT to predict VO_2max instead of heart rate.

Cumming and Glenn [116] argued that the 0.91 correlation obtained by Jette at al [115] used height, age and weight to predict VO_2max, not heart rate which the CHFT relies on. However, in response, Shephard [118] explained that the CHFT is not designed to be highly precise, but rather is designed to heighten awareness of fitness and motivate Canadians to be physically active.

Weller et al [119] assessed the validity of VO_2max values predicted using the equation of Jette et al [115]. They compared these predicted VO_2max values with peak VO_2 values measured during a treadmill protocol using a large sample of males and females of broad age range and varied fitness levels. Participants (n = 129) performed the CHFT on two laboratory visits. Forty five minutes after one of the CHFT tests participants performed a maximal treadmill test. Heart rates were recorded using ECG during the last 10 seconds of each stage of the CHFT and from 5 to 15 seconds after exercise. There were no significant differences in heart rates between the two CHFTs, suggesting there was no heart rate habituation to the CHFT. A correlation coefficient of r = 0.83 was obtained between treadmill measured peak VO_2 and CHFT VO_2max predicted using the Jette at al equation [115]. VO_2max values from the treadmill test were significantly higher than VO_2max predicted from CHFT using the equation of Jette al [115]. The similar regression coefficients (r = 0.83 and r = 0.75; Jette at al [115] and Weller at al [119] respectively) indicate that the Jette et al equation [115] is reliable across populations. The underestimation of VO_2max should probably be a result of the CHFT protocol, which has a limited number of stages that may not allow some participants to reach their target heart rate, rather than the equation.

One weakness of the Jette et al equation [115] is that more than 77% of the variance is attributed to the first two variables; the weight of the subject and the average oxygen cost of stepping. This leaves a small component of the prediction to be determined by a cardiovascular measure, in this case post exercise heart rate [120].

In its original form the CHFT could only categorise participants into three fitness categories. The Jette et al equation [115] enabled the CHFT to predict VO_2max. Studies [115,119] have shown that the CHFT is a valid test for the prediction of aerobic capacity. One major limitation and criticism of the CHFT was the error associated with the pulse count. This limitation cannot be minimised by the using heart rate monitors as a pulse count is different from heart rate measured with a heart rate monitor.

1.4.10 Chester Step Test

The Chester step test (CST) was developed in 1995 at University College Chester to assess aerobic fitness under submaximal conditions [121]. The test consists of five stages during which heart rate and exertion levels (RPE) [122] are measured continuously. The stepping rate is controlled by a metronome. The test begins with the participant stepping on a 15, 20, 25, or 30 centimetre step at the rate of 15 steps per minute for two minutes. The CST testing package provides standardised criteria for choosing step height according to the participant's age and training status. According to these criteria, the stepping rate increases by five steps per minute every two minutes until the participant reaches 80% of age estimated maximum heart rate (220 minus age). The maximum duration of the test is 10 minutes, which occurs with stage five. For each CST stage the predicted oxygen cost of exercise is provided (Table 5). Sykes and Roberts [83] did not explain how the oxygen cost for the CST was determined. Heart rates for the CST stages are plotted against the oxygen cost for each stage. A line of best fit is drawn joining the data points and then extrapolated to age-estimated maximum heart rate at which point the corresponding aerobic capacity is determined.

Table 5 CST oxygen cost estimates (VO_2 in $ml.kg^{-1}.min^{-1}$) for varying step heights (m) and stepping rates (steps per minute) [123]

	Stage				
	I	**II**	**III**	**IV**	**V**
	Stepping rate				
Step height (m)	15	20	25	30	35
0.15m	11	14	18	21	25
0.20m	12	17	21	26	29
0.25m	14	19	24	28	33
0.30m	16	21	27	32	37

The predictive procedure of the CST assumes that there is a linear relationship between CST stages and heart rates and VO_2. It also assumes that maximum heart rate coincides with VO_2max and that maximum heart rate equals 220 minus age.

Buckley et al [123] assessed the validity and reliability of the following CST measures: predicted VO_2 at each CST stage, heart rate, RPE, age estimated maximum heart rate, predicted VO_2max, the correlation between RPE and % VO_2max, the correlation between RPE and % HRmax and the correlation between % VO_2max and % HRmax. Thirteen students (seven males and six females) performed the CST on two separate days. On the third day participants performed an incremental treadmill protocol to determine actual maximum heart rate and VO_2max. Heart rate and RPE were recorded during the last 15 seconds of each stage.

Results showed a linear response for RPE, a curvilinear response for VO_2 and a curvilinear response for heart rate with each progressive CST stage. The curvilinear response could be attributed to a significant underestimation of VO_2 at stage one of the CST. If heart rate data from stage one were excluding when drawing the line of best fit there would be a linear relationship between work rate increments and heart rate and VO_2. Estimated VO_2 for CST stages differed from measured VO_2 with errors ranging between 11% and 19%. There were no significant differences between trial one and trial two for RPE, submaximal heart rate or VO_2 at each stage of the CST. The 95% limits of agreement of the CST predicted VO_2max between trial one and trial two of 3.7 $ml.kg^{-1}.min^{-1}$ was not statistically significant, making the CST a reliable test. Measured maximum heart rate was significantly lower (five beats per minute) than age predicted maximum heart rate.

The 95% limits of agreement around the maximum heart rate bias was 12 beats per minute. Therefore the difference between actual and estimated maximum heart rate could be as much as 17 beats per minute, a result in agreement with reported errors of age estimated maximum heart rate [124,125,126]. The CST predicted VO_2max was an underestimation of actual VO_2max by -2.8 $ml.kg^{-1}.min^{-1}$ in trial one. The 95% limits of agreement showed that the CST could underestimate VO_2max by 9 $ml.kg^{-1}.min^{-1}$ or overestimate VO_2max by 5.5 $ml.kg^{-1}.min^{-1}$. Therefore, based on these results the CTS can be assumed to be a reliable field test in detecting improvements in aerobic fitness. However, its validity to predict VO_2max is questionable [123].

Contrary to the results of Buckley et al, the CST developers found the test valid at predicting VO_2max. Sykes and Roberts [83] compared the CST predicted VO_2max with VO_2max measured directly on a treadmill. There was a high correlation between treadmill measured VO_2max and VO_2max predicted from the CST ($r = 0.92$; $P < 0.001$) with a standard error of estimate of 3.9 $ml.kg^{-1}\ min^{-1}$ giving prediction accuracy of approximately 5 to 15% in participants with VO_2max ranging from 25 to 68 $ml.kg^{-1}.min^{-1}$. The prediction was slightly more accurate in females than males. They also tested the reproducibility of the test with participants of varying ages and fitness levels. Sixty-eight participants (18 to 52 years) performed a treadmill VO_2max test and then the CST twice, on separate occasions. A test-retest reliability for the CST obtained as the mean difference between CST one and CST two was -0.7 $ml.kg^{-1}.min^{-1}$.

Elliott et al [127] examined the influence of an active arm action when performing the CST on predicted VO_2max. Twenty-five participants (10 males and 15 females) performed the CST, once with an active arm action and once with a passive arm action in a random cross over design. Active arm action resulted in an increase of about seven beats per minute at the three stages of the CST that were completed, a difference that falls within the CST test-retest variation. The increase in heart rate did not have a significant impact on VO_2max.

The basis of the CST is the estimated VO_2 for each stage of the test. The CST assumes that the heart rate and VO_2 responses to increasing work rate should be linear, that maximum heart rate is equal to 220 minus age and that maximum heart rate coincides with VO_2max. An error in one assumption reduces the validity of the test. All assumptions were proved to be wrong. Buckley et al [123] found a non-linear response which renders the predictions made from the extrapolated line of best fit inaccurate. Age estimated maximum heart rate significantly overestimated actual maximum heart rate [123]. There were differences between measured and estimated VO_2 for the CST stages [123]. The CST should therefore be used as a reliable fitness test where the focus is on assessing improvement in fitness and not in predicting VO_2max.

1.4.11 Cambridge Step Test

The test was developed by researchers at the MRC Epidemiology unit in Cambridge [84,85]. The participant steps on and off a 21.5 cm step at a slow pace, one leg movement per second, for one minute. This converts to one step in four seconds and 15 steps per minute. Stepping pace increases gradually to 33 steps per minute by the end of the eighth minute. Heart rate is recorded at 30 second intervals during the test and at 15 seconds intervals after the test for two minutes. Exercise heart rates are combined with resting heart rate to determine the relationship between heart rate and VO_2. The relationship is extrapolated to age-predicted maximal heart rate to estimate VO_2max [128].

The mechanical work rate for lifting the body was given by the product of body lift frequency, step height and gravitational force as shown in the following equation [128]:

$$\textit{Lift power } (J.min^{-1}.kg^{-1}) = \textit{lift frequency (lifts/min) x step height (m) x } 9.81\ m.s^{-1} \qquad \text{(Equation xi)}$$

Another equation was derived to estimate the physiological activity intensity (PAI) or net energy turnover required for the mechanical work for the step test [128]:

$$PAI\ (J.min^{-1}.kg^{-1}) = (3.72^{*}\ Lift\ power) + (64.1\ x\ time) - (13.2\ x\ time^{2}) + 0.99\ x\ time$$

(Equation xii)

Data for the first minute of stepping were excluded and a linear regression was computed between estimated PAI and the heart rate above rest (HRaR) to yield slope ($beta_{step}$) and intercept ($alpha_{step}$). The first 90 seconds of recovery heart rate were included into a quadratic regression equation against recovery time from which one minute recovery heart rate HRaR ($recovHRaR_{step}$) was calculated. Submaximal PAI during treadmill walking and running was derived using five parameters: $beta_{step}$, $alpha_{step}$, one minute recovery heart rate, step test duration and resting heart rate.

$$PAI_{walk/run}\ (J.min^{-1}.kg^{-1}) = 4.2 + 0.45*beta_{step} - 0.014*recovHRaR_{step})*\ HRaR + 0.37*alpha_{step} + 14.8*step\ test\ duration - 0.63*recovHRaR_{step} - 0.14*RHR - 149$$ [128] (Equation xiii)

Maximal PAI (VO_2max) can be derived by substituting exercise heart rate by an estimate of the maximal heart rate predicted from age [129] and adding an estimate of resting metabolic rate (RMR) [130] to yield maximal total metabolic yield. Joules are divided by the energetic value of oxygen $0.23J.ml^{-1}$ to convert into millilitres of oxygen [131].

$$VO_2max\ (ml.kg^{-1}.\ min^{-1}) = (max\ PAI_{walk/run} + RMR)/0.23$$ (Equation xiv)

The Cambridge step test has not been validated in a published paper. However, the method was developed from that devised by researchers in the MRC Epidemiology Unit at Cambridge [132] using information from a variety of studies. This information included a step test field pilot on the Health Survey for England (HSE) in 2005 recorded in an unpublished report on step test feasibility, and again in 2007 using the protocol that was used in the main HSE 2008. Previous research had demonstrated that the step test was suitable for use in a general population household survey. The 2005 HSE feasibility study found that it was practical to administer the test once the step was in the participant's home and that the participants enjoyed the test. The test was used in a Physical activity and fitness Household Survey that was done in England in 2008 as an objective measure of physical fitness for adults aged 16 to 74 years. The survey was published in 2009 as two volumes [84,85].

1.5 Summary

The purpose of an exercise test varies. In most cases an exercise test provides information about the person's physical condition. For example, a person may have a cardiac or pulmonary condition, be a sedentary adult about to embark on an exercise training programme or an already trained person. Just as the reasons for testing vary, as such do the testing procedures. Some people can withstand maximum tests where they exercise to exhaustion. Others cannot because of the risks associated with exercising to exhaustion. Expense and availability of equipment are also limiting. Submaximal tests incorporate either walking, running, cycling or stepping as the mode of exercise. Submaximal tests are only meaningful if they can predict maximal aerobic capacity with accuracy. A submaximal test with stepping exercise has advantages over other submaximal tests. They do not need expensive equipment and are easy to administer.

A review of the existing step tests was conducted to determine whether there is a reliable, easy to use submaximal fitness test that caters for people of all ages and fitness levels. The review showed that although some step tests have been validated, others have not. The protocols also vary. A summary of the protocols of the step tests that have been developed to predict fitness is shown in Table 6.

Table 6 Parameters of the step tests developed to predict fitness

Step test	Step height (cm)	Steps per min	Duration	Measurements	Stages	Fitness determination
Cardiovascular efficiency test	45.7	20	15 s	[1]HRR: 15 s intervals for 2 min	Single	Fitness score from summation of 6 items
Pulse-Ratio test	33	15-60	1–3 min	HRR: 2 min	Single	Graph of number of steps against pulse-ratio
Harvard step test	50.8	30	5 min	HRR: 60-90, 120-150, 180-220 s	Single	Fitness index: Test duration divided by HRR
YMCA 3-Minute step test	30.5	24	3 min	HRR 60 s	Single	Fitness category
Balke step test	2 to 50	24/30	20/Exhaustion	[2]VO_2	Single	Total VO_2
Queen's College step test	41.3	22	3 min	HRR: 5-20 s, 60-75 s	Single	[3]VO_2max: Regression line
Canadian Home fitness test	20 x 2	11 –25	6 min	HRR: 5-15 s	2	10 s [4]HR. Regression equation
Chester step test	15-30	15-35	10 min	HR for each stage	5	HR against [5]O_2. Line of best fit
Cambridge	21.5	15-33	8 min	HR: 30 s intervals, HRR: 15 s intervals for 2 min.	Single	Max [6]PAI added to [7]RMR to give VO_2max

[1]Heart rate recovery
[2]Volume of oxygen consumed
[3]Maximal oxygen consumption
[4]Heart rate
[5]Oxygen
[6]Physiological activity intensity
[7]Resting metabolic rate

Each test has strengths and weaknesses associated with the protocol. These are summarised in Table 7.

Table 7 Strengths and weaknesses of step tests

Step test	Strengths	Weaknesses
Cardiovascular efficiency test	Cardiovascular efficiency results agreed with medical examination results	Test duration short; does not test cardiorespiratory fitness, only categorises as "fit" or "unfit"; uses heart beats count
Pulse-Ratio test	Measures cardiac response to exercise; Standardised relative workload	Use of 2.5 as standard pulse ratio; when the calculated number of steps required for a 2.5 ratio was performed, the resulting pulse-ratio was not 2.5; Use of 50 as the steps that result in 100% efficiency; does not predict VO_2max; extremely high stepping rates cause peripheral fatigue
Harvard step test	Index categorises fitness	Step very high; test difficult, caters only for fit adult men; index has no units; uses heart beats; does not predict VO_2max
YMCA 3-minute step test	Caters for the unfit, test has short duration, stepping rate manageable	Does not predict VO_2max; test too short to allow meaningful cardiorespiratory response to exercise
Balke step test	Accounted for negative work; used 2 stepping rates to cater for individuals of low working capacity	Maximal effort test therefore not suitable for everyone; adjustable step complicated to make and operate, detracts from the simplicity of a step test; extreme step heights, too low to pose physical strain, or very high causing local fatigue; cannot be used by participants of low stature; stipulated duration very unlike a maximal test, some participants do not attain their maximum; could not accommodate highly trained participants whose metabolic levels exceeded 12 times resting metabolic rate.
Queen's College step test	Predicts VO_2max with the appropriate equation in men and women	Original test used recovery pulse count; too short to allow meaningful physiological responses to exercise especially in fit individuals

Canadian home fitness test	Self-administered; Predicts VO_2max with the Jette equation	Pulse counting errors; Original test only had three fitness categories
Chester step test	Predicts VO_2max	The predictive procedure assumes there is a linear relationship between CST stages and heart rates and VO_2; also assumes that maximum heart rate coincides with VO_2max and that maximum heart rate equals 220 – age; Step height determined by age and training status instead of by stature
Cambridge step test	Predicts VO_2max	Has not been validated in a published paper

The common strength of the step tests is that they all give some measure or indication of an individual's fitness. A weakness of the early tests is the use of heart beat counts as the main outcome measure. This measurement is marred with numerous counting errors. It is difficult to overcome these sources of error, even with heart rate monitors, as the heart rate monitors measure rate, not count.

Some early tests did not predict VO_2max, which limited their use. For the tests that predicted VO_2max, the predictive capacity needs to be refined. Whilst some tests used more than one step height, none of the reviewed tests adjusted step height according to the participant's height, or considered the participant's body mass. Most step tests have a standardised task in terms of duration [79,113,115] or in terms of distance the participant would theoretically cover [133]. Therefore each test provided an absolute workload and the relative work done by the participant was not considered. While it may be argued that the Pulse-ratio test has a relative workload, it is based on an assumed standard ratio, which may vary from person-to-person.

Therefore, there is a need to develop a step test that is submaximal with the ability to predict VO_2max with reasonable accuracy. There is also a need for a step test that considers the size (stature and body mass) of the participant, and adjusts the protocol parameters accordingly to make the demands of the test relative to each person's characteristics. The submaximal step test should cater for people of varied ages and physical fitness levels. In developing this test the principles of clinimetrics need to be applied. These principles will be described in the next section.

1.6 Clinimetrics

Clinimetrics is a methodological and statistical discipline that focuses on the development of quality instruments and the assessment of the quality of their measurement [134]. It is a discipline of the methodology of measuring biologic phenomena. The key concepts of clinimetrics are reliability, validity and responsiveness. Clinimetrics is fundamental in clinical medicine, sports medicine, health science, or sports science. Diagnostic, evaluative or prognostic information from any instrument can only be trusted and used with confidence if the instrument quality has been positively evaluated. When developing an instrument the measurement quality is a major concern and is reviewed through a series of steps including selection of proper outcome measures, standardisation of material and assessment procedures and attention to interpretability of test results. Even if the process of instrument development addresses all aspects to do with minimising error, clinimetrics remains a crucial process. An instrument cannot be used with confidence until it has fulfilled the criteria of a clinimetrics assessment. Potential sources of error should be identified and adjustments and modifications made to improve measurement quality [134]. This is made from published data or from empirical research done to assess the properties. If a new instrument is developed for use, the quality of the measurement has to be assessed before it is used in a clinical setting or for research. The first step involves determining the reliability of the measurement. The next step involves validation of the instrument. A measurement is valid if it measures what it is intended to measure [134]. The responsiveness and measurement error also have to be determined.

The development of measuring instruments is needs driven and the process of development and evaluation may take a long time. The discussion about the various step test protocols has highlighted their deficiencies. It is clear that a step test needs to be developed that overcomes these deficiencies. In particular, there is a need for a submaximal step test that quantifies the work done by the participant and predicts cardiorespiratory fitness with accuracy. The step test also needs to be suitable for a range of participants, varying in size and fitness. The next section discusses the broad outline associated with developing the step test and describes the objectives of this thesis.

CHAPTER 2

PURPOSE OF THE STUDY

2.1 Introduction

Fitness testing provides information in the quest to promote health and exercise habits among individuals and populations. Fitness testing is used to evaluate health and the response to exercise training and monitor training status. VO_2max is used to measure cardiorespiratory fitness. The VO_2max test requires expensive equipment and a maximal effort from the participant. Due to risks associated with cardiovascular disease some people cannot perform the VO_2max test. Since the test is not readily available for the majority of people due to expense, complexity, technical expertise and health issues, submaximal tests are used to predict VO_2max.

When testing an unscreened participant in field conditions the submaximal testing protocol should be easy to administer, convenient and safe, the equipment inexpensive and the testing conditions and time requirements reasonable. The exercise modality of stepping satisfies the characteristics of an exercise test. Stepping is a simple and inexpensive exercise mode that can be performed by individuals of all abilities with low risk of injury. The stepping protocol can be regulated to increase metabolic rate in a predictable way. It is for these reasons that stepping has been selected as the mode of exercise for the submaximal test that forms the basis of this thesis.

The main requirements of an exercise test are accuracy, feasibility and safety. Accuracy presupposes validity (criterion-valid) and reliability of test parameters and data interpretation. Feasibility refers to the practicality of the test; or the degree to which the test can be easily and conveniently done. Feasibility also refers to the test's usefulness for assessing the fitness of relevant population samples. Step tests have been used to test fitness for about a century now. However, the review of literature in Chapter 1 on step tests has exposed their weaknesses. One common weakness is that participants perform the same protocol, which does not consider differences in size. Stepping involves lifting the body mass, up a height, defined by the height of the step. Therefore the load imposed by the test is influenced by the participant's body mass. If the duration and stepping rate of the test is constant, participants with a different body mass will do different amounts of work.

It stands to reason that a step test with a standardised workload overcomes many of the limitations that were exposed in the review of the literature in Chapter 1. The workload can be standardised by accounting for body mass, duration and stepping rate (cadence) in the protocol. The physiological responses to a standardised protocol are likely to be more interpretable than the physiological responses resulting from a protocol in which physiological demands differ. This thesis revolves around developing a standardised step test, which overcomes the limitations of the various step tests that have been developed. The overall goal is to develop a step test that is reliable and valid and suitable for testing participants with a range of fitness levels.

2.2 Aim of the Thesis

The aim of the thesis is to develop and evaluate a step test which fulfils the characteristics of being valid, reliable, feasible, safe, simple and practicable, and that can be used to test the cardiorespiratory fitness of participants who vary in sex, age and level of fitness.

2.3 Objectives of the Thesis

The following objectives will be achieved by the thesis:

- To pilot the step test to assess feasibility and protocol configurations.
- To test the reliability of the step test using three configurations of the protocol, each with varying stepping rates (16, 20 and 24 steps per minute).
- To test the repeatability of the step test using a stepping rate of the participant's choice.
- To validate the step test against the VO_2max test measured directly on a treadmill using a diverse sample of participants.
- To cross-validate the step test using the same protocol on a different sample of the same population characteristics.

2.4 Summary

The purpose of this thesis is to develop a submaximal test of cardiorespiratory fitness using a novel step test that has been designed specifically to overcome the weaknesses of the previously published step tests. Each phase of the test will be subjected to evaluation so that the final protocol is supported by a series of studies supporting the piloting, development, validation and cross-validation of the test.

CHAPTER 3

STEP TEST DEVELOPMENT

3.1 Introduction

The need for a submaximal step test that accurately predicts cardiorespiratory fitness in people with varying fitness levels has formed the basis of this protocol for a step test. The variables of a step test are stepping rate, step height, duration and workload. Step tests differ in the configurations of these variables. In the subsequent sections the development of the step test goes through several phases to determine each variable; each phase is explained and subjected to evaluation.

Several steps were followed in the development of the test. First, configurations were trialled theoretically to determine the magnitude of each variable for a certain workload. Then two pilot studies were done to assess the test in practice. Attention was paid to the stepping frequency, ensuring that participants could cope with the speed. Also workload and how it affects test duration and the physiological responses such as heart rate were considered. The resultant step test, standardised for workload, was then validated to satisfy the dictates of clinimetrics [134].

3.2 Why Step Test?

The reason a step test was selected as the modality of exercise was addressed in Chapters 1 and 2. However, as a reminder, a step test was chosen over the other tests that used cycling and running on a treadmill because step testing is flexible in terms of administration and is inexpensive. It only requires a platform of the required stepping height. The platform can be placed indoors or outdoors and does not occupy much space. The administration of the step testing protocol does not require much expertise; anyone can administer it with appropriate instruction, including the participant administering to self, as in the case of the Canadian step test [11] which was designed specifically for self-administration. Also most people are familiar with the mode of stepping and therefore do not need to be familiarised with the activity.

The next section will discuss the impact of workload, step height and stepping rate on the step test protocol and how decisions were taken to refine the protocol.

3.3 Workload

The workload in a step test involves lifting the body mass as high as the step height. Research by Reedy, Saiger and Hostler [93] on the Harvard step test showed that lighter men achieved significantly higher scores than heavier men regardless of their fitness. In this case the test had the same duration so the lighter men did less work than the heavy men, hence the high scores. The workload for a step test is calculated using body mass of the participant since step testing involves lifting a weight up. Body mass in stepping up onto a bench influences the accurate calculation of cardiorespiratory fitness given that VO_2 is proportional to workload during submaximal exercise.

Exercise standardised to an absolute external workload may produce large differences in internal cardiovascular and metabolic stress between individuals, particularly if there is a wide range of fitness levels. Therefore a common practice is to prescribe exercise according to relative intensity [135,136,137]. This approach produces an approximately equal exercise stress among individuals and provides a foundation for explaining differences in physiological and functional capacity between participants. There are different ways to prescribe relative exercise intensity [138]. The most conventional way uses either the percentage of maximal oxygen consumption (VO_2max) or maximal heart rate (HRmax). These methods have been favoured in many studies [139,140,141,142,143,144,145]. However the use of % VO_2max and % HRmax for prescription of exercise intensity has been criticised [146,147,148,149,150,151,152,153]. Criticisms state that the use of % VO_2max does not account for individual differences in resting metabolic rate and that it is preferable to prescribe exercise relative to an individual's oxygen consumption reserve (VO_2R); VO_2max minus resting oxygen consumption (VO_2). Percentage of oxygen consumption reserve (% VO_2R) places individuals at equivalent relative intensity. Research shows that % VO_2R and percent heart rate reserve (% $HR_{reserve}$); HRmax minus resting heart rate, are equivalent methods of exercise intensity prescription whereas % VO_2max and % $HR_{reserve}$ may differ noticeably at lower exercise intensities [147,148,154]. The 1998 ACSM Position Stand recommends prescribing exercise using the % VO_2R - % $HR_{reserve}$ relationship for heart rate based training monitoring [7]. However, some research has questioned the use of the % VO_2R - % $HR_{reserve}$ relationship [155,156,157]. The 2011 ACSM guidelines [137] recommend all four, % VO_2max, % HRmax, % VO_2R and % $HR_{reserve}$ for prescription of exercise intensity.

Another criticism for % VO_2max and % HRmax is that the methods fail to account for differences in metabolic stress [149,150,151,152,153]. The critics of % VO_2max and % HRmax recommend the use of metabolic thresholds, i.e. aerobic and anaerobic threshold for relative exercise prescription [158,159,160,161]. However, the method of threshold calculation is difficult to implement outside the laboratory and lacks consistency in the laboratory rendering the theoretical basis of thresholds controversial [162,163,164].

Each method of prescribing relative exercise intensity has strengths and limitations when both theoretical and practical aspects are considered [138]. Therefore when making a decision about how to prescribe relative exercise intensity, factors such as exercise intensity, number of participants, participant characteristics and laboratory resources should be considered.

Exercise intensity, exercise duration and other variables specific to tests and exercise mode make up workload. Just like exercise intensity, prescription of workload can either be absolute or relative. The physiological responses to absolute workload are different from the responses to a relative workload.

In this study we decided to control for relative external workload. This decision was made for two reasons: (i) external workload is a key outcome of stepping exercise which can be controlled relatively easily, (ii) it provides a quantifiable external load, therefore the physiological responses to this load have a fundamental source of comparison. The decision to standardise relative external workload was based on three assumptions: (i) the standardised external load would elicit responses commensurate with the fitness of the participant, (ii) the magnitude of the differences in duration of the test would not impact on the physiological responses to the test and (iii) the magnitude of the differences in exercise intensity would not impact on the physiological responses to the test.

The evidence that contributed to decisions about the step height follows.

3.4 Step Height

The impact of the step height in the step test protocol was considered as early as 1946 when Seltzer [165] noted a correlation between the Harvard step test index and the length of the lower limb. Ebel et al [166] found a significant correlation ($P < 0.05$) between the Harvard step test index scores and limb length. Keen and Sloan [167] observed stature and limb length as factors which have an influence on the Harvard step test scores. The Harvard step test step height was adjusted to accommodate women [94]. The original Harvard step test protocol caused local fatigue due to the high step and fast cadence that compelled participants to stop the test prematurely.

Shahnawaz investigated the effect of step height adjusted to participant's limb length on physiological responses (oxygen consumption) at standard workload in a step test exercise [168]. Workload was standardised per participant at 10 $m.min^{-1}$ multiplied by body mass at various stepping rates for each step height. Oxygen consumption at step heights 40 to 55% of limb length were significantly lower ($p < 0.05$) than at any other step height. There exists an optimal step height expressed as a percentage of the participants' limb length (for efficiency in oxygen consumption). The validity of any form of step test is enhanced if step height is related to the participant's limb length.

According to Francis and Culpepper the lack of consideration of an individual's stature may cause tall or short individuals to work at different intensities during a test that is purported to be equivalent. As a result cardiovascular responses may differ, and hence estimates of oxygen consumption may deviate sharply among individuals of various heights within the target group being tested [169]. Francis and Culpepper acknowledge that the use of a uniform step height exposes participants to different work episodes that may influence or bias cardiovascular responses. However they did not adjust the duration of the test. As a result participants performed varying amounts of work during the test according to their body mass.

Just as high steps are inappropriate as they cause peripheral fatigue, very low steps are inefficient. Biomechanical efficiency, oxygen consumption and work rate are determined by step height. A decrease in efficiency due to a high platform results in the consumption of more energy and oxygen. A study designed to determine efficiency when stepping found minimum oxygen consumption for a step height of 25.4 cm when compared to a lower step height of 12.7 cm or a higher step height of 50.8 cm [133]. The study confirms that step height affects the stepping exercise and should be considered in the protocol. If the step height is such that knee flexion at the initiation of stepping is greater for a shorter person, the centre of mass travels through a greater range of motion to complete the step than for a taller person. Therefore consideration of participant's height when determining step height improves the standardisation of the test [54]. High step heights are not reliable for assessing cardiorespiratory fitness in short participants since they cause local muscle fatigue before an accurate estimate of aerobic capacity can be established. Low step heights do not provide much of a physiological challenge and produce low correlations between recovery heart rate and VO_2max [170]. Shephard and Bouchard [120] reported differences in external work performance depending on how participants placed both feet on the floor (whether flat or not) and how participants stand on the step (erect or not). A step test with an adjustable step height proportionate with participant height provides standardised efficiency of stepping that accommodates variations in heights and is more applicable as a field test for testing various groups of people.

Culpepper and Francis [54] developed an equation that used participant height to calculate step height. Through a series of equations they established that step height can be calculated using the equation:

$$H_f = (h)\ (1 - \cos\theta) \qquad \text{(Equation xv)}$$

where H_f is the height the foot rises when the hip is flexed at angle θ, and h is the length of the femur in centimetres [54]. Anderson and Green [171] established that femur length can be calculated as 0.2626 and 0.2672 times the statute height for mature females and males respectively. Therefore, where I_h is statute height, step height can be calculated using the equations:

$$H_f = (02626\ I_h)\ (1 - \cos\theta) \quad \textit{females} \qquad \text{(Equation xvi)}$$

$H_f = (02672\ I_h)\ (1 - \cos\theta)$ *males* (Equation xvii)

Greater correlations of recovery heart rate and aerobic capacity were obtained when step height created a hip angle closer to 73.3º [54,170]. Therefore, 73.3º was used to determine hip angle in the model and was substituted for θ in the above equations to determine the foot height (i.e. the height the foot is raised). The angle is formed between the thigh and the vertical.

$H_f = 0.187\ I_h$ *females* (Equation xviii)

$H_f = 0.190\ I_h$ *males* (Equation xix)

Tests were done to determine the relationship between the angle of flexion and foot height. Participants placed their right foot onto a step platform and the resulting hip angles were measured. Hip angles were varied by raising or lowering the step 0.5 cm. Step height and corresponding hip angles were recorded. Correlation coefficients of $r = 0.93$ and $r = 0.99$ between hip angles and foot heights were obtained in females and males respectively, leading to the conclusion that hip angles determine step height [54].

Step heights were set according to the equations xviii and xix and hip angles of participants were measured. Mean hip angles of 73.3º ± 2.2 and 73.3º ± 2.1 in females and males respectively were obtained [54]. Therefore the model can accurately predict step height with reasonable accuracy given stature and hip angle, or hip angle given stature and foot height.

Francis and Culpepper [53] validated the anatomical model with step height adjusted based on height of the foot when the hip was flexed at 73.3º using a three minute step test with female students. A regression line was used to predict VO_2max from 15 seconds (5 to 20 s) heart rate recovery. Prediction accuracy was such that 68% of the points were within ± one standard error unit around the best fit line. A significant ($p < 0.05$) correlation coefficient of prediction between heart rate recovery and directly measured VO_2max of $r = 0.70$ was obtained. The standard error of estimate was ± 2.9 $ml.kg^{-1}.min^{-1}$ which is on average within 7% of actual values and compares well with results from well-known submaximal tests such as the Astrand-Ryhming test [172]. The average step height from the height adjusted step heights was 32.5 cm, a height similar to the more predictable fixed step heights of 32.5 to 40.0 cm, which have produced significant correlations between recovery heart rates and VO_2 max [53,82,170].

Francis and Brasher [110] validated the height-adjusted, rate specific, single stage step test in males. Forty-three males performed three step tests randomly at 22, 26 and 30 steps per minute on a participant height adjusted platform for three minutes. The first step test was followed by the VO_2max test on a treadmill. The remaining step tests were completed 24 to 48 hours later. Step height was obtained by multiplying participant height with a constant 0.190. Recovery heart rate was measured from 5 to 15 seconds post exercise. The height adjusted step height and stepping rate of 26 steps per minute produced the highest correlation between recovery heart rate and VO_2max ($r = 0.81$), similar to the correlation in females ($r = 0.80$) with the same stepping rate. Shapiro et al [170] found the same correlation with a fixed step height and stepping rate of 25 steps per minute. At 22 steps per minute the relationship ($r = 0.72$) is comparable to that found by McArdle et al [82] ($r = 0.75$) at the same stepping rate. The cross validation of the observed VO_2max and the calculated VO_2max at 26 steps per minute was highly significant ($p < 0.001$) with a correlation coefficient of $r = 0.98$. There was no significant difference between VO_2max obtained in the cross-validation group and the initial test group. The participant height-adjustable step test is therefore a valid method for the prediction of VO_2max from heart rate recovery. All three stepping frequencies provide similar r values for the prediction of VO_2max from heart rate recovery.

3.5 Stepping Rate

Passmore and Thomson [133] tested the efficiency of stepping rates from 6 steps per minute to 60 steps per minute and found that stepping rates between 14 and 18 steps per minute had the least oxygen consumption. In an earlier study Lupton [173] had found similar results of minimum oxygen consumption at a stepping rate of 1.3 seconds a step when climbing a flight of stairs. This translates to about 23 steps per minute even though the conversion is confounded because the participants do not have both feet placement on the step and do not step down. Shahnawaz [168] found minimum oxygen consumption when stepping at 20 to 25 steps per minute, and therefore concluded the most efficient rate for stepping was within this range.

In another study Francis and Culpepper [169] validated the anatomical model using the 3-minute step test by McArdle et al [82] in a group of female students. Step height was substituted with a height-adjusted step height and two more stepping frequencies of 26 and 30 steps per minute were added to the established 22 steps per minute. Participants performed the three step tests in a random order. The treadmill test followed the first step test. The other two step tests were done 24 to 48 hours later. Step height was defined as the foot height when the hip was flexed at 73.3º. Recovery heart rate was recorded from 5 to 20 seconds post exercise for the three stepping rates of 22, 26 and 30 steps per minute. Recovery heart rate increased with increasing stepping frequency. For example, the heart rate recovery was 33, 37 and 39 beats for 22, 26 and 30 steps per minute, respectively. The Pearson product moment correlation coefficients for the stepping rates of 22, 26 and 30 steps per minute were $r = 0.74$, $r = 0.80$ and $r = 0.77$ respectively (all significant). Approximately 68% of the points were within ± one standard error unit about the best fit line. The standard errors of estimates were relatively small, 3.1, 2.9 and 2.6 $ml.kg^{-1}.min^{-1}$ for the respective stepping frequencies of 22, 26 and 30 steps per minute. The smallest standard error of estimate of 2.6 from the 30 steps per minute test is within 5.9% of actual values, and provides a more accurate estimate than both the Astrand-Ryhming nomogram [172] and the McArdle et al step test [82] which was modified in this study by adjusting height. The stepping rate of 22 steps per minute produced a correlation coefficient ($r = 0.74$) between predicted and directly measured VO_2max, which is similar to the McArdle et al test [82] ($r = 0.75$) which used the same stepping frequency. The highest correlation coefficient between predicted and measured VO_2max ($r = 0.8$) occurred with the stepping frequency of 26 steps per minute.

The prediction capacity of a submaximal test improves with increasing intensity. The faster the stepping rate the higher the intensity and the better the predictability. Nagle at al [81] had better predictability at 30 steps per minute than at 24 steps per minute. The study was done on healthy men. Participants of low physical fitness levels may have greater predictability at lower stepping rates.

Whilst maximum stepping efficiency exhibits a broad optimum it should be noted that stepping rates at the extremes present challenges. A stepping rate of 36 steps per minute is fast and therefore presents two problems. Firstly it makes the test a high intensity test with the potential of being a maximal test to the relatively unfit participants. Secondly unfit participants generally struggle with rhythm and maintaining the cadence. Stepping rates as slow as 10 steps per minute have limitations. Firstly they increase the duration of the test to achieve required heart rates or workload. Secondly energy is wasted in posture maintenance and balance. Based on these studies the stepping rates used in the subsequent pilot studies ranged from 16 steps per minute to 30 steps per minute.

3.6 Trialling and Pilot Studies

Based on the above discussion we decided to standardise the workload in the novel step test. There were several stages to achieve this goal. These stages involved trialling different configurations of step test variables, namely stepping rate, duration and the most appropriate workload. Since there is much research on the relationship between participant height and step height, (discussed in section 3.4), we decided to use these data and calculate step height from the participant's height.

Configurations in Table 8 were tested in theory with a hypothetical participant of height 160 cm, a body mass of 65 kg and a workload of 30 kJ, excluding the work of stepping down. Step height was rounded to the nearest cm.

Table 8 Step test configurations

Configuration	Step height (cm)	Stepping rate (steps/min)	Duration (min)
1	30	36	4.36
2	30	30	5.23
3	30	28	5.60
4	30	24	6.53
5	30	20	7.84

The test duration to produce an external workload of 30 kJ was nearly 8 minutes for a test with a stepping frequency of 20 steps per minute and for a participant of medium body build. This was a reasonable time and was within workloads of other step tests. Therefore 30 kJ was used for the subsequent piloting studies.

The next phase of step test development was piloting the test workload and stepping rate. Three pilot studies were done before the more formal experiments.

3.6.1 Pilot Study 1

In the first pilot study the researcher self-administered the step test. The objective of the trial was to establish workable stepping rates and workload. She worked with three stepping rates of 22, 25 and 30 steps per minute. The tests were administered in three consecutive days at the same time of day. Heart rate and oxygen consumption were measured during the tests. Test duration ranged from 5.23 minutes (5 minutes and 14 seconds) to 7.13 minutes (7 minutes and 8 seconds). The participant's body mass was 65 kg. Workload was set at 30 kJ according to the configurations in table 8. A step height of 30 centimetres, calculated from participant height [54] was used.

The participant finished all tests without undue distress. The peak heart rate for all tests were below age predicted maximum heart rate. The height adjusted step height did not cause local fatigue. Therefore step height calculated from participant height [54] was used in the subsequent pilot studies.

3.6.2 Pilot Study 2

The objective of the second pilot study was to establish the workload for the test and stepping rates on participants of varied fitness levels. Eleven participants (five males and six females) aged 22 to 27 years performed three step tests at 20, 24 and 28 steps per minute. Participant height ranged from 165.5 to 183.0 cm and body mass ranged from 50.6 to 87.2 kg. The workload for the step tests was 30 kJ. Participant mass, step height, stepping rate and gravitational force were used to determine step test duration. Step height was determined using the equations for step height described earlier. Participants performed the three step tests on three consecutive days at the same time of day, with the exception of four participants who skipped one day between two tests due to commitments. Participants maintained a constant diet and constant level of physical activity during the testing days. An Oxycon (VIASYS health care, Germany) was used to measure gas exchange and respiratory exchange ratio (RER) and a Suunto heart rate monitor (Suunto Oy, Vantaa, Finland) measured heart rate. At the end of the test participants stood still and heart rate recovery was measured for two minutes. Energy expenditure (EE) was calculated using caloric equivalent of oxygen in kilocalories per litre ($kcal.l^{-1}$) of oxygen and respiratory exchange ratio (indirect calorimetry) [174] and then converted to kilojoules.

Table 9 Energy expenditure (EE) heart rate recovery (HRR), total heart beats and respiratory exchange ratio (RER) for stepping rates 20, 24 and 28 steps per minute. Data expressed as means and standard deviations.

	Stepping rate		
Variable	20	24	28
EE kJ	215 ± 19	214 ± 16	204 ± 23
HRR (beats)	27 ± 7	35 ± 15	41 ± 13
Total heart beats	989 ± 258	907 ± 206	811 ± 204
RER	0.97 ± 0.07	0.99 ± 0.07	1.02 ± 0.07

There were no significant differences in energy expenditure for all the tests. Heart rate recovery and respiratory exchange ratio showed differences between 20 and 28 steps per minute. Total heart beats were different for all tests. Of major concern was the short duration of the test for some participants. Test duration ranged from 3 minutes 46 seconds to 10 minutes 4 seconds.

3.6.3 Pilot Study 3

The third pilot study was a repeatability study which sought to find if the same test results could be obtained when the test was done three times. Eight participants (three males and five females) performed a step test on three different days at the same time of day in three consecutive days. Participants were 23 to 31 years old, 50.6 to 87.8 kg in body mass and 1.60 to 1.75 metres tall. The stepping rate was 24 steps per minute, controlled by a metronome. Step height varied according to participant height and test duration depended on participant body mass and step height. The mechanical work of the step test was 30 kJ, a product of step height, stepping frequency and test duration. Oxygen consumption, carbon dioxide production and respiratory exchange ratio were measured using an oxycon (VIASYS health care, Germany). Heart rate was measured throughout the test and two minutes after using a Suunto heart rate monitor (Suunto Oy, Vantaa, Finland). Table 10 shows the means and standard deviations of the measured variables.

Table 10 Energy expenditure (EE), heart rate recovery (HRR), total heart beats, respiratory exchange ratio (RER) and rating of perceived exertion (RPE) for 24 steps per minute. Data expressed as means and standard deviation.

	Stepping rate 24 steps per minute		
Variable	Test 1	Test 2	Test 3
EE kJ	210 ± 14	206 ± 26	212 ± 17
HRR	28 ± 16	28 ± 12	28 ± 13
Total heart beats	874 ± 202	906 ± 179	888 ± 169
RER	1.04 ± 0.08	1.01 ± 0.05	1.01 ± 0.07
RPE	12 ± 1	11 ± 1	11 ± 1

The results show that the step test is repeatable. There were no significant differences for energy expenditure, heart rate recovery, heart beats and rating of perceived exertion.

3.7 Workload Determination

After the pilot study workload was increased from 30 kilojoules to 45 kilojoules. The decision was based on a number of reasons. Firstly, when stepping at 24 steps per minute participants rated the test as *light* on the rating of perceived exertion scale. Secondly, the test duration for participants of large body mass was very short. Even though the sample did not have participants who were heavy with a body mass exceeding 100 kg (heaviest was 87.8 kg) or taller than two metres (tallest was 1.75 m), the shortest duration of the test was 3 minutes and 46 seconds. The duration would have been even shorter if heavier or taller participants were tested. Thirdly, the external workload of 30 kilojoules in many cases did not achieve a steady state for oxygen consumption and heart rate. The workload of other step tests was calculated using mean body mass for study samples. One minute workload ranged from 4 to 11 kilojoules and averaged 6 kilojoules. The workload for the tests ranged from 13 to 57 kilojoules and averaged 26 kilojoules with the YMCA-3 minute step test at the lower end and the Harvard Step test at the upper end. The 45 kJ workload for the standardised step test fell within the range of workloads of previous step tests, a measurement large enough to elicit desired physiological responses without straining the participant.

3.8 Stepping Rate Determination

Previous literature provided the recommended range of stepping rates. Pilot studies confirmed workable stepping rates. For the reliability and validity studies that followed stepping rates of 16, 20 and 24 steps per minute were used. The choice was made basing on methodological and research reasons. All stepping rates had to accommodate participants weighing between 50 and 100 kg and the test had to be at least six minutes long. Testing rates of 20, 24 and 28 steps per minute could still have been used but 28 steps per minute made the test duration too short for participants who weighed about a 100 kg. We decided to use 16, 20 and 24 steps per minute for the next phase of testing.

3.9 Test Duration

The workload standardised step test has no predetermined duration, although we decided from a practical perspective it should not be longer than 15 minutes. All the other variables, workload, step height, stepping rate, body mass, are combined to determine the test duration. Each individual has different combinations of step test variables, but a standardised workload. The pilot studies ensured that the test would neither be very short nor very long for people of very large and very small body masses respectively.

3.10 Summary

A step test standardised for external workload was developed and named the "workload standardised step test" (WSST). Some aspects of the protocol were determined using previous research, others were pilot tested. The product was a step test protocol designed to provide a workload of 45 kJ with individualised step height based on the participant's stature. The duration of the test varied to provide the 45 kJ. The principle of clinimetrics requires that a new instrument should be thoroughly assessed before it is used and applied. The following chapters explain how the step test was evaluated through reliability and validity studies.

CHAPTER 4

THE ASSOCIATION BETWEEN MEASURES OF ENERGY EXPENDITURE AND HEART RATE IN THREE SUBMAXIMAL STEPPING TESTS STANDARDISED FOR EXTERNAL WORKLOAD.

4.1 Introduction

As previously described the step test protocol was developed based on established step test protocols in the literature and pilot studies designed to refine the measurements. The protocol comprised a variable step height, constant stepping rate, and variable duration calculated to produce a constant workload (45 kJ). Step height was adjusted according to the participant's stature. Stepping rate was constant during the test for each participant, but varied from trial to trial. Test duration varied among participants and depended on step height and stepping rate. The aim of this study was to test the reliability of three configurations of the step test using 16, 20 and 24 steps per minute.

4.2 Methods

4.2.1 Participants

Thirty one untrained to moderately trained participants, 13 males and 18 females (20 to 60 years), participated in the study. Sampling criteria excluded people with orthopaedic problems that may have interfered with the trial, and chronic conditions requiring medication that might have interfered with cardiorespiratory and metabolic responses to exercise. Participants with a body mass of less than 50 and above 100 kg were also excluded. The Human Research Ethics Committee, University of Cape Town approved the study (HREC REF: 170/2012) (Appendix 5).

4.2.2 Sample Size

The sample size for this study was based on a similar study [23], which examined the repeatability of submaximal heart rate in a shuttle test. That study had sufficient statistical power with 44 participants. The workload was better controlled in our step test study, hence the slightly smaller sample size needed to yield the same accuracy.

4.2.3 Pre-participation

Before the start of the study participants completed a pre-participation fitness screening questionnaire according to the American College of Sports Medicine guidelines Appendix 1, to screen for cardiovascular and pulmonary disease and orthopaedic problems [175]. The experimental protocol was explained and participants who met the study inclusion criteria were asked to sign informed consent forms before participation.

4.2.4 Anthropometric Measurements

Participants' stature, body mass and body fat were measured. Body mass was measured on a calibrated scale before testing on all the three testing days and recorded to the nearest 100 g. The participant was weighed in the minimum clothes possible; men in shorts only and women in shirts and shorts, without shoes.

Stature was measured in cm the first day of testing using the Seca Leicester portable height measure, (Seca, Birmingham, UK). Prior to measurement the participant was instructed to look ahead and take a deep breath. Stature was recorded as the height from the floor to the vertex of the head. The vertex is the highest point on the skull when an imaginary line between the lower margin of the eye socket and the upper margin of the zygomatic bone is parallel to the ground. The participants stood barefoot with their arms hanging by their sides. The heels, buttocks, upper back and head were in contact with the wall. The measurement was recorded to the nearest mm.

Body fat was measured on the first visit using callipers (Holtain Limited, Crymych, United Kingdom). Body fat was represented as the sum of the seven skinfolds (biceps, triceps, subscapular, suprailiac, thigh, calf, abdominal) and as body fat percent [176]. The skinfold was measured by grasping the compressed thickness of a double layer fold of skin and the underlying subcutaneous tissue, which is assumed to be adipose tissue, between the thumb and forefinger, one to two centimetres above the site that was to be measured. The fold was pulled away from the underlying muscle and the jaws of the callipers were placed on either side of the site, at a depth of approximately one centimetre. The skinfold was held firmly throughout the application of the calliper and the reading was taken when the needle became steady after the full pressure of the calliper jaws had been applied. The callipers were applied at right angles to the fold at all times. All measurements were taken on the participant's right side except for the abdominal skinfold that was taken on the participant's left side and recorded in millimetres.

Triceps skinfolds were measured from the back on the posterior surface of the right arm midway between the top of the shoulder (acromion process) and the elbow (olecranon process). The participant stood with the upper limb hanging loosely by the side. Biceps skin folds were measured from the front on the anterior surface of the right arm midway between the top of the shoulder and the elbow. The participant stood in the same posture as for the triceps measurement.

The subscapular skinfold was measured just below the inferior angle of the right scapula with the fold in an oblique plane descending laterally (outwards) and downwards at an angle of approximately 45° to the horizontal.

The suprailiac skinfold was measured five centimetres above the right iliac crest with the fold oblique, descending medially (inwards) and downwards at an angle of about 45° to the horizontal. The participant should stand erect with the upper limbs by the side and the abdominal muscles relaxed. The abdominal skinfold was measured in a vertical plane five centimetres to the left of the participant's umbilicus.

The thigh skinfold was measured at the mid-point on the anterior surface of the right thigh with the fold parallel to the long axis of the thigh. The participant's weight was on the left leg so that the knee joint of the measured leg formed an angle of about 120°. The calf skinfold was measured on the medial surface of the right calf at the level of the greatest calf circumference. The participant's weight was placed on the left leg during measurement.

4.2.5 Step Test

Mechanical work in a step test is a product of step height, stepping rate, test duration and the participant's mass. The amount of work done can be standardised by manipulating variables that contribute to mechanical work. The formula used is,

$W = m \times g \times h$ (Equation xx)

Where:

- W is work in joules (J),

- m is the participant's weight in kilogrammes,
- g is acceleration due to gravity ($9.81\ m.s^{-1}$), and
- h is the step height in metres [177].

The work done per single climb is multiplied by the stepping rate to get the work done in one minute and by the test duration (minutes) to get the work done for the test. The step test provided a constant external workload (45 kJ) by manipulating step height and step test duration in accordance with participant's mass and stature.

Step height was adjusted according to participant's stature to ensure biomechanical stepping efficiency using equations xviii and xix [54]. Step height was manipulated by adding one centimetre boards to five centimetre and ten centimetre piling boards. The step platform was 110 centimetres long and 40 centimetres wide. The adjustable boards were 110 centimetres long and 45 centimetres wide. The platform was rubberised so that the participant's feet were comfortable without any danger of sliding or slipping.

Table 11 shows the range of stature of the participants, from the shortest to the tallest, and their corresponding step heights.

Table 11 Range of participant height in relation to step height from the shortest female (♀) to the tallest male (♂).

	Stature (cm)	Step height (cm)
Participant 1 (♂)	189	36
Participant 2 (♀)	156	29

The heights of the remaining participants were between the two values (156 and 189 centimetres). Participants performed three step test protocols at step frequencies of 16, 20 and 24 steps per minute controlled by a metronome set at 64, 80 and 96 beats per minute respectively. At the first beat the first leg stepped on the step, second beat both legs on step, third beat one leg down and fourth beat both legs down (i.e. four beats per step cycle). The three step test protocols were completed in random order within five days (Monday to Friday). The time of day the test was conducted was kept constant to within one hour. Participants were asked to keep their eating and physical activity habits constant during the five days in an attempt to maintain a similar metabolic and physiological state. Before testing each day the researcher asked the participant about their general condition and feeling. There were no reported violations of the protocol.

The duration of each test was modified to elicit 45 kJ work per test. Participants' body mass, step height, stepping rate and gravitational force were used to determine step test duration. In this study duration ranged from five minutes 46 seconds for the heaviest participant to 19 minutes 30 seconds for the lightest participant. Participants were asked to step with a flat foot and to stand erect on the step to control for energy expenditure [120].

Participants were allowed ten seconds to adjust to the cadence of the metronome. Ambient temperature was controlled (20 - 22°C) and humidity varied between 50 and 60 mmHg. Heart rate was recorded throughout the test and for two minutes after the test using a Suunto T6 chest heart rate transmitter and wrist monitor (Suunto Oy, Vantaa, Finland). During the two minute recovery period the participant stood upright and motionless while heart rate was recorded. After the step protocol, heart rate data were transferred from the wrist monitor to a computer for analysis. Heart rate recovery and total number of heart beats when performing a step test were calculated. Maximum heart rate attained during the test was also recorded. Heart rate data were checked using Suunto training manager and any spurious recordings were deleted. This resulted in missing data for heart rate recovery and total heart beats. Oxygen consumption and respiratory exchange ratio (RER) were measured at 15 seconds intervals using an Oxycon (VIASYS health care, Germany). Energy expenditure during the test was calculated using respiratory exchange ratio and caloric equivalent of oxygen in kilocalories per litre ($kcal.l^{-1}$) of oxygen (indirect calorimetry) according to the fuel used during the exercise [174] and then converted to kilojoules. The participant's perception of effort (RPE) was recorded at the end of each minute using the Borg 6-20 point scale [122]. The scale assesses participants' feelings of exertion, effort, discomfort and strain experienced when doing physical activity.

4.3 Data Analysis

Descriptive statistics, (means and standard deviations), were used for the physical characteristics of participants; i.e. age, stature, body mass, body mass index and body fat percent. Descriptive statistics were also used to determine the means and standard deviations for energy expenditure, heart rate recovery, total heart beats, rating of perceived exertion and maximum heart rate. An analysis of variance (ANOVA) with repeated measures was used to compare the means of the three step tests for energy expenditure, heart rate recovery, total heart beats, rating of perceived exertion and maximum heart rate. A Tukey's *post-hoc* analysis was used to determine the specific differences. Testing order was analysed to determine whether it had an effect on results. The Bland and Altman limits of agreement between the variables from the tests of different stepping frequencies was calculated [178].

4.4 Results

The general descriptive characteristics of all participants are shown in Table 12.

Table 12 Descriptive characteristics of participants (Means ± standard deviations)

Variable	Males (n = 13)	Females (n =18)	Total (n = 31)
Age (Years)	24.4 ± 3.3	24.4 ± 3.3	24.3 ± 5.2
Stature (m)	1.75 ± 0.09	1.65 ± 0.07	1.69 ± 0.09
Body mass (kg)	73.6 ± 12.6	64.6 ± 9.1	68.4 ± 11.4
BMI (kg/m^2)	23.9 ± 3.1	23.8 ± 3.4	23.9 ± 3.5
Body fat percent	18 ± 4	29 ± 5	24 ±7

The energy expenditure, heart rate recovery, maximum heart rate, maximum heart rate as a percentage of age predicted maximum heart rate, total heart beats and rating of perceived exertion for the three stepping rates (16, 20 and 24 steps per minute) are shown in Table 13. The significance of the comparisons between the tests is also shown in this table. There were significant differences among all three step tests for all the variables measured except heart rate recovery between 16 and 20 steps per minute. Energy expenditure was highest at 16 steps per minute and steadily decreased with increasing stepping frequency.

Table 13 Energy expenditure (EE), heart rate recovery (HRR), maximum heart rate (MHR), maximum heart rate as a percentage of age predicted maximum heart rate, (% AP MHR), total heart beats (THB) and rating of perceived exertion (RPE) for 3 stepping rates: 16, 20 and 24 steps per minute. Data expressed as mean ± standard deviation, F value and p value.

	Stepping rate				Comparison		
Variable	**16**	**20**	**24**	**F and P**	**16 vs. 20**	**20 vs. 24**	**16 vs. 24**
EE (kJ)	355 ± 30	335 ± 35	321 ± 29	$F_{2,60} = 23.213$ (P = 0.00001)	P < 0.001	P < 0.05	P < 0.001
HRR (b)	28 ± 7	29 ± 7	34 ± 9	$F_{2,50} = 17.058$ (P = 0.00001)	P > 0.05	P < 0.001	P < 0.001
MHR (bpm)	136 ± 22	149 ± 24	160 ± 22	$F_{2.32} = 53.552$ (P = 0.00001)	P < 0.001	P < 0.001	P < 0.001
% AP MHR	70 ± 11	76 ± 12	81 ± 10	$F_{2,32} = 53.675$ (P = 0.00001)	P > 0.05	P > 0.05	P < 0.01
THB (b)	1723 ± 545	1600 ± 474	1375 ± 440	$F_{2.26} = 69.993$ (P = 0.00001)	P < 0.001	P < 0.001	P < 0.001
RPE	10 ± 2	11 ± 2	12 ± 3	$F_{2,56} = 16.980$ (P = 0.00001)	P < 0.01	P < 0.05	P < 0.001

Figure 2 is a graphic representation of the relationship between the three stepping frequencies 16, 20 and 24 steps per minute and energy expenditure. Energy expenditure decreased with increasing stepping frequency.

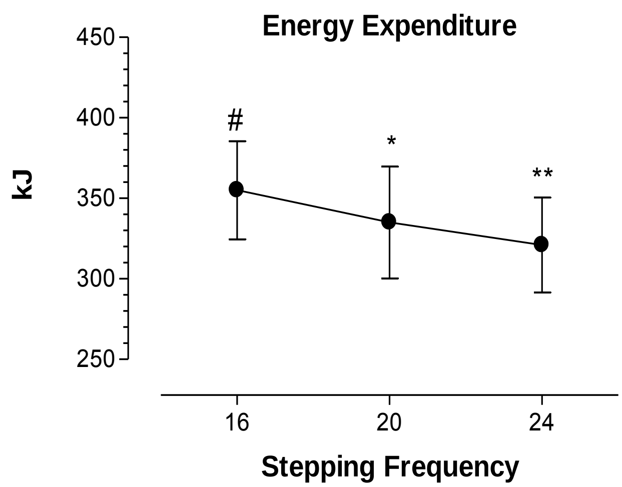

Figure 2 Energy expenditure for stepping rates 16, 20 and 24 steps per minute.

Figure 3 shows heart rate recovery, maximum heart rate, total heart beats and the rating of perceived exertion for the three stepping frequencies. Heart rate recovery, maximum heart rate and rating of perceived exertion increased with increasing stepping frequency whereas total heart beats decreased.

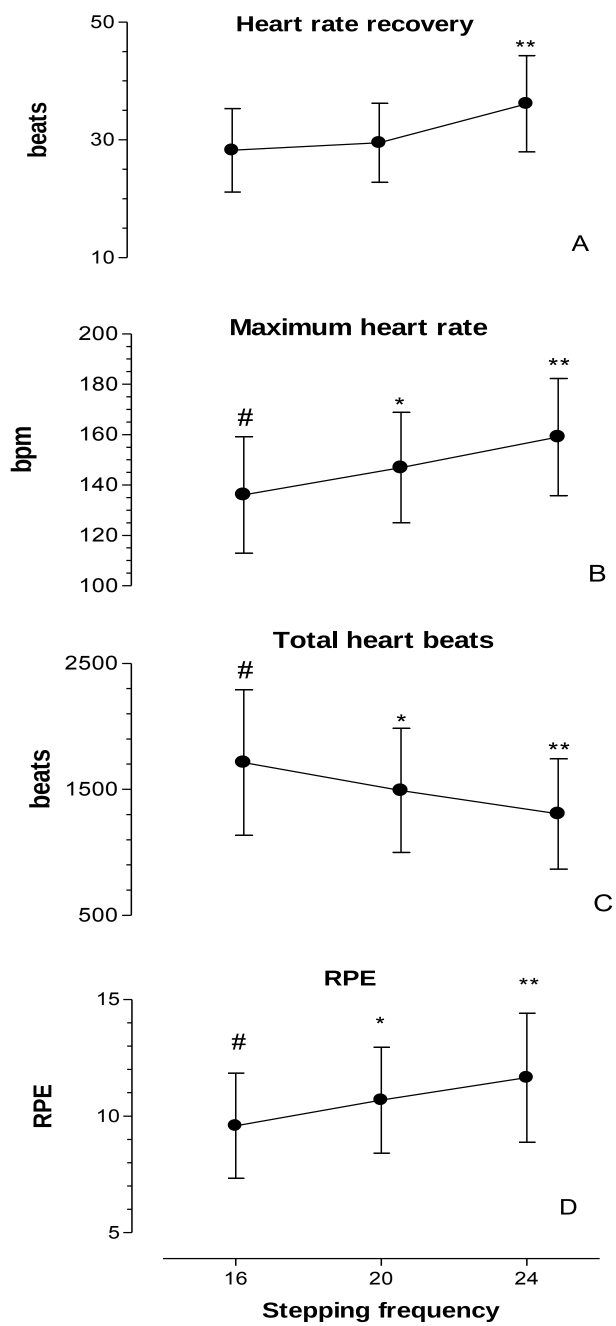

Figure 3 Heart rate recovery (A), maximum heart rate (B), total heart beats (C) and rating of perceived exertion (D) for 16, 20 and 24 steps per minute.

The limits of agreement were calculated between stepping frequencies of 16-20, 16-24 and 20-24 steps per minute for energy expenditure, heart rate recovery, total heart beats, maximum heart rate and rating of perceived exertion (Table 14). The biggest differences for all the variables occurred between the 16 and 24 steps per minute.

Table 14 Limits of agreement for energy expenditure (EE), heart rate recovery (HRR), total heart beats (THB), maximum heart rate (MHR), maximum heart rate as a percentage of age predicted maximum heart rate (% AP MHR) and rating of perceived exertion (RPE) for the three stepping rates 16, 20 and 24 steps per minute.

Variable	**16 vs. 20**	**16 vs. 24**	**20 vs. 24**
EE (kJ)	-42 to 83	-26 to 94	-29 to 56
HRR (b)	-11 to 9	-24 to 8	-23 to 11
MHR (bpm)	-28 to 7	-40 to -5	-34 to 9
% AP MHR	-14 to 3	-21 to -2	-17 to 4
THB (b)	-43 to 522	116 to 721	-134 to 472
RPE	-5 to 3	-6 to 2	-4 to 2

Data for the step tests at 16, 20 and 24 steps per minute were sorted according to the order of testing for all variables to determine whether the order had an effect on the results. Table 15 shows the means and standard deviations of energy expenditure, heart rate recovery, maximum heart rate, maximum heart rate as a percentage of age predicted maximum heart rate, total heart beats, and rating of perceived exertion. The p values ($P > 0.05$) show that the testing order had no effect on the variables measured.

Table 15 Energy expenditure (EE), heart rate recovery (HRR), total heart beats (THB), maximum heart rate (MHR), maximum heart rate as a percentage of age predicted maximum heart rate (% AP MHR) and rating of perceived exertion (RPE) for testing order 1, 2 and 3 of the 3 step tests.

Variables	Test 1	Test 2	Test 3	F value	P Values
EE (kJ)	340 ± 38	343 ± 30	328 ± 33	1.7	0.19
HRR (b)	29 ± 8	31 ± 8	32 ± 8	1.0	0.38
MHR (beats.min^{-1})	148 ± 24	148 ± 26	153 ± 22	0.3	0.71
THB (b)	1623 ± 545	1562 ± 483	1478 ± 480	0.5	0.61
% AP MHR (b)	75 ± 12	76 ± 12	78 ± 11	0.4	0.69
RPE	11 ± 3	10 ± 2	11 ± 3	0.6	0.53

4.5 Discussion

The aim of this study was to determine whether three step test protocols, varying in step frequency and duration but standardised for 45 kJ external workload elicit the same physiological responses. The study showed there were significant differences in the physiological responses between the three stepping rates and therefore the different configurations of the test are not interchangeable.

The three stepping rates of 16, 20 and 24 steps per minute differed in exercise intensities, as measured by maximum heart rate and perception of effort during the test (Table 13). Maximum heart rate during the test increased as stepping frequency increased. Therefore by implication the intensity increased as the stepping frequency increased. Indeed maximum heart rate as a percentage of age predicted maximum heart rate during the step test increased from a mean of 70% (16 steps per minute) to 81% (24 steps per minute).

The change in energy expenditure, despite the external workload remaining constant, can be attributed to the fact that the anaerobic component was not accounted for in the calculation of energy expenditure as the stepping frequency and exercise intensity increased. This is because the method used to calculate energy expenditure of each participant has limitations as it is based on oxygen consumption and does not include energy derived from oxygen independent methods [179]. Measurement of oxygen to predict energy expenditure is valid providing the substrate is known (glucose or fat) and the exercise intensity is steady at a low to moderate rate. During short duration high intensity exercise ATP is resynthesised through anaerobic glycolysis. An anaerobic measurement is therefore required to account for this type of energy transfer. Oxygen consumption can only be used to measure energy expenditure for exercises that are entirely aerobic, and has limitations when measuring brief, intense, non-steady rate exercise that has a large glycolytic ATP turnover component [179]. Therefore it may be concluded that in this study, as the intensity increased with increased stepping rate more of the energy was derived from oxygen independent pathways.

There were significant differences in heart rate recovery between 16 and 24 steps per minute and between 20 and 24 steps per minute but no significant difference between 16 and 20 steps per minute. The differences were largest between the 16 steps per minute compared to the 24 steps per minute (Table 13). Studies on heart rate during and after exercise found that changes in heart rate and heart rate recovery had the least day-to-day variation and highest level of sensitivity if a submaximal protocol elicits heart rate between 86 and 93% of maximum heart rate [23,24]. In our study all stepping rates did not elicit 86% of age predicted maximum heart rate and this could have had an effect on measurement of heart rate recovery (Table 13).

The heart rate at the starting point of recovery influences the rate of recovery [27]. High intensity exercise causes both sympathetic stimulation and parasympathetic withdrawal. Low intensity exercise causes parasympathetic withdrawal only. During heart rate recovery there is parasympathetic reactivation and sympathetic withdrawal. Therefore exercise intensity has an effect on heart rate recovery. Participants recovered faster from the 24 steps per minute test than from the 20 steps per minute. Heart rate recovery is also influenced by temporary physical status, load level, activity level and pre and post movement [64].

The total heart beats during the test decreased as stepping frequency increased. Step test duration was shorter at higher stepping rates and longer at lower stepping rates. Since the total heart beats is a product of heart rate and duration, it may be concluded that the decreasing trend in total heart beats shows that the increase in heart rate with increasing stepping frequency was offset by the shorter test duration.

There were significant differences in rating of perceived exertion for the three stepping frequencies with 16 steps per minute being perceived as the lowest. Rating of perceived exertion reflects the combined feedback from the cardiorespiratory, metabolic and thermal stimuli [180]. Rating of perceived exertion correlates with average heart rate [181] and acute changes in heart rate [182].

4.6 Conclusions

A standardised external workload elicits different physiological responses to exercise. This can be attributed to different exercise intensities and test duration. Three step tests, all 45 kJ but with different parameters (stepping rate and duration) produced significant differences ($p < 0.05$) in energy expenditure and heart rate recovery in participants. Energy expenditure was highest at 16 steps per minute and steadily decreased with increasing stepping frequency. This can be attributed to the duration of the test that lasted longer at low stepping frequencies and the exclusion of the anaerobic component in the calculation of energy expenditure at high stepping frequencies. Total heart beats decreased as stepping frequency increased. Step test duration had a greater effect on the total heart beats than exercise intensity. Heart rate recovery was also different (16, 20 and 24 steps per minute) possibly as a consequence of different exercise intensities in the preceding exercise. Therefore we conclude that standardisation of external workload by manipulating step height, duration of the test and stepping frequency elicits different physiological responses when the stepping frequency varies.

CHAPTER 5

THE REPEATABILITY OF THE MEASUREMENTS OF ENERGY EXPENDITURE AND HEART RATE IN A STEPPING TEST STANDARDISED FOR EXTERNAL WORKLOAD

5.1 Introduction

The principle of clinimetrics requires that a tool for measurement must be tested for reliability and validated before it can be used to make informative and interpretative measurements. Reliability represents the reproducibility of observed values of a test, assay or other measurement in repeated trials on the same individuals [183]. Reliability is concerned with the consistency of observed values when the measurements are repeated in the same environment by the same tester on the same participants and under the same conditions.

Quantifying the reliability of a measurement enables decisions to be made about whether the differences after intervention are real or a result of testing error. Within-participant variation is the most important type of repeatability measure. The smaller the within-participant variation (typical error of measurement) the better the precision of single measurements and better observation of changes [183]. Typical error of measurement (TEM) and typical error as a coefficient of variation (CV_{TEM}) quantify the amount of noise associated with a testing instrument and procedure. The units of TEM are the same as the measurement whereas CV_{TEM} is expressed as a percentage.

Quantifying reliability associated with testing contributes to better interpretation of results by determining the smallest worthwhile difference of a measurement. In addition it is important to establish if the differences in measurements are of practical relevance. The threshold for differences considered to be practically relevant is based on Cohen's effect size concept [184] and is called the smallest worthwhile difference (SWD) (See calculation in methods section page 99). Measurements that have a mean typical error of measurement (TEM) and typical error as a coefficient of variation (CV_{TEM}) lower than the smallest worthwhile difference have "good" sensitivity while measurements that have differences following repeated trials equal to, or greater than, the smallest worthwhile difference have "satisfactory" or "poor" sensitivity respectively [185].

Relative reliability is the degree to which individuals maintain their position in a sample over repeated measurements [186]. Intraclass correlation coefficient measures relative reliability. Correlation coefficients define the degree of association between two sets of data or the consistency of position within the distribution [186]. A high intraclass correlation coefficient represents a high relative reliability and a low influence of measurement error. Correlation coefficient does not detect systematic error so two sets of data may be highly correlated but not repeatable. If a group is heterogeneous, the intraclass correlation coefficient is high as there is little chance for swapping positions of a measurement. Therefore, while intraclass correlation coefficient provides useful information there is need for further analysis to confirm the reliability of the measurements.

Absolute reliability is the degree to which repeated measurements vary for individuals [186]. The less they vary the higher the reliability. Absolute reliability is expressed in the actual units of the measurements or as a proportion of the measurements. The standard error of measurement (SEM), coefficient of variation (CV) and Bland and Altman's limits of agreement all measure absolute reliability [186]. Coefficient of variation is defined as the ratio of standard deviation (σ) to the mean (μ), σ/μ. Quantifying typical error contributes to an interpretation of whether the difference between two trials is real or due to testing error.

This study follows the study in Chapter 4 that investigated physiological responses to three submaximal step test protocols at stepping frequencies of 16, 20 and 24 steps per minute with step height adjusted for participants' height and test duration adjusted to standardise the external workload at 45 kJ. In that study (Chapter 4) the workload was standardised at 45 kJ so that all participants performed the same amount of external work. The study showed that the different configurations of the test are not interchangeable with differences mostly occurring between the 16 and 24 steps per minute.

We therefore decided to keep the stepping rate constant when the repeatability of the step test adjusted for an external workload of 45 kJ was determined. We also wanted to determine the preferred cadence if a participant was given a choice. The study was approved by the Human Research Ethics Committee of the Faculty of Health Sciences of the University of Cape Town (HREC REF: 170/2012) (Appendix 5).

Research question

What is the typical error of measurement and the smallest worthwhile difference of measurement of a step test protocol with step height and duration manipulated to produce 45 kJ of external work while stepping rate remains constant?

5.2 Methods

The study was a cross sectional comparative design with repeated measures.

5.2.1 Sample

The sample consisted of healthy, untrained to moderately trained men (n = 19) and women (n =15) aged 20 to 60 years who weighed between 50 and 100 kg. Sampling criteria excluded people with orthopaedic problems that may have interfered with the trial, and chronic conditions requiring medication that might have interfered with cardiorespiratory and metabolic responses to exercise. The recruitment of participants was marketed through emails, fliers and word of mouth.

5.2.2 Pre-participation

Before the start of the study participants completed a pre-participation fitness screening questionnaire according to the American College of Sports Medicine guidelines (Appendix 1). This questionnaire screened for cardiovascular and pulmonary disease and orthopaedic problems. The experimental protocol was explained and participants who met the study inclusion criteria were asked to sign informed consent forms before participation.

5.2.3 Anthropometric Measurements

Stature, body mass and body fat of the participants were measured as described in the previous study (Chapter 4, section 4.2.4).

5.2.4 Testing

Participants reported for testing four times a week. They performed a step test on the first three days and on the fourth day they performed a twelve minute walk/run test in which they were required to cover as much distance as possible.

During the familiarisation period on the first day of testing, participants were allowed to experience three step test protocols of stepping rates 16, 20 and 24 steps per minute. They selected a stepping rate that they found most comfortable. Ten participants chose 20 steps per minute and 24 participants chose 24 steps per minute. Nobody selected 16 steps per minutes. Step height was adjusted to participant stature using equations xviii and xix [54]. The duration of the protocol was calculated considering the step height and body mass to produce an external workload of 45 kJ. The same protocol was repeated on three days within a five day period (Monday to Friday), at the same time of day (within one hour) and under the same laboratory conditions.

Reliability is affected by testing protocol, equipment and calibration, participant characteristics and the period between repeated trials and testing conditions (testing time, temperature and humidity). Ambient temperature (20 - 22°C) and relative humidity (50 - 60 mmHg) were controlled in air-conditioned laboratories. The same investigator recorded all measurements to minimise random error as much as possible. Participants were asked to maintain a constant diet and not change their physical activity habits during the five days. Participants were asked to refrain from drinking caffeinated beverages two hours before testing. Participants did not warm up before the test but were allowed 10 seconds to adjust to the cadence of the metronome (Vic Firth, Korea).

Respiratory gas exchange was measured using an Oxycon breath-by-breath analyser (Jaeger Pro®, VIASYS health care, Hoechberg, Germany). The Oxycon was calibrated before each trial using a three litre syringe (SensorMedics®, Milan, Italy) and a reference gas of known composition (16% oxygen, 5% carbon dioxide, balance nitrogen). Respiratory data were averaged at 15 seconds intervals. Energy expenditure was calculated using respiratory exchange ratio and caloric equivalent of oxygen in kilocalories per litre ($kcal.l^{-1}$) of oxygen (indirect calorimetry) according to the fuel used during the exercise [174] and then converted to kilojoules.

Heart rate for the test duration and two minutes after the test was measured with a Suunto T6 heart rate monitor (Suunto Oy, Vantaa, Finland). Heart rate was recorded every two seconds. After the test heart rate data were transferred from the wrist monitor to a computer for analysis. Heart rate data were checked using the Suunto training manager (Suunto Oy, Vantaa, Finland). Heart rate recovery was calculated as the difference between the end of exercise heart rate (taken as the average of the last 16 seconds of the test) and the one minute recovery heart rate (taken as the average of the last 16 seconds of the first minute of recovery as previously described [24]. Total heart beats during the test were calculated. Maximum heart rate during the test was also recorded. The participant's perception of effort (RPE) was recorded at the end of each minute using the Borg 6-20 point scale [122].

5.2.5 Physical Performance

All participants did the 12 minute walk/run motion test adapted from the Cooper test [9] within the same week as the step tests. After an adequate warm-up of jogging and stretching participants were asked to cover as much distance as possible in 12 minutes by either walking, jogging or running. Participants were verbally encouraged to maintain motion at the highest speed possible so that they could cover the maximal distance during the 12 minutes. The test was done on a synthetic track (inside line 133 metres, middle of lane one 135 metres, line between lane one and lane two 140 metres, middle of lane two lane 144 metres) in the Fitness Centre of the Sports Science Institute of South Africa (SSISA). Participants were asked to use the inside line during the test.

5.2.6 Data Analysis

Descriptive statistics were calculated and used to analyse physical characteristics of participants and as well as step test outcome measures. Reliability data were analysed for statistical significance using repeated measures analysis of variance (ANOVA) and significant differences were further investigated using a Tukey's *post-hoc* test using Statistica version 12 (Statsoft Inc., Tulsa, OK, USA) and Prism 5 (GraphPad Software, Inc., CA, USA). ANOVA and paired t tests detect systematic bias between the means of two sets of data. Statistical significance was defined as $p \leq 0.05$. Between-trial differences were also investigated by calculating Cohen's effect sizes from the effect size calculator spreadsheet [184]. These were interpreted as < 0.2 = trivial, ≥ 0.2 to < 0.5 = small, ≥ 0.5 to < 0.8 = moderate and ≥ 0.8 = large [184]. Confidence intervals for the effect sizes were also calculated. The smallest worthwhile difference was defined as the difference equating to an effect size of 0.2. This was calculated as 0.2 multiplied by pooled standard deviation. The smallest worthwhile difference (SWD) was compared with the noise in the measurement as suggested by Hopkins [187].

Measurement reliability in the form of intraclass correlation coefficient (ICC), typical error of measurement (TEM) and typical error as a coefficient of variation (CV_{TEM}) were determined using the spreadsheet "Reliability from consecutive pairs of trials", in: A new view of statistics downloaded from www.sportsci.org: Internet Society for Sport Science, sportsci.org/resource/stats/xrely.xls [185]. The between trial reliability statistic of typical error was calculated as the standard deviation of the difference score divided by square root of two and was converted to a coefficient of variation (CV_{TEM}). All measures of reliability are expressed with 90% confidence intervals (90% C.I.) [185].

An independent *t*-test was used to determine the significance of differences between the group that selected 20 steps per minute and the group that selected 24 steps per minute.

5.3 Results

The results will be presented in two sections: (i) whole group and (ii) comparison between 20 and 24 steps per minute (step cadence).

5.3.1 A. Whole Group

Participants' height ranged from 154.5 cm to 198.0 cm. The step height accommodating these heights ranged from 29 cm to 37 cm. The shortest duration of the test for the heaviest participant was 5 minutes and 47 seconds and the longest duration of the test for the lightest participant was 12 minutes and 15 seconds.

The mean age of the participants was just over 33 years (Table 16). There were no significant differences between the ages of men and women (P = 0.56). Men were generally taller (P = 0.01) but average body mass and body mass index (BMI) of males and females were similar; (P = 0.63) and (P = 0.26) respectively. Women generally had more fat than men as shown by the body fat percent (P = 0.0001) and sum of seven skinfolds (P = 0.003).

Table 16 Descriptive characteristics of participants (means and standard deviations)

Variable	**Males (n = 19)**	**Females (n = 15)**	**Total (n = 34)**
Age (years)	32.4 ± 9.4	34.5 ± 11.7	33.4 ± 10.3
Stature (cm)	174.8 ± 9.2	166.3 ± 7.7	171.0 ± 9.5
Body mass (kg)	71.8 ± 13.9	69.4 ± 13.9	70.7 ± 13.7
BMI (kg/m^2)	23.4 ± 3.7	25.2 ± 5.2	24.2 ± 4.5
Body fat %	17.8 ± 7.0	30.8 ± 6.5	24.1 ± 9.4
Sum of 7 skinfolds (mm)	86.7 ± 48.3	147.9 ±57.9	116.3 ± 60.8

Energy expenditure, heart rate recovery and peak respiratory exchange ratio (RER) were not different between trials (Table 17). There were however differences between the first trial and third trial for maximum heart rate, age predicted maximum heart rate, heart beats and rating of perceived exertion (RPE). RPE was also different between the first and second trials. However, for average RPE (not shown in the table) there were no significant differences between the first and the second trial and between the second and third trial.

Table 17 Energy expenditure (EE), heart rate recovery (HRR), maximum heart rate (MHR), maximum heart rate as a percentage of age predicted maximum heart rate, (% AP MHR), total heart beats (THB), rating of perceived exertion (RPE) and peak respiratory exchange ratio (RER).

	Stepping rate					Comparison		
Variable	**1**	**2**	**3**	**Mean**	**F**	**1 vs. 2**	**2 vs. 3**	**1 vs. 3**
EE (kJ)	293 ± 36	293 ± 40	297 ± 40	295 ± 39	$F_{2,66}$ = 0.4 (P = 0.65)	P > 0.05	P > 0.05	P > 0.05
HRR (b)	30 ± 12	32 ± 11	30 ± 12	31 ± 11	$F_{2,66}$ = 2.8 (P = 0.07)	P > 0.05	P > 0.05	P > 0.05
MHR (bpm)	147 ± 22	145 ± 20	144 ± 20	146 ± 21	$F_{2,66}$=3.7 (P = 0.03)	P > 0.05	P > 0.05	P < 0.05
% AP MHR	79 ± 12	78 ± 11	77 ± 11	78 ± 11	$F_{2,66}$ =3.8 (P = 0.03)	P > 0.05	P > 0.05	P < 0.05
THB (b)	1256 ± 375	1233 ± 337	1213 ± 332	1234 ± 348	$F_{2,66}$= 4.2 (P = 0.02)	P > 0.05	P > 0.05	P < 0.05
RPE	13 ± 3	12 ± 3	12 ± 3	12 ± 3	$F_{2.66}$= 12.5 (P = 0.00)	P < 0.01	P > 0.05	P < 0.001
RER	1.00 ± 0.06	0.99 ± 0.07	0.98 ± 0.07	0.99 ± 0.07	$F_{2,66}$ = 2.4 (P = 0.09)	P > 0.05	P > 0.05	P > 0.05

Intraclass correlation coefficients (R) were calculated to test for relative reliability. The data for all the measured variables are presented in Table 18. Generally there was high intraclass correlation among all measured variables with maximum heart rate, maximum heart rate as a percentage of age predicted maximum heart rate, total heart beats and rating of perceived exertion all R ≥ 0.95.

Table 18 Intraclass correlation coefficient and confidence intervals for energy expenditure (EE), heart rate recovery (HRR), maximum heart rate (MHR), maximum heart rate as a percentage of age predicted maximum heart rate, (% AP MHR), total heart beats (THB), rating of perceived exertion (RPE) and peak respiratory exchange ratio (RER).

Variable	**Intraclass correlation coefficient**			**Mean**
	1 vs. 2	2 vs. 3	1 vs. 3	
EE (kJ)	0.69 (0.51– 0.81)	0.79 (0.66 – 0.88)	0.62 (0.41 -0.77)	0.69 (0.57– 0.80)
HRR (beats)	0.89 (0.82– 0.94)	0.90 (0.83 – 0.94)	0.88 (0.80 – 0.93)	0.89 (0.84– 0.94)
MHR (bpm)	0.96 (0.93 – 0.98)	0.95 (0.91 – 0.97)	0.95 (0.91 – 0.97)	0.96 (0.93– 0.97)
% APMHR	0.96 (0.93 – 0.98)	0.95 (0.92– 0.97)	0.95 (0.92 – 0.97)	0.96 (0.93 – 0.97)
THB (b)	0.97 (0.95 – 0.99)	0.98 (0.96 – 0.99)	0.96 (0.93-0.98)	0.97 (0.96 – 0.98)
RPE	0.96 (0.92 – 0.98)	0.97 (0.94 – 0.98)	0.93 (0.89 – 0.96)	0.95 (0.93 – 0.97)
RER	0.68 (0.49 - 0.81)	0.62 (0.40 - 0.77)	0.46 (0.21 - 0.66)	0.59 (0.45 - 0.73)

The effect sizes for the differences were calculated (Table 19) and were either *trivial* or *small*. Standardised differences were *trivial* for energy expenditure, heart rate recovery, maximum heart rate, total heart beats and maximum heart rate as a percentage of age predicted maximum heart rate. For rating of perceived exertion and peak respiratory exchange ratio the differences were *trivial* when the first two trials were compared and *small* when the first trial and third trial were compared.

Table 19 Effect size and 95% confidence intervals for the effect size (in brackets) for energy expenditure (EE), heart rate recovery (HRR), maximum heart rate (MHR), maximum heart rate as a percentage of age predicted maximum heart rate, (% AP MHR), total heart beats (THB), rating of perceived exertion (RPE) and peak respiratory exchange ratio (RER).

Variable	**Effect size**		
	1 vs. 2	**2 vs. 3**	**1 vs. 3**
EE (kJ)	0.0 (-0.5 – 0.5)	-0.1 (-0.6 – 0.4)	-0.1 (-0.6 – 0.4)
HRR (Beats)	-0.1 (-0.6 – 0.3)	0.2 (-0.3 – 0.7)	0.1 (-0.4 -0.5)
MHR (bpm)	0.1 (-0.4 – 0.6)	0.0 (-0.4 – 0.5)	0.1 (-0.3 – 0.6)
% AP MHR	0.1 (-0.4 – 0.6)	0.0 (-0.4 – 0.5)	0.1 (-0.3 – 0.6)
THB (beats)	0.1 (-0.4 – 0.5)	0.1 (-0.4 – 0.5)	0.1 (-0.4 – 0.6)
RPE	0.2 (-0.3 – 0.7)	0.1 (-0.4 – 0.6)	0.3 (-0.2 – 0.7)
RER	0.1 (-0.4 – 0.6)	0.2 (-0.3 – 0.7)	0.3 (-0.2 – 0.8)

Effect size < 0.2 = trivial, ≥ 0.2 to < 0.5 = small, ≥ 0.5 to < 0.8 moderate, ≥ 0.8 = large

Measurement error and confidence intervals for all the measured variables are presented in (Table 20). Typical error as a coefficient of variation is shown in Table 21.

Table 20 Measurement error and confidence intervals for energy expenditure (EE), heart rate recovery (HRR), maximum heart rate (MHR), maximum heart rate as a percentage of age predicted maximum heart rate, (% AP MHR), total heart beats (THB), rating of perceived exertion (RPE) and peak respiratory exchange ratio (RER).

Variable	Typical error			Mean
	1 vs. 2	2 vs. 3	1 vs. 3	
EE (kJ)	22 (18 - 27)	19 (16 - 23)	24 (20 - 30)	22 (19 - 24)
HRR (beats)	4 (3 - 5)	4 (3 - 4)	4 (3 - 5)	4 (3 - 4)
MHR (bpm)	4 (4 - 5)	5 (4 - 6)	5 (4 - 6)	5 (4 - 5)
% APMHR	2 (2 - 3)	2 (2 - 3)	3 (2 - 3)	2 (2 - 3)
THB (b)	59 (49 - 74)	50 (42 - 63)	75 (62 - 94)	62 (56 - 70)
RPE	0.7 (0.6 – 0.8)	0.6 (0.5 – 0.7)	0.8 (0.7 – 1.0)	0.7 (0.6 – 0.8)
RER	0.04 (0.03 - 0.04)	0.04 (0.03 - 0.04)	0.03 (0.03 - 0.04)	0.04 (0.03 - 0.04)

Table 21 Typical error as a coefficient of variation (CV_{TEM}) and confidence intervals for energy expenditure (EE), heart rate recovery (HRR), maximum heart rate (MHR), maximum heart rate as a percentage of age predicted maximum heart rate, (% AP MHR), total heart beats (THB), rating of perceived exertion (RPE) and peak respiratory exchange ratio (RER).

Variable	**Typical error as a coefficient of variation (%)**			**Mean**
	1 vs. 2	**2 vs. 3**	**1 vs. 3**	
EE (kJ)	8.3 (6.9 – 10.6)	7.9 (6.6 – 10.1)	9.4 (7.8 – 12.0)	8.6 (7.6 – 9.8)
HRR (beats)	13.3 (11.0 – 17.0)	16.3 (13.4 – 20.9)	15.6 (12.9 – 20.1)	15.1 (13.5 – 17.3)
MHR (bpm)	3.0 (2.5 – 3.8)	3.3 (2.7 – 4.1)	3.4 (2.8 – 4.3)	3.2 (2.9 – 3.7
% APMHR	3.0 (2.5 – 3.8)	3.3 (2.7 – 4.1)	3.4 (2.8 – 4.3	3.2 (2.9 – 3.7)
THB	4.6 (3.9 – 5.9)	5.4 (4.5 – 6.8)	6.6 (5.5 – 8.3)	5.6 (5.0 – 6.4)
RPE	5.7 (4.7 – 7.2)	5.1 (4.3 – 6.5)	6.8 (5.6 – 8.6)	5.9 (5.3 – 6.7)
RER	3.6 (3.0 – 4.5)	3.7 (3.0 – 4.6)	3.5 (2.9 – 4.4)	3.6 (3.2 – 4.1)

Table 22 is a summary and extension of Table 20 and Table 21 showing the mean typical error of measurement (TEM), mean typical error of measurement as a coefficient of variation (CV_{TEM}) and the smallest worthwhile difference (SWD) for all the variables measured. The categories of comparison of measurement error and the smallest worthwhile difference suggested by Buchheit et al [188] were used. If the TEM was smaller than the SWD the measurement was rated as "good", if TEM was the same as SWD the measurement was rated "OK" and if TEM was greater than SWD the measurement was rated "marginal".

Table 22 Typical error of measurement (TEM), typical error as a coefficient of variation (CV_{TEM}) and the smallest worthwhile difference (SWD) for energy expenditure (EE), heart rate recovery (HRR), maximum heart rate (MHR), maximum heart rate as a percentage of age predicted maximum heart rate, (% AP MHR), total heart beats (THB), rating of perceived exertion (RPE) and peak respiratory exchange ratio (RER).

Variable	**TEM**	**CV_{TEM}**	**SWD**	**Sensitivity**
EE (kJ)	22	8.6	8	*Marginal*
HRR (b)	4	15.1	2	*Marginal*
MHR (bpm)	5	3.2	4	*Marginal*
% APMHR	2	3.2	2	*OK*
THB (b)	62	5.6	71	*Good*
RPE	1	5.9	1	*OK*
RER	0.04	3.6	0.01	*Marginal*

Energy expenditure, heart rate recovery, maximum heart rate and peak respiratory exchange ratio had typical error of measurement greater than the smallest worthwhile difference. Total heart beats had typical error of measurement lower than the smallest worthwhile difference whilst maximum heart rate as a percentage of age predicted maximum heart rate and rating of perceived exertion had typical error of measurement the same as the smallest worthwhile difference.

5.3.2 B. Step Cadence

The anthropometric characteristics of the participants who chose the 20 steps per minute were compared with those who chose 24 steps per minute. There were no significant differences in age, stature, body mass, body mass index, body fat percent and sum of seven skinfolds between the two groups (Table 23).

Table 23 Descriptive characteristics of participants who chose 20 steps per minute versus 24 steps per minute

Variable	Step cadence		All	P value
	20 (n = 10)	**24 (n = 24)**		
Age (years)	33.5 ± 11.2	33.3 ± 10.2	33.4 ± 10.3	0.96
Stature (cm)	173.3 ± 9.4	170.1 ± 9.6	171.0 ± 9.5	0.38
Body mass (kg)	74.0 ± 11.6	69.4 ± 14.5	70.7 ± 13.7	0.37
BMI (kg/m^2)	24.9 ± 5.0	23.9 ± 4.3	24.2 ± 4.5	0.58
Body fat %	29.0 ± 10.3	22.4 ± 8.6	24.1 ± 9.4	0.09
Sum of 7 skinfolds (mm)	144.0 ± 69.5	106.7 ± 55.9	116.3 ± 60.8	0.14

The measurement error about the two stepping cadences was also analysed and presented in Table 24. The measurement error for the 20 steps per minute was similar to that for 24 steps per minute except for energy expenditure where the typical error of measurement was higher in the 24 steps per minute group.

Table 24 Measurement error for 20 steps per minute and 24 steps per minute for energy expenditure (EE), heart rate recovery (HRR), maximum heart rate (MHR), maximum heart rate as a percentage of age predicted maximum heart rate, (% AP MHR), total heart beats (THB), rating of perceived exertion (RPE) and peak respiratory exchange ratio (RER).

Variable	20 steps per minute TEM				24 steps per minute TEM			
	1 vs. 2	2 vs. 3	1 vs. 3	Mean	1 vs. 2	2 vs. 3	1 vs. 3	Mean
EE (kJ)	9 (7-15)	16 (12-26)	9 (8-12)	11 (9-13)	25 (21-34)	20 (16-26)	22 (18-28)	22 (20-26)
HRR (b)	5 (3-8)	4 (3-7)	2 (2-3)	3 (3-4)	3 (3-4)	3 (3-4)	3 (3-4)	3 (3-4)
MHR (bpm)	4 (3-7)	4 (3-6)	2 (2-2)	3 (2-3)	5 (4-6)	5 (4-7)	5 (4-6)	5 (4-5)
%APMHR	2 (2-4)	2 (2-4)	1 (1-1)	2 (1-2)	2 (2-3)	2 (2-3)	2 (2-3)	2 (2-3)
THB (b)	76 (55-125)	32 (23-53)	46 (38-58)	51 (44-61)	49 (40-65)	56 (45-74)	63 (52-79)	57 (51-66)
RPE	0.7 (0.5-1.1)	0.6 (0.4-1.0)	0.5 (0.4-0.6)	0.5 (0.5-0.7)	0.7 (0.5-0.9)	0.6 (0.5-0.8)	0.7 (0.6-0.9)	0.7 (0.6-0.7)
RER	0.03 0.02-0.05	0.04 0.03-0.06	0.02 0.02-0.03	0.03 0.02-0.03	0.04 0.03-0.05	0.04 0.03-0.05	0.03 0.02-0.03	0.03 0.03-0.04

5.3.3 Twelve Minute Motion Test

The average distance covered in the 12 minute motion test [9] was 2229 ± 420 metres (range: 1347 to 2993 metres). Figure 4 is a graphic representation of all the step test measured variables against the 12 minute motion test. The strongest relationships were inverse and between maximum heart rate and distance (r = 0.69) and respiratory exchange ratio and distance (r = 0.69). There were weaker inverse relationships between the 12 minute motion test and total heart beats (r = 0.47) and rating of perceived exertion (r = 0.59). The relationship between the 12 minute motion test compared to energy expenditure and heart rate recovery were not significant. There was no relationship between the 12 minute motion test and energy expenditure and heart rate recovery.

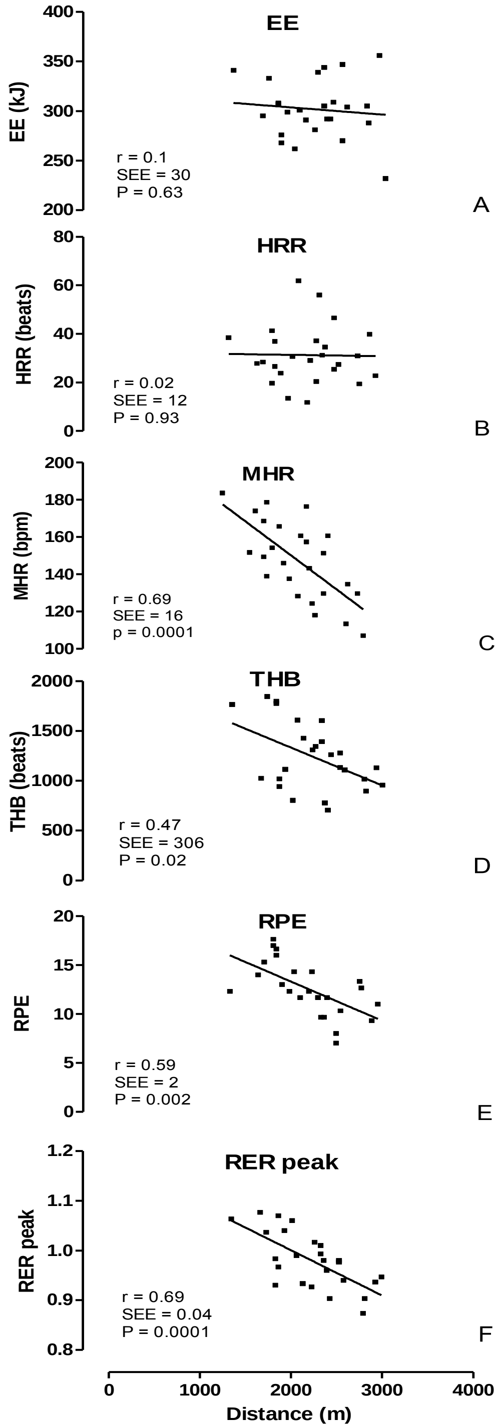

Figure 4 12 minute motion test distance versus (A) energy expenditure (EE), (B) heart rate recovery (HRR), (C) maximum heart rate (MHR), (D) total heart beats (THB), (E) rating of perceived exertion (RPE) and (F) respiratory exchange ratio (RER).

5.4 Discussion

The relative reliability of the workload standardised step test was investigated using intraclass correlation coefficient. The ranking of all measured variables were highly correlated between tests implying that participants maintained their ranked positions in the three trials. Maximum heart rate, maximum heart rate as a percentage of age predicted maximum heart rate, total heart beats and rating of perceived exertion, all had intraclass correlation coefficients around 0.95 indicating that 95% of the observed variance could be accounted for and only 5% of the variance was due to error [189] (Table 18). The heart rate recovery intraclass correlation coefficient ranged from r = 0.88 to 0.90. The mean (0.89) (Table 18) was higher than that reported by Dupuy et al [190] for both their submaximal (0.69) and maximal (0.77) tests. Intraclass correlation coefficient values above 0.75 indicate good reliability and those below 0.75 indicate poor to moderate reliability [191]. We therefore can interpret the relative reliability of heart rate recovery from the workload standardised step test as reasonably high [192]. However, intraclass correlation can be influenced by whether the group is heterogeneous or not [192]. A heterogeneous group has a higher intraclass correlation coefficient than a homogenous group for the same measurement. The coefficient of variation for performance in the 12 minute motion test (Figure 4) was 19%. This shows that the group was heterogeneous for this variable. Results from the 12 minute motion test confirm that participants were of varying degrees of fitness. Hence the chance of participants maintaining the same position in physiological responses to the step test in consecutive trials was high. Further analyses were done to confirm the reliability of the measurements.

Firstly, the analysis of variance was used to test the differences between the means. This provides an indication of systematic error. One likely source of systematic error for some of the variables measured was a learning effect. Most participants tended to perform better in the second and third trials. The significant differences between the first and third trial for maximum heart rate and rating of perceived exertion (Table 17) could be attributed to familiarisation and learning effect [183]. Participants probably got used to the test and had less anxiety, hence the decrease in variables such as heart rate and respiratory exchange ratio. This resulted in the first and third trial measurements being the furthest apart compared to the first and second or second and third measurements. The time between trials was too short and the number of trials too few to attribute any differences to physiological adaptations to training.

The maintenance of the same testing conditions for each participant for the three trials, especially the stepping rate reduced the source of random error in the calculation of energy expenditure. Energy expenditure was calculated using oxygen consumption [174]. Participants stepped at a particular stepping rate for all three tests. They respired either aerobically or anaerobically depending on the cadence chosen and the fitness status of the participants. The exercise intensity for the three trials was the same. The same energy pathways [179] were used as such the discrepancy of the method of calculating energy expenditure which could not account for the anaerobic component had the same effected on the calculation of energy expenditure for the three trials. Hence the absence of significant differences in energy expenditure between trials.

The characteristics of the participants who chose 20 steps per minute were not different from the characteristics of those who chose 24 steps per minute (Table 23). Therefore it can be concluded that these characteristics did not influence their preferred cadence. Also the mean typical error of measurement for all the variables measured during the tests were similar for the two stepping cadences, except for energy expenditure. The mean typical error of measurement for energy expenditure was slightly higher for the 24 steps per minute compared to 20 steps per minute (Table 24). The measurement error could be due to the anaerobic component at higher stepping frequencies that was not accounted for in the method of calculating energy expenditure. This was discussed in the previous study. The differences however were negligible so the 24 steps per minute cadence was used in the next study, since it was chosen by the majority of the participants.

Typical error of measurement was calculated to predict random error. Random error is due to chance and is unpredictable [186]. Typical error of measurement as a coefficient of variation (CV_{TEM}) was greatest for energy expenditure and heart rate recovery (Table 21) and was larger than the smallest worthwhile difference (Table 22) for these variables. The absolute typical error for heart rate recovery of four beats in the first minute of recovery is similar to that reported by Mann et al [193] and Lamberts et al [24] from the same laboratory. However it is smaller than typical error reported in other studies of eight to ten beats [194,61,195,196]. Heart rate recovery is therefore a better measure than in the reported studies.

There is no specific scale for interpretation of standard error of measurement and coefficient of variation. In one study Buchheit defined a coefficient of variation less than 5% as representing a reliable measurement [188]. However, there is no evidence to suggest that 5% marks the level of reliability for all measurements. The mean CV_{TEM} for energy expenditure and heart rate recovery was 9% (Table 21). The heart rate recovery CV_{TEM} that ranged from 13 to 16% with a mean of 15% (Table 21) was slightly higher than that reported by Dupuy et al [190] from their submaximal test (13%) and their maximal test (11%). Measurement error clouded the measurement making the absolute reliability of heart rate recovery moderate. Differences in the methods of calculating heart rate recovery could account for some of the differences as Dupuy et al [190] averaged the last five seconds whereas we averaged the last 16 seconds in this study. We chose this method because this has been used in several studies previously [24,197,193]. The rest of the variables: maximum heart rate, maximum heart rate as a percentage of age predicted maximum heart rate, total heart beats, rating of perceived exertion and respiratory exchange ratio, all had good repeatability as shown by coefficient of variation around 5% (Table 21) and a measurement error smaller than or equal to the smallest worthwhile difference (Table 22).

The sensitivity of the measurements for energy expenditure, heart rate recovery, maximum heart rate, rating of perceived exertion and peak respiratory exchange ratio were “marginal” due to measurement error (Table 22). Total heart beats had “good” sensitivity whilst maximum heart rate as a percentage of age predicted maximum heart rate was rated “OK”.

Day-to-day variation in heart rate recovery decreases with increasing exercise intensity [24] and is most stable when the exercise ranges between 86 to 93% [61] of maximum heart rate. The standardised step test is a submaximal test with a mean age predicted maximum heart rate of 78%, at which level heart rate recovery tends to vary. Heart rate recovery one minute after exercise has less variation than after two minutes [24]. Variations of seven or eight beats in heart rate recovery one minute after exercise were reported [24,198]. The mean heart rate recovery for trials one to three were 30, 32 and 30 respectively, a variation of two beats and non-significant. Since the differences were within the seven beats accounted for by day-to-day variation it could also be attributed to such.

Oxycon data output was set every 15 seconds to agree with the method for calculating energy expenditure. Errors were noted in data where in some cases the first recording was at 00:00 or 00:01 and yet in other cases the first recording was at 00:15. The error affected the point at which the test ended which also varied. There was no explanation for this variation in reporting data. The same applied to the end of exercise, which also varied. This could have contributed to overall measurement error as different data points would then have been used.

People who are trained tend to have a lower heart rate than unfit or untrained people at the same absolute workload. This was confirmed by the results from the 12 minute motion test. Participants who completed the longest distances in the 12 minute motion test were considered the fittest; these participants generally had lower maximum heart rates for the step test. The same applied to total heart beats where fit participants also had lower values. In terms of rating of perceived exertion, participants who rated the step test as an easy test completed longer distances in the 12 minute motions test. Fit participants had a lower respiratory exchange ratio, the majority of which were below a value of one. This implies that they utilised a higher proportion of fat as a fuel during the test [199]. We expected energy expenditure and heart rate recovery to follow the same trend, that is, fitter participants expected to recover faster and use less energy for the test. Whilst that seems to be the case, some outliers distorted the image.

The adjustment of step height to participant height improves the reliability of the workload standardised step test. A study that compared the reliability between a 30 cm step height and a 40 cm step height found highest reliability was when using a 30 cm step height [64]. The average height of the male participants was 173.4 cm. The adjusted step height for such a stature would be 32.43 cm, a step height closer to 30 cm than to 40 cm. However the researchers could not account for such a finding and attributed the result to the moderate load of the test [64].

5.5 Conclusions

Ideally the typical error of measurement should be smaller than the smallest worthwhile difference for a measurement to be reliable. The workload standardised step test variables of heart rate recovery, maximum heart rate, step test maximum heart rate as a percentage of age predicted maximum heart rate, total heart beats, rating of perceived exertion and respiratory exchange ratio all were reliable as there was not much difference between the typical error of measurement and the smallest worthwhile difference.

The study determined the typical error of measurement and the smallest worthwhile difference of measurement of the external work standardised step test for heart rate measurements, energy expenditure, rating of perceived exertion and respiratory exchange ratio. The study showed that the workload standardised step test is repeatable for most variables measured and therefore is a reliable test of fitness. However typical error "noise" for some of the measurements needs to be considered when data are interpreted. Since the step test is designed to be used for screening purposes in a diverse group, it may be concluded that the reliability of all variables is satisfactory and that there is sufficient precision in the measurements to proceed to the validation phase of the protocol.

Reliability of a measurement is not an all-or-none phenomenon and is open to interpretation. Reliability is population specific and related to the variability of the group. It is best estimated by more than one index. Having the best reliability does not necessarily mean the measurement is the most useful as a number of physiological measures have high reliability but may not be sensitive or valid tools.

CHAPTER 6

THE ASSOCIATION BETWEEN CARDIORESPIRATORY FITNESS AND PERFORMANCE IN A SUBMAXIMAL STEPPING TEST STANDARDISED FOR EXTERNAL WORKLOAD

6.1 Introduction

The aim of this study was to determine which variables, or combination of variables measured in the submaximal step test, predicted VO_2max measured directly in a maximal test on a treadmill. This was the next step in the clinimetric process of validating the novel step test protocol designed to predict VO_2max in a heterogeneous population. To summarise the steps, the first part of this process showed that energy expenditure increased with increasing duration of the test, even when the total mechanical work was kept constant (Chapter 4). This was followed by a study that showed that the measurements of energy expenditure and heart rate from a step test standardised for external workload were repeatable (Chapter 5). These studies also showed that the stepping frequencies of 20 and 24 steps per minute are associated with the most repeatable results. The outcome measures from the standardised step test that had an acceptable ratio between the technical error of measurement and smallest worthwhile difference were total heart beats, maximum heart rate, rating of perceived exertion, heart rate recovery and respiratory exchange ratio. All the measurements were therefore considered in the determination of an equation to predict VO_2max from the step test (i.e. heart rate during the test and heart rate recovery after the test, maximum heart rate, total heart beats and rating of perceived exertion. Respiratory exchange ratio was not included since it is not readily measured and involves laboratories and expensive machines. Step test maximum heart rate as a percentage of VO_2max maximum heart rate was calculated to find the intensity of the exercise but could not be used in the prediction equation since it used VO_2max data. Age predicted maximum heart rate [129] could not be used either as the inclusion of predicted data would weaken the precision of the equation.

6.1.1 Aim of the Study

The study was designed to answer the following questions:

A) Can the outcome measures of the workload standardised step test (i.e. heart rate recovery, maximum heart rate achieved during the test, total heart beats for the test, average heart rate and perception of effort) be used to predict VO_2max either on their own or in combination in a heterogeneous group of males and females?

B) What is the relationship between VO_2max measured during a treadmill protocol and VO_2max predicted from the equation established during the first part of this study?

6.2 Methods

6.2.1 Study Design

Testing was done in the laboratory at the Sports Science Institute of South Africa (SSISA). During the first visit to the laboratory participants completed the American College of Sports Medicine (ACSM) (Appendix 1) screening questionnaire to screen for cardiovascular and pulmonary disease and orthopaedic problems [200]. The experimental protocol was explained (Appendix 11). Participants that were eligible then signed the informed consent form (Appendix 10) and responded to the Global Physical Activity Questionnaire (GPAQ) (Appendix 2) that was used to categorise participants into three groups of physical activity [201]. Participants performed the step test first and had a familiarisation session on the treadmill. On the second visit participants did a VO_2max test (Bruce protocol) on the treadmill. The two tests were conducted on the same time of day. Temperature and humidity were kept constant in air-conditioned laboratories.

6.2.2 Participants

Participants were recruited (Appendix 7) through fliers, emails, visiting organisations, word of mouth and staff and students in the SSISA building. The original plan was to recruit two hundred and forty participants, 120 males and 120 females (20 - 60 years), of four age groups and varying levels of physical activity. However when testing started it was easier to recruit participants in the age group 20 to 30 years and more participants in this age group were tested than was expected. This accounted for a bigger sample size (n = 290). Seventeen participants withdrew from the study after the first visit for various reasons ranging from commitments at work, at home and being sick. It could also be inferred that some participants who did not report for the second visit decided against doing a maximum test though they were not explicit about it. Two hundred and seventy three participants (145 males and 128 females) completed the study (Table 25). A sample size of n = 10 in each cell, with maximum rates of statistical error of 5% (type 1 error) and 20% (type 2 error) has the power to detect a correlation of r = 0.8. The magnitude of this relationship was considered acceptable for the goals of the study. Although the sample size calculation was based on each cell, it was anticipated that the data from each cell would also be merged and analysed. This would increase the heterogeneity of the sample and increase the potential for establishing relationships between variables. Therefore we were confident a sample size of n = 240 would provide sufficient power for the planned statistical analyses.

The Global Physical Activity Questionnaire (GPAQ) [201,202] (Appendix 2) was used to predict the physical activity level of each participant. The assignment to groups was based on their scoring in the GPAQ. Participants were assigned to one of three groups; either "*below the recommended level of physical activity*", "*achieved the recommended level of physical activity*", or "*above the recommended level of physical activity*".

Table 25 Participants in each cell defined by age and level of physical activity (n = 273)

	Males				Females			
Age (years)	**below**	**achieved**	**above**	**Total**	**below**	**achieved**	**above**	**Total**
20-30	27	13	10	50	14	11	10	35
31-40	10	11	10	31	11	9	12	32
41-50	13	10	10	33	10	10	9	29
51-60	11	10	10	31	10	12	10	32
Total	61	44	40	145	45	42	41	128

below: below the recommended level of physical activity
achieved: achieved the recommended level of physical activity
above: above the recommended level of physical activity

Exclusion criteria

- younger than 20 and older than 60 years
- orthopaedic problems which may interfere with the trial
- chronic conditions requiring medication that might interfere with cardiorespiratory and metabolic responses to exercise
- Participant mass less than 50 kg or more than 100 kg

6.2.3 Participant Physical Characteristics

The stature, body mass and skin fold thickness of participants were measured during their first visit to the laboratory. Body fat was represented as the sum of the seven skinfolds (biceps, triceps, subscapular, suprailiac, abdominal, thigh, calf) (Appendix 17) measured using callipers as described by Ross and Marfell-Jones [203]. The tester gently pinched the skin at the appropriate site to separate a double layer of skin and the underlying adipose tissue from the muscle. The procedure is painless and non-invasive. Body fat was also estimated as a percentage from the equation of Durnin and Womersley [176] (Appendix 17). Detailed descriptions of measurements are in the previous study (Chapter 4, section 4.2.4).

6.2.4 Step Test

After the assessment of body composition each participant performed a step test. As shown in Chapter 5 there were no major differences in outcome measures for the cadences of 20 and 24 steps per minute. However, for methodological reasons we decided to standardise the test and use 24 steps per minute in this validation study and cross validation study that follows. The duration of each test was modified to elicit 45 kJ external work during the test. Step height was determined by equations xviii and xix by Francis and Culpepper [54].

Table 26 shows the duration of the step test protocol for the variations in size of participants that could be expected in the study. For this hypothetical example a short man (1.55 metres) and a tall man (2.00 metres) of varying body mass from 50 kg to 100 kg has been used.

Table 26 Step test durations for a male 1.55 m tall (step height 29 cm) and 2.00 m tall (step height 38 cm) and varying body mass (50 kg to 100 kg)

	Duration in minutes					
Stature (m)	**50 kg**	**60 kg**	**70 kg**	**80 kg**	**90 kg**	**100 kg**
1.55 m	13.18	10.98	9.42	8.24	7.32	6.59
2.00 m	10.06	8.38	7.19	6.29	5.59	5.03

Adjusting the step height to accommodate differences in stature ensured that stepping was efficient from a biomechanical perspective [54]. Participants did not warm up before the test but were allowed 10 seconds to adjust to the cadence of the metronome. Ambient temperature was controlled (20 - 22°C) and humidity varied between 50 and 60 mmHg in the laboratory. Ambient conditions were measured before testing to ensure the conditions were within the expected range.

Heart rate was measured continuously during the test and for two minutes after the test using a Suunto T6 chest heart rate transmitter and wrist monitor (Suunto Oy, Vantaa, Finland). Heart rate was recorded every two seconds. After the test the heart rate data were transferred from the wrist monitor to a computer for analysis. Heart rate recovery was calculated as the difference between the end of exercise heart rate (taken as the average of the last 16 seconds of the test) and the first minute recovery heart rate (taken as the average of the last 16 seconds of the first minute of recovery) as previously described [24]. Total heart beats during the test were calculated. Maximum heart rate during the test and average heart rate were also recorded.

The participant's perceived exertion (RPE) (Appendix 4) was recorded every minute using the Borg's rating of perceived exertion 6-20 point scale [122]. The scale is numbered from 6 (no exertion) to 20 (maximal exertion). The participant gave a verbal or visual score from the scale that corresponded with the perceived intensity of the workout. The scale is based on the assumption that physiological strain grows linearly with exercise intensity and that perception of effort follows the same linear pattern. RPE can therefore be compared with physiological measures such as heart rate or oxygen consumption.

6.2.5 VO_2max Test

The Bruce protocol [117] is a validated test for measuring VO_2max from maximal performance. The test also caters for a range of fitness levels. The protocol starts at a low work level allowing time for warm up and cardiovascular adaptation. The Bruce treadmill protocol was considered the most appropriate for untrained participants as it gradually increases speed and gradient [117]. The participant warmed up for six minutes by walking, jogging or running on the treadmill at their own pace after which they stretched for about five minutes. The test began at a treadmill speed of 2.74 $km.h^{-1}$ and 10% gradient (Motor driven treadmill, Quinton Instruments, Seattle, WA, USA). Speed and incline were increased every three minutes until the participant could not continue with the test. Volitional fatigue was used as the termination point for the VO_2max test. Participants were verbally encouraged throughout the test to produce a maximum effort performance. Following the protocol precisely is important. Due to the nature of the sample, which comprised a wide range of age groups and physical activity levels, participants were allowed to hold on the rails if they felt insecure**.**

Table 27 shows how the test progresses. During the test oxygen consumption and respiratory exchange ratio were measured using an Oxycon (Jaeger Pro®, VIASYS health care, Hoechberg, Germany).

Table 27 The Bruce treadmill protocol [117]

Level	Time (min)	Speed ($km.h^{-1}$)	Gradient (%)
1	0	2.74	10
2	3	4.02	12
3	6	5.47	14
4	9	6.76	16
5	12	8.05	18
6	15	8.85	20
7	18	9.65	22
8	21	10.46	24
9	24	11.26	26
10	27	12.07	28

Participants wore face masks and respiratory gas exchange was measured using an Oxycon breath-by-breath analyser (Jaeger Pro®, VIASYS health care, Hoechberg, Germany). The Oxycon was calibrated before each trial using a three litre syringe (SensorMedics®, Milan, Italy) and a reference gas of known composition (16% oxygen, 5% carbon dioxide, balance nitrogen).

The test ended when the participant could not continue with the test and stepped off the treadmill to the side platform. VO_2max was defined as the highest oxygen consumption measured in the last stage the participant reached. When the exercise intensity was high, there were occasions when participants took in deep breaths. These were identified by a sudden decrease in respiratory exchange ratio and in most cases were followed by a deep exhalation. Such cases were not recorded as the VO_2max if they happened to be the highest achieved. VO_2max was expressed in relative terms as $ml.kg^{-1}.min^{-1}$.

6.2.6 Ethical Considerations

The study was approved by the Research and Ethics Committee of the Faculty of Health Sciences, University of Cape Town (HREC/REF: 161/2013) (Appendix 6). Participants who met the selection criteria were invited to participate after giving their signed informed consent. The researcher provided a full and adequate written and verbal explanation of the requirements of the study and the participant had an opportunity to ask questions. Participants had a right to withdraw from the study at any stage without having to provide a reason. Study personnel also had the right to withdraw a research participant from the study at any time. Data generated from the trial were stored in a computer database in a secure facility and in a manner that maintained the participant's confidentiality.

6.2.7 Benefits to the Participants

There was no financial remuneration for participation in this study. Participants were given a report (Appendix 13 and Appendix 14) of their data (VO_2max, heart rate and body composition). The feedback was in most cases novel for the participants and was written in a way that was of interest for them.

6.2.8 Statistical Analysis

Descriptive analyses were done on age, stature, body mass, body mass index, body fat percent, sum of seven skinfolds and self-reported physical activity levels. Descriptive data of each cluster and for the entire group were calculated and presented as means and standard deviations. The relationship between the variables and VO_2max were determined with Pearson's correlation coefficients (Prism 5, GraphPad Software, Inc., CA, USA). VO_2max was plotted against physical characteristics of participants and against outcome measures of the step test using Prism 5. Linear regression analysis was done in Prism to get the correlation coefficient, standard error of estimate and p value. Several multiple regressions were done using Statistica version 13 (Statsoft Inc., Tulsa, OK, USA) to determine the best model that predicts VO_2max.

6.3 Results

6.3.1 Physical Characteristics of Participants

The means and standard deviations of the physical characteristics of participants (age, stature, body mass, body mass index, body fat percent, sum of seven skinfolds, and self-reported physical activity levels) were calculated according to sex, age group and physical activity level as shown in Table 28 and Table 29.

Table 28 Mean and standard deviation of physical characteristics (Males, n = 145). The sample size for each cell is shown in brackets (). The range is shown in [].

Variable	Physical activity	20-30 years	31-40 years	41-50 years	51-60 years	All age groups
Age (years)	***All***	**25 ± 3 (50)**	**35 ± 3 (31)**	**45 ± 3 (33)**	**56 ± 2 (31)**	**38 ± 12 (145)**
	Above	*24 ± 3 (27)*	*35 ± 3 (10)*	*45 ± 3 (13)*	*55 ± 3 (11)*	
	Achieved	*27 ± 3 (13)*	*36 ± 3 (11)*	*45 ± 3 (10)*	*56 ± 2 (10)*	[20 - 60]
	Below	*26 ± 3 (10)*	*35 ± 3 (10)*	*45 ± 3 (10)*	*57 ± 2 (10)*	
Stature (cm)	**All**	**177.9 ± 7.4 (50)**	**179.9 ± 6.5 (31)**	**178.6 ± 7.0 (33)**	**174.5 ± 7.8 (31)**	**177.8 ± 7.4 (145)**
	Above	*178.9 ± 6.7 (27)*	*180.5 ± 7.4 (10)*	*177.1 ± 5.8 (13)*	177.8 ± 7.5 (11)	
	Achieved	*177.4 ± 4.6 (13)*	*178.5 ± 7.4 (11)*	*182.3 ± 7.0 (10)*	174.2 ± 8.3 (10)	[159 – 195.3]
	Below	*175.9 ± 11.6 (10)*	*180.9 ± 4.5 (10)*	*177.0 ± 7.6 (10)*	171.1 ± 6.6 (10)	
Body mass (kg)	**All**	**74.6 ± 10.2 (50)**	**80.7 ± 10.9 (31)**	**84.2 ± 11.9 (33)**	**77.4 ± 12.1 (31)**	**78.7 ± 11.7 (145)**
	Above	*72.3 ± 8.7 (27)*	*80.0 ± 10.9 (10)*	*80.0 ± 13.8 (13)*	*77.8 ± 10.1 (11)*	
	Achieved	*78.6 ± 10.2 (13)*	*76.5 ± 8.6 (11)*	*87.5 ± 8.3 (10)*	*75.7 ± 12.5 (10)*	[48.3 – 105.95]
	Below	*75.7 ± 12.9 (10)*	*85.9 ± 12.0 (10)*	*86.4 ± 11.5 (10)*	*78.6 ± 14.6 (10)*	
BMI (kg/m^2)	**All**	**23.7 ± 3.1 (49)**	**25.0 ± 3.4 (31)**	**26.1 ± 3.4 (33)**	**25.5 ± 4.0 (31)**	**24.9 ± 3.6 (144)**
	Above	*22.6 ± 2.4 (27)*	*24.4 ± 3.4 (10)*	*25.5 ± 4.2 (13)*	*24.6 ± 2.6 (11)*	
	Achieved	*24.8 ± 3.2 (13)*	*24.1 ± 1.7 (11)*	*26.3 ± 1.3 (10)*	*24.9 ± 3.7 (10)*	[18 – 36.5]
	Below	*25.1 ± 4.1 (9)*	*26.4 ± 4.6 (10)*	*26.6 ± 3.9 (10)*	*26.9 ± 5.4 (10)*	
Body fat %	**All**	**15.4 ± 4.8 (49)**	**19.3 ± 5.4 (31)**	**22.8 ± 5.2 (33)**	**22.1 ± 5.8 (31)**	**19.4 ±6.1 (144)**
	Above	*13.2 ±4.0 (27)*	*17.8 ± 4.8 (10)*	*19.6 ± 5.7 (13)*	*22.4 ± 4.8 (11)*	
	Achieved	*17.3 ± 4.6 (13)*	*19.5 ± 6.2 (11)*	*24.3 ± 4.0 (10)*	*21.4 ± 6.3 (10)*	[6.5 – 34.4]
	Below	*19.1 ± 4.0 (9)*	*20.6 ± 5.3 (10)*	*25.3 ± 3.5 (10)*	*22.5 ± 6.9 (10)*	
Sum of skinfolds (mm)	**All**	**84 ± 39 (49)**	**95 ± 49 (31)**	**100 ± 34 (33)**	**87 ± 32 (31)**	**91 ± 39 (144)**
	Above	*67 ± 26 (27)*	*82 ± 43 (10)*	*80 ± 33 (13)*	*88 ± 26 (11)*	
	Achieved	*97 ± 44 (13)*	*94 ± 45 (11)*	*110 ± 28 (10)*	*82 ± 32 (10)*	[27.6 – 214.5]
	Below	*115 ± 37 (9)*	*110 ± 59 (10)*	*117 ± 31 (10)*	*90 ± 41 (10)*	
METS	**All**	**2572 ± 1603 (50)**	**1763 ± 1400 (31)**	**1842 ± 1285(33)**	**1509 ± 1005(31)**	**2006 ± 1430 (145)**
	Above	*3661 ± 1216 (27)*	3254 ± 1265 (10)	*3134 ± 903 (13)*	*2536 ± 789 (11)*	
	Achieved	*1863 ± 807 (13)*	1200 ± 455 (11)	*1422 ± 493 (10)*	*1300 ± 489 (10)*	[0 – 6720]
	Below	*554 ± 208 (10)*	890 ± 999 (10)	*584 ± 420 (10)*	*588 ± 397 (10)*	

Table 29 Mean and standard deviation of physical characteristics (Females, n = 128). The sample size for each cell is shown in brackets (). The range is shown in [].

Variable	Physical activity	20-30 years	31-40 years	41-50 years	51-60 years	All age groups
Age (Years)	**All**	**25 ± 3 (35)**	**35 ± 3 (32)**	**46 ± 3 (29)**	**55 ± 3 (32)**	**40 ± 12 (128)**
	Above	*24 ± 3 (14)*	*35 ± 3 (11)*	*47 ± 3 (10)*	*55 ± 3 (10)*	
	Achieved	*26 ± 3 (11)*	*34 ± 3 (9)*	*47 ± 3 (10)*	*55 ± 3 (12)*	[21 – 60]
	Below	*25 ± 4 (10)*	*35 ± 3 (12)*	*46 ± 2 (9)*	*55 ± 2 (10)*	
Stature (cm)	**All**	**167.1 ± 6.4 (35)**	**164.2 ± 6.5 (32)**	**165.4 ±6.7 (29)**	**165.6 ±7.1 (32)**	**165.6 ±6.7 (128)**
	Above	*167.9 ± 5.6 (14)*	*166.7 ± 5.0 (11)*	*167.5 ±7.4 (10)*	*163.8 ±5.5 (10)*	
	Achieved	*166.6 ± 5.8 (11)*	*167.2 ± 5.3 (9)*	*162.5 ±6.7 (10)*	*165.7 ±8.4 (12)*	[151.5 – 180.5]
	Below	*166.3 ± 8.3 (10)*	*159.5 ± 6.2 (12)*	*166.4 ±5.1 (9)*	*167.4 ±7.0 (10)*	
Body mass (kg)	**All**	**66.1 ± 10.3 (35)**	**66.7 ± 9.5 (32)**	**68.0 ± 10.7 (29)**	**65.1 ± 9.2 (32)**	**66.4 ± 9.9 (128)**
	Above	*65.9 ± 11.1 (14)*	*65.7 ± 6.0 (11)*	*66.6 ± 12.6 (10)*	*62.0 ± 9.3 (10)*	
	Achieved	*60.8 ± 6.5 (11)*	*66.6 ± 13.2 (9)*	*68.9 ± 9.9 (10)*	*62.5 ± 6.7 (12)*	[48.2 – 97.7]
	Below	*72.3 ± 9.8 (10)*	*67.7 ± 9.5 (12)*	*68.4 ± 10.3 (9)*	*71.3 ± 9.5 (10)*	
BMI (kg/m^2)	**All**	**23.5 ± 3.6 (35)**	**24.9 ± 3.4 (31)**	**24.9 ± 4.5 (29)**	**23.6 ± 3.1 (32)**	**24.2 ± 3.7 (127)**
	Above	*23.2 ± 3.7 (14)*	*24.0 ± 2.2 (10)*	*23.7 ± 4.6 (10)*	*23.1 ± 3.4 (10)*	
	Achieved	*21.6 ± 2.4 (11)*	*23.7 ± 3.6 (9)*	*26.4 ± 5.3 (10)*	*22.5 ± 2.4 (12)*	[17.4 – 37.7]
	Below	*26.2 ± 3.4 (10)*	*26.6 ± 3.7 (12)*	*24.6 ± 3.1 (9)*	*25.4 ± 3.0 (10)*	
Body fat %	**All**	**28.5 ± 4.7 (35)**	**30.2 ± 4.2 (31)**	**32.4 ± 4.4 (29)**	**32.0 ± 4.1 (32)**	**30.7 ± 4.6 (127)**
	Above	*28.2 ± 4.7 (14)*	*28.6 ± 2.2 (10)*	*30.6 ± 5.1 (10)*	*30.0 ± 4.7 (10)*	
	Achieved	*26.6 ± 4.0 (11)*	*29.0 ± 5.9 (9)*	*33.9 ± 4.6 (10)*	*31.3 ± 3.0 (12)*	[18.3 – 43.8]
	Below	*31.0 ± 4.8 (10)*	*32.6 ± 3.1 (12)*	*32.7 ± 2.6 (9)*	*34.9 ± 3.1 (10)*	
Sum of skinfolds (mm)	**All**	**134 ± 39 (35)**	**137 ± 42 (31)**	**134 ± 47 (29)**	**113 ± 32 (32)**	**129 ± 41 (127)**
	Above	*136 ± 43 (14)*	*124 ± 28 (10)*	*119 ± 46 (10)*	*101 ± 38 (10)*	
	Achieved	*114 ± 27 (11)*	*123 ± 51 (9)*	*147 ± 62 (10)*	*107 ± 24 (12)*	[46.2 – 307]
	Below	*153 ± 35 (10)*	*158 ± 37 (12)*	*136 ± 25 (9)*	*133 ± 26 (10)*	
METS	**All**	**1784 ± 1001 (35)**	**1361 ± 992 (32)**	**1652 ± 1338 (29)**	**1718 ± 1314 (32)**	**1632 ± 1162 (128)**
	Above	*2533 ± 781 (14)*	*2511 ± 529 (11)*	*3002±1078 (10)*	*3166 ± 1166 (10)*	
	Achieved	*1885 ± 499 (11)*	*1219 ± 391 (9)*	*1612±443 (10)*	*1434 ± 695 (12)*	[0 – 5520]
	Below	*624 ± 499 (10)*	*413 ± 297 (12)*	*198±277 (9)*	*610 ± 442 (10)*	

Men were generally taller and heavier than women. They also tended to engage in more physical activity than women. Women had more fat than men. As expected the mean age of men and women was similar because the recruitment process was stratified according to age.

6.3.2 Step Test Components

The means and standard deviations of the two components of the step test that varied according to the characteristics of the participant, i.e. step height and test duration, were calculated (Table 30 and Table 31).

Table 30 Mean and standard deviation of step test components (Males). The sample size for each cell is shown in brackets (). The range is shown in [].

Variable	Physical activity	20-30 years	31-40 years	41-50years	51-60years	All age groups
Step height (cm)	**All**	**34 ± 2 (50)**	**34 ± 1 (31)**	**34 ± 1 (33)**	**33 ± 2 (31)**	**34 ± 1 (145)**
	Above	*34 ± 1 (27)*	*34 ± 1 (10)*	*33 ± 1 (13)*	*34 ± 1 (11)*	
	Achieved	*34 ± 1 (13)*	*34 ± 2 (11)*	*35 ± 1 (10)*	*33 ± 2 (10)*	[30 – 37]
	Below	*33 ± 2 (10)*	*34 ± 1 (10)*	*34 ± 1 (10)*	*32 ± 1 (10)*	
Duration (Minutes)	**All**	**7.78 ± 1.38 (50)**	**7.06 ± 1.05 (31)**	**6.88 ± 1.21 (33)**	**7.70 ± 1.52 (31)**	**7.40 ±1.36 (145)**
	Above	7.96 ± 1.40 (27)	*7.08 ± 1.07 (10)*	*7.38 ± 1.45 (13)*	*7.41 ± 1.10 (11)*	
	Achieved	7.33 ± 1.06 (13)	*7.49 ± 1.08 (11)*	*6.41 ± 0.81 (10)*	*7.91 ± 1.71 (10)*	[5.13 – 13.19]
	Below	7.85 ± 1.66 (10)	*6.58 ± 0.84 (10)*	*6.69 ± 1.03 (10)*	*7.82 ± 1.80 (10)*	

Table 31 Mean and standard deviation of step test components (Females). The sample size for each cell is shown in brackets (). The range is shown in [].

Variable	Physical activity	20-30 years	31-40 years	41-50years	51-60years	All age groups
Step height (cm)	**All**	**31 ± 1 (35)**	**31 ± 1 (32)**	**31 ± 1 (29)**	**31 ± 1 (32)**	**31 ± 1 (128)**
	Above	*31 ± 1 (14)*	*31 ± 1 (11)*	*32 ± 1 (10)*	*31 ± 1 (10)*	
	Achieved	*31 ± 1 (11)*	*31 ± 1 (9)*	*31 ± 1 (10)*	*31 ± 2 (12)*	[28 – 34]
	Below	*31 ± 2 (10)*	*30 ± 1 (12)*	*31 ± 1 (9)*	*31 ± 1 (10)*	
Duration (Minutes)	**All**	**10 ± 2 (35)**	**10 ± 1 (32)**	**9 ± 2 (29)**	**10 ± 2 (32)**	**10 ± 2 (128)**
	Above	*10 ± 2 (14)*	*9 ± 1 (11)*	*9 ± 2 (10)*	*10 ± 2 (10)*	
	Achieved	*10 ± 1 (11)*	*9 ± 2 (9)*	*9 ± 1 (10)*	*10 ± 1 (12)*	[5.93 – 13.83]
	Below	*9 ± 1 (10)*	*10 ± 2 (12)*	*10 ± 2 (9)*	*9 ± 1 (10)*	

Due to the stature of men the mean step height for men was higher than that for women. The average step height was 34 cm for men and 31 cm for women. Women had longer tests than men. The duration of the test ranged from 5 minutes and 8 seconds to 13 minutes and 11 seconds for males and 5 and 56 seconds to 13 minutes and 49 seconds for females.

6.3.3 Step Test Outcome Measures

Heart rate recovery, maximum heart rate, step test maximum heart rate as a percentage of VO_2max test maximum heart rate, total heart beats, average heart rate, minimum heart rate and the rating of perceived exertion from the step test, all had their means and standard deviations calculated according to sex, age group and physical activity levels (Table 32 and Table 33).

Table 32 Mean and standard deviation of step test measures (Males). The sample size for each cell is shown in brackets (). The range is shown in [].

Variable	Physical activity	20-30 years	31-40 years	41-50 years	51-60 years	All age groups
Heart rate recovery (beats)	**All**	**28 ± 7 (50)**	**25 ± 10 (31)**	**30 ± 8 (33)**	**26 ± 9 (31)**	**27 ± 8 (145)**
	Above	*27 ± 7 (27)*	*29 ± 12 (10)*	*29 ± 7 (13)*	*30 ± 11 (11)*	
	Achieved	*26 ± 6 (13)*	*24 ± 8 (11)*	*34 ± 4 (10)*	*27 ± 9 (10)*	[9 - 47]
	Below	*32 ± 7 (10)*	*20 ± 9 (10)*	*26 ± 11 (10)*	*22 ± 7 (10)*	
Maximum heart rate (beats. min^{-1})	**All**	**144 ± 18 (50)**	**144 ± 22 (31)**	**136 ± 18 (33)**	**129 ± 18 (31)**	**139 ± 20 (145)**
	Above	*141 ± 18 (27)*	*135 ± 19 (10)*	*127 ± 19 (13)*	*125 ± 17 (11)*	
	Achieved	*140 ± 19 (13)*	*141 ± 20 (11)*	*139 ± 16 (10)*	*125 ± 16 (10)*	[88 - 187]
	Below	*155 ± 16 (10)*	*156 ± 23 (10)*	*146 ± 13 (10)*	*138 ± 18 (10)*	
% of maximum heart rate	**All**	**76 ± 9 (50)**	**77 ± 10 (31)**	**76 ± 9 (33)**	**76 ± 10 (31)**	**76 ± 9 (145)**
	Above	*74 ± 9 (27)*	*74 ± 9 (10)*	*72 ± 10 (13)*	*73 ± 8 (11)*	
	Achieved	*74 ± 10 (13)*	*75 ± 10 (11)*	*78 ± 8 (10)*	*74 ± 9 (10)*	[55 - 98]
	Below	*83 ± 7 (10)*	*83 ± 10 (10)*	*80 ± 5 (10)*	*81 ± 10 (10)*	
Minimum heart rate (beats. min^{-1})	**All**	**92 ± 15 (50)**	**92 ± 15 (31)**	**84 ± 15 (33)**	**79 ± 16 (31)**	**87 ± 16 (145)**
	Above	*89 ± 17 (27)*	*85 ± 14 (10)*	*82 ± 16 (13)*	*76 ± 14 (11)*	
	Achieved	*92 ± 11 (13)*	*94 ± 14 (11)*	*84 ± 15 (10)*	*74 ± 20 (10)*	[40 – 141]
	Below	*97 ± 10 (10)*	*96 ± 15 (10)*	*87 ± 16 (10)*	*88 ± 12 (10)*	
Average heart rate (beats.min^{-1})	**All**	**126 ± 17 (50)**	**128 ± 19 (31)**	**119 ± 17 (33)**	**112 ± 19 (31)**	**122 ± 19 (145)**
	Above	*123 ± 18 (27)*	*120 ± 16 (10)*	*112 ± 16 (13)*	*109 ± 14 (11)*	
	Achieved	*125 ± 16 (13)*	*126 ± 18 (11)*	*123 ± 16 (10)*	*106 ± 24 (10)*	[53 – 173]
	Below	*136 ± 14 (10)*	*137 ± 21 (10)*	*124 ± 17 (10)*	*121 ± 15 (10)*	
Heart beats	**All**	**1017 ± 246 (50)**	**929 ± 189 (31)**	**843 ± 146 (33)**	**881 ± 196 (31)**	**929 ± 214 (145)**
	Above	*1022 ± 273 (27)*	*883 ± 129 (10)*	*855 ± 157 (13)*	834 ± 140 (11)	
	Achieved	*948 ± 195 (13)*	*982 ± 247 (11)*	*823 ± 134 (10)*	850 ± 203 (10)	[606 – 1953]
	Below	*1091 ± 222 (10)*	*918 ± 169 (10)*	*846 ± 156 (10)*	*963 ± 233 (10)*	
Rating of perceived exertion	**All**	**12 ± 2 (50)**	**13 ± 3 (31)**	**13 ± 2 (33)**	**13 ± 3 (31)**	**13 ± 2 (145)**
	Above	*12 ± 1 (27)*	*12 ± 2 (10)*	*12 ± 1 (13)*	*12 ± 2 (11)*	
	Achieved	*12 ± 2 (13)*	*12 ± 2 (11)*	*13 ± 2 (10)*	*13 ± 2 (10)*	[7 – 20]
	Below	*15 ± 3 (10)*	*15 ± 3 (10)*	*15 ± 1 (10)*	*14 ± 3 (10)*	

There was no particular trend that could be established between heart rate recovery and age for men. Maximum heart rate, minimum heart rate, average heart rate and total heart beats all decreased with increasing age. For women all heart rate variables decreased with increasing age. Rating of perceived exertion produced no detectable trend with age.

Table 33 Mean and standard deviation of step test measures (Females). The sample size for each cell is shown in brackets (). The range is shown in [].

Variable	Physical activity	20-30 years	31-40 years	41-50 years	51-60 years	All age groups
Heart rate recovery (beats)	**All**	**32 ± 7 (35)**	**31 ± 10 (32)**	**29 ± 12 (29)**	**27 ± 10 (32)**	**30 ± 10 (128)**
	Above	*34 ± 7 (14)*	*34 ± 11 (11)*	*31 ± 9 (10)*	*30 ± 10 (10)*	
	Achieved	*33 ± 9 (11)*	*29 ± 9 (9)*	*32 ± 16 (10)*	*28 ± 10 (12)*	[12 – 68]
	Below	*30 ± 5 (10)*	*31 ± 10 (12)*	*22 ± 7 (9)*	*24 ± 11 (10)*	
Maximum heart rate ($beats.min^{-1}$)	**All**	**160 ± 20 (35)**	**157 ± 21 (32)**	**151 ± 18 (29)**	**146 ± 21 (32)**	**154 ± 21 (128)**
	Above	*154 ± 19 (14)*	*144 ± 18 (11)*	*140 ± 16 (10)*	*127 ± 17 (10)*	
	Achieved	*153 ± 19 (11)*	*161 ± 21 (9)*	*152 ± 16 (10)*	*151 ± 16 (12)*	[107 – 196]
	Below	*175 ± 11 (10)*	*165 ± 19 (12)*	*162 ± 15 (9)*	*160 ± 18 (10)*	
% of Maximum heart rate	**All**	**87 ± 10 (35)**	**84 ± 9 (32)**	**85 ± 11 (29)**	**87 ± 12 (32)**	**86 ± 11 (128)**
	Above	*83 ± 9 (14)*	*78 ± 9 (11)*	*79 ± 10 (10)*	*76 ± 9 (10)*	
	Achieved	*83 ± 9 (11)*	*86 ± 10 (9)*	*86 ± 10 (10)*	*88 ± 5 (12)*	[63 – 115]
	Below	*96 ± 6 (10)*	*89 ± 7 (12)*	*92 ± 10 (9)*	*96 ± 12 (10)*	
Minimum heart rate ($beats.min^{-1}$)	**All**	**99 ± 16 (35)**	**91 ± 17 (32)**	**89 ± 13 (29)**	**82 ± 18 (32)**	**91 ± 17 (128)**
	Above	*96 ± 13 (14)*	*90 ± 17 (11)*	*88 ± 13 (10)*	*77 ± 15 (10)*	
	Achieved	*93 ± 16 (11)*	*84 ± 21 (9)*	*87 ± 13 (10)*	*82 ± 13 (12)*	[46 – 130]
	Below	*111 ± 17 (10)*	*99 ± 11 (12)*	*94 ± 12 (9)*	*87 ± 26 (10)*	
Average heart rate ($beats.min^{-1}$)	**All**	**142 ± 19 (35)**	**138 ± 18 (32)**	**132 ± 15 (29)**	**127 ± 18 (32)**	**135 ± 18 (128)**
	Above	*138 ± 17 (14)*	*129 ± 17 (11)*	*122 ± 13 (10)*	*114 ± 16 (10)*	
	Achieved	*136 ± 20 (11)*	*137 ± 15 (9)*	*133 ± 15 (10)*	*131 ± 14 (12)*	[96 – 176]
	Below	*157 ± 12 (10)*	*146 ± 19 (12)*	*141 ± 11 (9)*	*137 ± 18 (10)*	
Heart beats	**All**	**1389 ± 270 (35)**	**1378 ± 306 (32)**	**1255 ± 215 (29)**	**1248 ± 260 (32)**	**1321 ±271 (128)**
	Above	*1343 ± 240 (14)*	*1246 ± 121 (11)*	*1198 ± 262 (10)*	*1198 ± 131 (10)*	
	Achieved	*1431 ± 285 (11)*	*1315 ± 341 (9)*	*1257 ± 124 (10)*	*1349 ± 267 (12)*	[620 – 2294]
	Below	*1408 ± 309 (10)*	*1547 ± 339 (12)*	*1317 ± 242 (9)*	*1177 ± 326 (10)*	
Rating of perceived exertion	**All**	**14 ± 3 (35)**	**13 ± 3 (32)**	**13 ± 3 (29)**	**13 ± 3 (32)**	**13 ± 3 (128)**
	Above	*13 ± 2 (14)*	12 ± 2 (11)	*11 ± 1 (10)*	12 ± 2 (10)	
	Achieved	*12 ± 2 (11)*	12 ± 2 (9)	*13 ± 3 (10)*	12 ± 2 (12)	[7 – 20]
	Below	*17 ± 2 (10)*	16 ± 3 (12)	*14 ± 4 (9)*	16 ± 4 (10)	

Heart rate recovery was highest either for the participants who achieved the recommended level of physical activity or those above the recommended level of physical activity. For all age groups, both males and females, the "*below the recommended level of physical activity*" group had the highest maximum heart rate for the step test and the "*above the recommended level of physical activity*" had the lowest. Average heart rate and minimum heart rate also increased with decreasing physical activity level. There was no defined trend for total heart beats with physical activity levels. Participants who had levels of physical activity below the recommended level perceived the step test as more difficult than those who do recommended and above recommended physical activity.

6.3.4 VO_2max Outcome Measures

The means and standard deviations of the variables measured during the VO_2max test are displayed in Table 34 and Table 35

Table 34 Mean and standard deviation of VO_2max measures (Males). The sample size for each cell is shown in brackets (). The range is shown in [].

Variable	Physical activity	20-30 years	31-40 years	41-50 years	51-60 years	All age groups
VO_2max	**All**	**54.6 ± 9.2 (50)**	**48.3 ± 11.4 (31)**	**47.7 ± 9.8 (33)**	**45.3 ± 9.4 (31)**	**49.7 ± 10.5 (145)**
($ml.kg^{-1}.min^{-1}$)	*Above*	*59.2 ± 8.0 (27)*	*53.4 ± 11.6 (10)*	*55.4 ± 9.2 (13)*	*46.8 ± 8.8 (11)*	
	Achieved	*51.9 ± 7.9 (13)*	*49.7 ± 11.8 (11)*	*46.5 ± 6.3 (10)*	*46.0 ± 11.3 (10)*	[26 - 75]
	Below	*45.9 ± 6.0 (10)*	*41.8 ± 7.9 (10)*	*39.2 ± 5.0 (10)*	*42.8 ± 8.2 (10)*	
Respiratory	**All**	**1.24 ± 0.08 (50)**	**1.24 ± 0.11 (31)**	**1.23 ± 0.09 (33)**	**1.21 ± 0.08 (31)**	**1.23 ± 0.09 (145)**
exchange ratio	*Above*	*1.22 ± 0.08 (27)*	*1.17 ± 0.06 (10)*	*1.16 ± 0.05 (13)*	*1.19 ± 0.07 (11)*	
	Achieved	*1.23 ± 0.07 (13)*	*1.26 ± 0.08 (11)*	*1.25 ± 0.08 (10)*	*1.21 ± 0.08 (10)*	[1.03 - 1.5]
	Below	*1.29 ± 0.07 (10)*	*1.29 ± 0.14 (10)*	*1.29 ± 0.08 (10)*	*1.24 ± 0.08 (10)*	
Duration	**All**	**13.59 ± 2.03 (50)**	**12.79 ±2.09 (31)**	**12.66 ±2.36 (33)**	**12.13 ±2.18 (31)**	**12.90 ± 2.20 (145)**
(minutes)	*Above*	*14.50 ± 1.81 (27)*	*13.82 ±1.85 (10)*	*13.90 ±2.96 (13)*	*13.33 ±2.26 (11)*	
	Achieved	*13.35 ± 1.70 (13)*	*13.20 ±1.85 (11)*	*12.52 ±1.36 (10)*	*11.87 ±1.48 (10)*	[7.85 - 21.28]
	Below	*11.46 ± 1.24 (10)*	*11.31 ±1.87 (10)*	*11.20 ±1.27 (10)*	*11.06 ±2.20 (10)*	
Maximum	**All**	**189 ± 9 (50)**	**186 ± 10 (31)**	**179 ± 10 (33)**	**171 ± 9 (31)**	**182 ± 12 (145)**
heart rate	*Above*	*190 ± 11 (27)*	*182 ± 6 (10)*	*176 ± 10 (13)*	*171 ± 7 (11)*	
($beats.min^{-1}$)	*Achieved*	*188 ± 7 (13)*	*188 ± 10 (11)*	*178 ± 14 (10)*	*170 ± 10 (10)*	[147 - 212]
	Below	*187 ± 8 (10)*	*188 ± 12 (10)*	*183 ± 6 (10)*	*171 ± 11 (10)*	
Minimum	**All**	**95 ± 14 (50)**	**94 ± 9 (31)**	**90 ± 14 (33)**	**85 ± 10 (31)**	**95 ± 41 (145)**
heart rate	*Above*	*93 ± 16 (27)*	*91 ± 11 (10)*	*83 ± 11 (13)*	*82 ± 8 (11)*	
($beats.min^{-1}$)	*Achieved*	*93 ± 12 (13)*	*95 ± 9 (11)*	*94 ± 19 (10)*	*86 ± 14 (10)*	[56 - 137]
	Below	*99 ± 10 (10)*	*95 ± 8 (10)*	*94 ± 10 (10)*	*88 ± 8 (10)*	
Average heart	**All**	**139 ± 12 (50)**	**137 ± 9 (31)**	**132 ± 12 (33)**	**125 ± 9 (31)**	**134 ± 12 (145)**
rate	*Above*	*140 ± 15 (27)*	*135 ± 6 (10)*	*128 ± 11 (13)*	*126 ± 9 (11)*	
($beats.min^{-1}$)	*Achieved*	*138 ± 9 (13)*	*139 ± 12 (11)*	*135 ± 15 (10)*	*124 ± 12 (10)*	[104 -168]
	Below	*138 ± 8 (10)*	*138 ± 9 (10)*	*132 ± 9 (10)*	*125 ± 8 (10)*	
Rating of	**All**	**18 ± 2 (50)**	**18 ± 3 (31)**	**19 ± 1 (33)**	**18 ± 1 (31)**	**18 ± 2 (145)**
perceived	*Above*	*19 ± 2 (27)*	*17 ± 3 (10)*	*19 ± 1 (13)*	*18 ± 1 (11)*	
exertion	*Achieved*	*18 ± 2 (13)*	*19 ± 1 (11)*	*18 ± 1 (10)*	*18 ± 1 (10)*	[9 – 20]
	Below	*19 ± 1 (10)*	*18 ± 3 (10)*	*19 ± 1 (10)*	*19 ± 2 (10)*	

Table 35 Mean and standard deviation of VO_2max measures (Females). The sample size for each cell is shown in brackets (). The range is shown in [].

Variable	Physical activity	20-30 years	31-40 years	41-50 years	51-60 years	All age groups
VO_2max	**All**	**41.9 ± 8.4 (35)**	**40.5 ± 8.5 (32)**	**36.4 ± 8.3 (29)**	**37.7 ± 8.6 (32)**	**39.3 ± 8.6 (128)**
(ml.kg^{-1} min^{-1})	*Above*	*46.3 ± 6.5 (14)*	*46.7 ± 8.6 (11)*	*41.3 ± 8.5 (10)*	*45.7 ± 8.9 (10)*	
	Achieved	*43.9 ± 7.0 (11)*	*41.5 ± 6.3 (9)*	*35.2 ± 8.5 (10)*	*36.0 ± 5.5 (12)*	[21 – 59]
	Below	*33.5 ± 5.9 (10)*	*34.0 ± 4.6 (12)*	*32.4 ± 5.6 (9)*	*31.9 ± 5.3 (10)*	
Respiratory	**All**	**1.21 ± 0.11 (35)**	**1.23 ± 0.09 (32)**	**1.23 ± 0.10 (29)**	**1.22 ± 0.11 (32)**	**1.22 ± 0.10 (128)**
exchange ratio	*Above*	*1.16 ± 0.08 (14)*	*1.20 ± 0.08 (11)*	*1.19 ± 0.08 (10)*	*1.17 ± 0.08 (10)*	
	Achieved	*1.25 ± 0.11 (11)*	*1.20 ± 0.06 (9)*	*1.22 ± 0.07 (10)*	*1.23 ± 0.09 (12)*	[0.98 – 1.59]
	Below	*1.24 ± 0.13 (10)*	*1.28 ± 0.11 (12)*	*1.29 ± 0.14 (9)*	*1.25 ± 0.14 (10)*	
Duration	**All**	**10.89 ± 1.55 (35)**	**10.76 ± 2.03 (32)**	**10.49 ± 1.73 (29)**	**10.82 ± 2.78 (32)**	**10.75 ± 2.05 (128)**
(minutes)	*Above*	*11.66 ± 1.20 (14)*	*11.62 ± 1.03 (11)*	*11.52 ± 1.26 (10)*	*12.83 ± 2.50 (10)*	
	Achieved	*11.38 ± 1.18 (11)*	*11.90 ± 2.47 (9)*	*10.05 ± 1.55 (10)*	*10.93 ± 2.66 (12)*	[6.25 – 18.70]
	Below	*9.28 ± 1.14 (10)*	*9.11 ± 1.17 (12)*	*9.83 ± 1.99 (9)*	*8.67 ± 1.43 (10)*	
Maximum	**All**	**184 ± 9 (35)**	**185 ± 10 (32)**	**177 ± 9 (29)**	**169 ± 12 (32)**	**179 ± 12 (128)**
heart rate	*Above*	*185 ± 8 (14)*	*183 ± 7 (11)*	*177 ± 9 (10)*	*168 ± 10 (10)*	
(beats.min^{-1})	*Achieved*	*184 ± 9 (11)*	*187 ± 9 (9)*	*177 ± 9 (10)*	*171 ± 15 (12)*	[145 – 205]
	Below	*182 ± 10 (10)*	*186 ± 14 (12)*	*176 ± 9 (9)*	*167 ± 10 (10)*	
Minimum	**All**	**100 ± 14 (35)**	**103 ± 15 (32)**	**99 ± 12 (29)**	**92 ± 15 (32)**	**99 ± 14 (128)**
heart rate	*Above*	*101 ± 11 (14)*	*101 ± 14 (11)*	*96 ± 13 (10)*	*84 ± 14 (10)*	
(beats.min^{-1})	*Achieved*	*93 ± 11 (11)*	*102 ± 12 (9)*	*99 ± 9 (10)*	*95 ± 16 (12)*	[57 – 134]
	Below	*107 ± 16 (10)*	*106 ± 19 (12)*	*103 ± 13 (9)*	*96 ± 15 (10)*	
Av heart rate	**All**	**142 ± 11 (35)**	**144 ± 14 (32)**	**135 ± 10 (29)**	**129 ± 11 (32)**	**138 ± 13 (128)**
(beats.min^{-1})	*Above*	*143 ± 8 (14)*	*140 ± 11 (11)*	*134 ± 10 (10)*	127 ± 8 (10)	
	Achieved	*137 ± 10 (11)*	*147 ± 8 (9)*	*135 ± 9 (10)*	129 ± 13 (12)	[104 – 175]
	Below	*144 ± 13 (10)*	*147 ± 18 (12)*	*137 ± 11 (9)*	131 ± 10 (10)	
Rating of	**All**	**17 ± 2 (35)**	**18 ± 2 (32)**	**17 ± 2 (29)**	**17 ± 3 (32)**	**17 ± 2 (128)**
perceived	*Above*	*18 ± 2 (14)*	*17 ± 2 (11)*	*17 ± 2 (10)*	*19 ± 2 (10)*	
exertion	*Achieved*	*17 ± 2 (11)*	*18 ± 3 (9)*	*17 ± 1 (10)*	*17 ± 3 (12)*	[9 – 20]
	Below	*17 ± 3 (10)*	*19 ± 2 (12)*	*17 ± 2 (9)*	*16 ± 3 (10)*	

VO_2max, respiratory exchange ratio, test duration, maximum heart rate and average heart rate, all decreased with increasing age for men. Maximum heart rate also decreased with increasing age in women. Participants of high physical activity levels scored high in VO_2max, had low respiratory exchange ratio and longer test durations for all age groups. There was no defined trend for maximum heart rate with physical activity level. Participants of high physical activity levels had low minimum heart rates. The trend for perception of effort could not be established because the test required maximum effort and participants were expected to reach "20" before they disembarked from the treadmill. However there were situations where participants did not have the opportunity to report the “20” rating. Rating of perceived exertion was recorded each minute. Towards the end of the test at very high intensity perception of effort can change markedly within a minute, say from 17 to 20 and disembarking. The participant may then end the test before the next recording.

6.3.5 Relationship between VO_2max, Physical Characteristics of Participants and Step Test Measures

Figure 5 shows the relationship between the VO_2max and the physical characteristics of participants. The data for males and females have been combined in each graph, but distinguished by symbols (● males and □ females). The sample size for each graph can be obtained from Table 28 and Table 29.

There was an inverse relationship between age and VO_2max (r = -0.3), with a standard error of the estimate (SEE) of 10.51 $ml.kg^{-1}.min^{-}1$. Only 9% of the variance could be explained by this relationship. Stature and METS had positive relationships with VO_2max; 14 % and 36 % respectively of the variance could be explained by the relationships. Body mass, body fat percent and sum of seven skins folds were all inversely related to VO_2max with variances of 1%, 58 % and 45 % respectively.

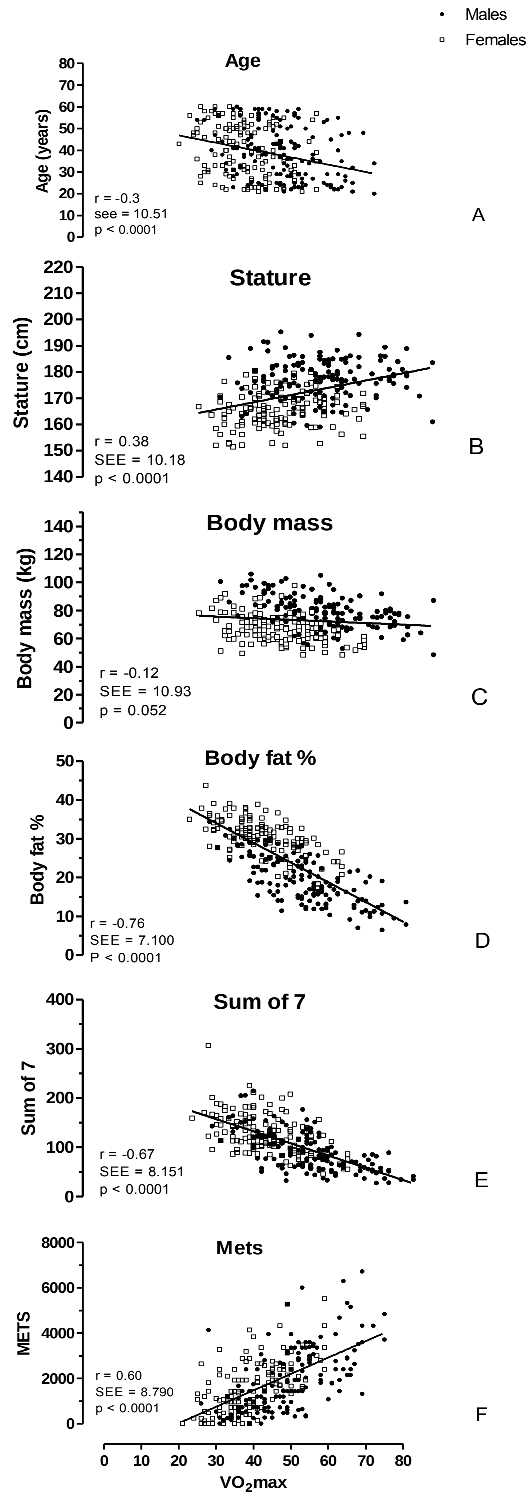

Figure 5 VO_2max versus (A) age, (B) stature, (C) body mass, (D) body fat percent, (E) sum of seven skinfolds and (F) METS of participants (● males and □ females)

The linear regression equations of VO_2max and physical characteristics of participants were tabulated (Table 36). Age, body mass, body fat percent and sum of seven skinfolds had inverse relationships. VO_2max decreases with increasing age. Body mass and fat also have a negative effect on VO_2max. The daily physical activity (METS) was directly related to VO_2max. Body fat percent had the lowest standard error of estimate whilst body mass had the highest.

Table 36 Linear regressions of the physical characteristics and VO_2max

Variable	Equation	SEE	r
Age	-3.079 (age) + 165.2	10.51	-0.3
Stature	3.111 (stature) -490.4	10.18	0.38
Body mass	-7.491 (body mass) + 591.3	10.93	-0.12
Body fat %	-1.835 (body fat %) + 90.10	7.10	-0.76
Sum of 7	-0.3690 (sum of 7) + 84.98	8.15	-0.67
METS	0.01381 (METS) + 19.59	8.79	0.60

Figure 6 is a graphic presentation of the linear regression results between VO_2max and step test variables. The relationship between VO_2max and heart rate recovery was not significant ($p = 0.17$). The remaining variables were inversely related to VO_2max. Twenty nine percent of the variance could be explained in the relationship between VO_2max and maximum heart rate, 7% with total heart beats, 22% with average heart rate and 18% with rating of perceived exertion.

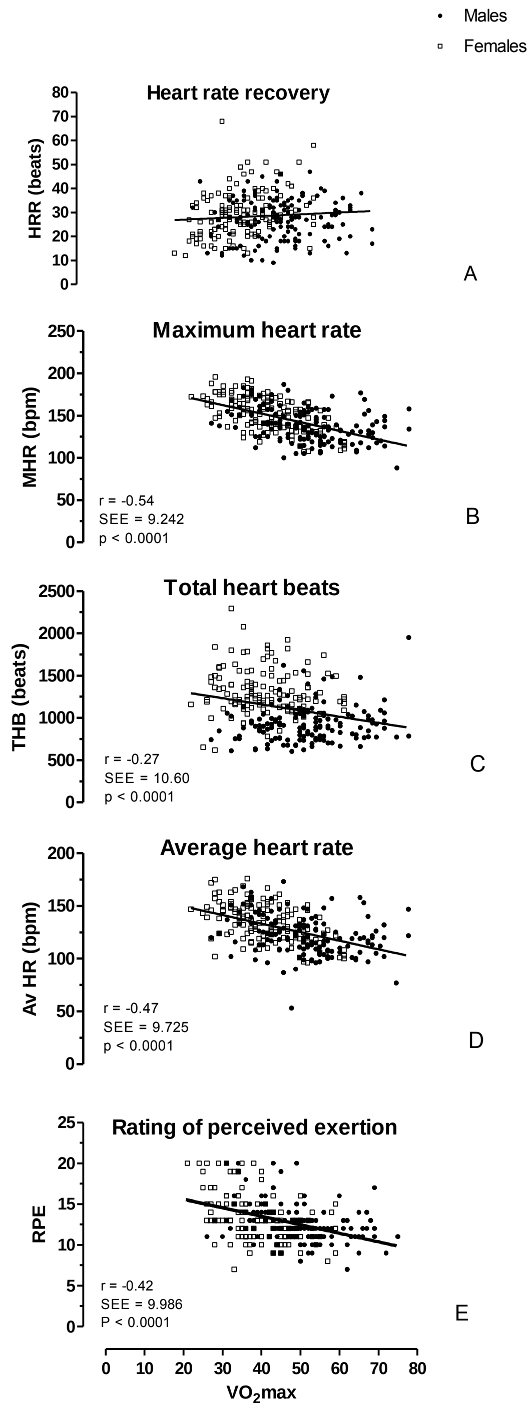

Figure 6 The relationship between VO_2max and variables measured during the step test: heart rate recovery, maximum heart rate, total heart beats, average heart rate and rating of perceived exertion.

Heart rate recovery had the highest standard error of estimate (Table 37). The other heart rate measures (maximum heart rate, total heart beats and average heart rate) were inversely and significantly related to VO_2max. Perception of effort also had a significant relationship.

Table 37 Linear regressions of the step test outcome measures and VO_2max

Variable	Equation	SEE	r
HRR	14.19 (HRR) – 360.0	10.96	0.08
MHR	-0.9484 (MHR) + 183.1	9.24	-0.54
THB	-0.1326 (THB) +192.4	10.6	-0.27
Av HR	-1.192 (Av HR) + 197.5	9.73	-0.47
RPE	-9.795 (RPE) + 171.7	9.99	-0.42

SEE = Standard error of estimate

6.3.6 Multiple Regression Steps and Results

Having established the bivariate relationship between VO_2max and the physical characteristics of participants and VO_2max and the step test variables, the next step was to determine which combination of variables best predicted VO_2max. Therefore multiple regression equations to estimate VO_2max were developed for the workload standardised step test. The development of these equations was done in stages. The first step was to develop a multiple regression between VO_2max and the physical characteristics of participants. This regression equation represents a minimalistic approach that does not require measurements from the step test. Sex, age, stature and body mass were included in the model first (Table 38). All the variables were significant and the overall model had a 49 % predictive power (Table 45).

Table 38 Regression summary: sex, age, stature and body mass (n = 273)

Variable	B*	Std Err	B	Std Err	t value	p value
Intercept			42.2098	13.36354	3.15858	0.001767
Sex	-0.533521	0.058790	-11.7051	1.28982	-9.07499	0.000001
Age	-0.199072	0.044387	-0.1813	0.04042	-4.48494	0.000011
Stature	0.302624	0.062237	0.3572	0.07346	4.86246	0.000002
Body mass	-0.537921	0.053985	-0.4741	0.04758	-9.96419	0.000001

B = regression coefficient/ parameter estimate; B* = Standardised regression coefficient; Std Err = Standard error

Body fat percent and METS were added to the model. These measurements were not included in the first analysis because measuring and calculating body fat percent (Appendix 17) needs a trained person and the participants cannot do the measurement on their own. METS were calculated from the Global physical activity questionnaire (GPAQ) (Appendix 2). The interpretation of responses and calculations also needs a person trained in using the GPAQ. Body mass index was left out of the regression because of its collinear relationship with body mass. Sum of seven skinfolds was also left out of the model, as it is associated with body fat percent. Physical characteristics of participants used in the development of the regression equation are presented in Table 39. The contribution of body mass, body fat percent and METS to predicting VO_2max were significant. The overall predictive power was 71 % (Table 45).

Table 39 Regression summary: Sex, age, stature, body mass, body fat percent and METS (n = 273)

Variable	b*	Std Err	B	Std Err	t value	p value
Intercept			61.04644	10.44343	5.84544	0.000001
Sex	-0.089503	0.077783	-1.96483	1.70754	-1.15068	0.250904
Age	-0.042982	0.038052	-0.03917	0.03468	-1.12957	0.259681
Stature	0.047853	0.053016	0.05632	0.06239	0.90261	0.367557
Body mass	-0.138278	0.060148	-0.12206	0.05309	-2.29896	0.022288
Body fat %	-0.523028	0.080108	-0.73254	0.11220	-6.52901	0.000001
METS	0.357398	0.036978	0.00296	0.00031	9.66518	0.000001

B = regression coefficient/ parameter estimate; B* = Standardised regression coefficient; Std Err = Standard error

Next the significant variables, body mass, body fat and METS were analysed. Multiple regression results show that they were still significant (Table 40) and had a predictive power of 70% (Table 45).

Table 40 Regression summary: Body mass, body fat %, METS (n = 273).

Variable	b*	Std Err	B	Std Err	t value	p value
Intercept			65.50026	2.762073	23.7142	0.000001
Body mass	-0.068091	0.033594	-0.06011	0.029655	-2.0269	0.043669
Body fat %	-0.629213	0.036103	-0.88126	0.050565	-17.4282	0.000001
METS	0.354818	0.036309	0.00294	0.000301	9.7723	0.000001

B = regression coefficient/ parameter estimate; B* = Standardised regression coefficient

This equation shows that VO_2max can be predicted with 71% accuracy without testing the participants.

The next phase of the multiple regression analysis was to include outcome variables from the step test in an attempt to improve the predictive power. Heart rate recovery, maximum heart rate, total heart beats, average heart rate and rating of perceived exertion were included in the model. Maximum heart rate, average heart rate and rating of perceived exertion were significant, heart rate recovery and total heart beats were not (Table 41). The predictive power was 35% (Table 45).

Table 41 Regression summary: Heart rate recovery, maximum heart rate, total heart beats, average heart rate and rating of perceived exertion. (n = 273)

Variable	b*	Std Err	B	Std Err	t value	p value
Intercept			88.09885	4.359982	20.20624	0.000001
HRR	0.057579	0.049556	0.06870	0.059126	1.16190	0.246315
MHR	-0.710991	0.141127	-0.36545	0.072539	-5.03794	0.000001
THB	0.300424	0.146270	0.16734	0.081473	2.05391	0.040959
Av HR	-0.026999	0.062199	-0.00095	0.002193	-0.43407	0.664585
RPE	-0.232371	0.054119	-0.95405	0.222195	-4.29373	0.000025

B = regression coefficient/ parameter estimate; B* = Standardised regression coefficient

The step test measures that were significant were analysed and they all remained significant in the multiple regression (Table 42). The predictive power remained at 35% (Table 45).

Table 42 Regression summary: Maximum heart rate, average heart rate and rating of perceived exertion. (n = 273)

Variable	b*	Std Err	B	Std Err	t value	p value
Intercept			90.33574	3.915255	23.07276	0.000001
MHR	-0.703977	0.140624	-0.36184	0.072280	-5.00610	0.000001
Av HR	0.275868	0.138030	0.15366	0.076883	1.99861	0.046657
RPE	-0.234447	0.053895	-0.96257	0.221278	-4.35005	0.000019

B = regression coefficient/ parameter estimate; B* = Standardised regression coefficient

Next the physical characteristics of participants were combined with step test variables in a regression analysis. Age, body mass, body fat percent, METS, heart rate recovery, maximum heart rate and average heart rate were significant (Table 43). The remaining variables (sex, total heart beats and rating of perceived exertion) were not significant. The predictive power increased to 76% (Table 45).

Table 43 Regression summary: Sex, age, stature, body mass, body fat %, METS, HRR, MHR, Av HR, heart beats, RPE (n = 273)

Variable	b*	Std Err	B	Std Err	t value	p value
Intercept			91.95516	13.54478	6.78897	0.000001
Sex	-0.096220	0.071126	-2.11227	1.56139	-1.35281	0.177296
Age	-0.141914	0.040824	-0.12934	0.03721	-3.47626	0.000596
Stature	0.011932	0.053373	0.01404	0.06281	0.22355	0.823283
Body mass	-0.214156	0.082316	-0.18904	0.07266	-2.60163	0.009812
Body fat %	-0.433628	0.076155	-0.60733	0.10666	-5.69399	0.000001
METS	0.244370	0.037858	0.00203	0.00031	6.45485	0.000001
HRR	0.102891	0.032560	0.12266	0.03882	3.16001	0.001765
MHR	-0.393206	0.091612	-0.20209	0.04709	-4.29209	0.000025
Av HR	0.228110	0.109726	0.12695	0.06106	2.07890	0.038611
Heart beats	-0.130771	0.102325	-0.00460	0.00360	-1.27800	0.202394
RPE	-0.028899	0.036619	-0.11955	0.15149	-0.78919	0.430722

B = regression coefficient/ parameter estimate; B* = Standardised regression coefficient

The non-significant variables were removed (Table 44). The contribution of average heart rate to the model became non-significant and the predictive power was 75% (Table 45). Removing average heart rate did not change the predictive capacity of the equation (Table 45).

Table 44 Regressions summary: Age, body mass, body fat %, METS, HRR, MHR, Av HR (n = 273)

Variable	b*	Std Err	B	Std Err	value	p value
Intercept			83.34846	4.550127	18.3178	0.000001
Age	-0.119722	0.038772	-0.10911	0.035336	-3.0879	0.002232
Body mass	-0.069984	0.030887	-0.06178	0.027265	-2.2658	0.024276
Body fat %	-0.538928	0.040440	-0.75481	0.056639	-13.3267	0.000001
METS	0.251126	0.036140	0.00208	0.000300	6.9486	0.000001
HRR	0.097606	0.032314	0.11636	0.038522	3.0206	0.002771
MHR	-0.380395	0.089473	-0.19551	0.045986	-4.2515	0.000030
Av HR	0.142939	0.086919	0.07955	0.048372	1.6445	0.101267

B = regression coefficient/ parameter estimate; B* = Standardised regression coefficient

A summary of the different models for predicting VO_2max is shown in Table 45.

Table 45 Multiple linear regression summary for predicting VO_2max from step test measures

Variables	R	R^2	ΔR^2	p	SEE
Sex, age, stature, mass,	0.70	0.49	0.49	0.00	7.87
Sex, age, stature, mass, body fat %, METS	0.84	0.71	0.70	0.00	6.03
Mass, body fat %,METS	0.84	0.70	0.70	0.00	6.03
HRR, MHR,THB, Av HR, RPE	0.60	0.35	0.34	0.00	8.89
MHR, Av HR, RPE	0.59	0.35	0.34	0.00	8.88
Sex, age, stature, mass, body fat %, METS, HRR, MHR, THB, Av HR, RPE	0.87	0.76	0.75	0.00	5.50
Age, mass, body fat %, METS, HRR, MHR, Av HR	0.87	0.75	0.75	0.00	5.51
Age, mass, body fat %, METS, HRR, MHR	0.87	0.75	0.75	0.00	5.53

R = Multiple regression correlation coefficient; R^2 = Coefficient of determination; ΔR^2 = Adjusted coefficient of determination; SEE = Standard error of Estimate.

Considering predictive power of the various equations and objective variables which are relatively easy to measure during and after in the step test, we selected the following equation as the most appropriate:

$$VO_2max\ (ml.kg^{-1}.min^{-1}) = -0.10911\ (age) - 0.06178\ (body\ mass) - 0.75481\ (body\ fat\ \%) + 0.00208\ (METS) + 0.11636\ (HRR) - 0.019551\ (MHR) + 0.07955\ (Av\ HR) + 83.34846$$

(Equation xxi)

Where METS is metabolic equivalents, HRR is heart rate recovery, MHR is maximum heart rate and Av HR is average heart rate.

The equation comprised a combination of significant physical characteristics and outcomes of the step test (Table 44) and had a predictive capacity of 75%. Furthermore, it was relatively easy to measure all the variables making the test inexpensive and practical.

6.4 Discussion

This study determined the equation for the prediction of VO_2max, using a combination of physical characteristics of participants and outcome measures of the step test. The model has potential for accurately predicting VO_2max as shown by a high regression correlation coefficient (R = 0.87) a high coefficient of determination (R^2 = 0.75) and a low standard error of estimate (SEE = 5.51 $ml.kg^{-1}.min^{-1}$). The correlation coefficient of a multiple regression informs how much the independent variables correlate with the outcome variable. R^2, the coefficient of determination shows how much variance in VO_2max is accounted for by the interaction of the independent variables. In this study the coefficient of determination was similar to that found from a peak performance treadmill work prediction model (R^2 = 0.75 for men and 0.72 for women) [73] in a study that developed VO_2max prediction models from peak performance treadmill work and submaximal performance treadmill work and better than that found from submaximal models (R^2 = 0.55 for men and 0.56 for women [73], R^2 = 0.48 [74] in a study that predicted aerobic capacity in fire fighters using submaximal treadmill and stair mill protocols). The SEE was similar to that reported in previous studies for both peak performance (SEE = 4.63 $ml.kg^{-1}.min^{-1}$ for men and

4.11 $ml.kg^{-1}.min^{-1}$ for women [73]) and submaximal performance (SEE = 6.24 $ml.kg^{-1}.min^{-1}$ for men and 5.17 $ml.kg^{-1}.min^{-1}$ for women [73], SEE = 4.85 $ml.kg^{-1}.min^{-1}$ [74]). SEE represents the variability around the regression line, hence the smaller the SEE the better the predictive validity. Therefore in this example, 75% of the variance in predicting VO_2max is accounted for by age, body mass, body fat percent, metabolic equivalent, heart rate recovery, maximum heart rate and average heart rate. There was no difference between R^2 and adjusted R^2, which suggests that all the dependent variables were contributing to the prediction of the independent variable (VO_2max) and were not related to each other. This also shows there was minimal shrinkage in the prediction, which is a favourable outcome. Small shrinkage gives confidence in the generalisability of the equation.

The standardised beta weights indicate that of all the significant variables in the prediction equation, body fat percent is the key determinant of VO_2max and explained the most amount of variance in VO_2max values followed by maximum heart rate, then METS. Body mass had the least influence.

Rating of perceived exertion was among the variables that were non-significant and was left out of the prediction equation. Whilst physiological strain increases linearly with exercise intensity and perception of effort follows the same linear pattern, participants may underrate or overrate their perception of effort [204,205]. Since the measure may be considered subjective, leaving it out of the model makes the prediction of VO_2max based entirely on objective measurements.

The equation of the step test was developed from a heterogeneous sample of participants. For example, the participants in this study had a broad range of ages (20 to 60 years) and habitual physical activity (physically inactive to exceeding the daily recommendation of physical activity). This increases the generalisability and usefulness of the standardised step test in a variety of settings.

As expected VO_2max scores were highest in participants of high physical activity levels for all age groups, confirming a relationship between physical activity level and physical fitness. This relationship has been found in a previous study [70]. VO_2max was also higher in young participants than in older participants. The level of fitness is dependent upon age, gender, anthropometry (body mass and stature) and training or exercise intensity [64]. The prediction equation shows that age is an important variable in predicting cardiorespiratory fitness in a heterogeneous sample. The result concurs with earlier studies [72,206]. The type of test, body mass and stature have significant influence on the validity of a test depending on the intensity of the workload [64,72,207]. Body mass and stature influence cardiorespiratory tests significantly as they are closely related to the load intensity of the test. Jinzhou et al [64] assessed the influence of stature and body mass on the reliability and sensitivity of three submaximal tests. They examined the relative heart rate recovery index of the tests. Relative heart rate recovery index was normalised by stature and body mass. Body mass influenced the test reliability significantly while stature was at a minimal level. Normalisation by body mass increased the test sensitivity while the influence of stature was negligible.

The inverse relationship between age and VO_2max was due to the aging process that causes muscle loss [208,209] and low oxygen consumption which reduces functional capacity [209,210,211]. The results confirm previous findings that age is an important variable in the prediction of cardiorespiratory fitness [72,212]. The age range of the participants in this study was 20 to 60 years. The risk of performing a maximal test increases with age. Since the study involved a maximal test participants older than 60 were left out of the study for safety reason. There had to be a cut-off point between adults and children and for this study we settled for twenty. However the prediction equation can be used for participants outside the age range of the participants as it has proved to be quite generalisable.

Participant effort in the VO_2max test was satisfactory. The mean respiratory exchange ratio (RER) was 1.23 and 1.22 for men and women respectively. A respiratory exchange ratio of 1.10 has been used to mark the end of other studies [213,76]. RER is the ratio between the amount of CO_2 exhaled and O_2 inhaled in one breath (VCO_2/VO_2). It is used for estimating respiratory quotient (RQ), an indicator of which fuel, carbohydrate or fat is being metabolised to supply the body with energy. RER of 0.70 indicates that fat is the predominant fuel source, 0.85 indicates a mixture of fat and carbon dioxide, and 1.00 and above shows that carbohydrate is the predominant source of fuel.

Exercise intensities ranging between 86% and 93% of maximum heart rate have the most stable heart rate recovery, therefore the highest sensitivity to detect meaningful changes on a day-to-day basis [61]. The workload standardised step test induced maximum heart rate ranging between 55% and 98% and the means for the age groups ranged between 72% and 96%. Participants who did the least activity had the highest maximum heart rate and women had higher maximum heart rates than men. Since the workload standardised step test was designed to predict VO_2max and not detect changes on a day-to-day basis maximum heart rates varied according to physical activity, a fact that did not affect the prediction capacity of the test.

6.5 Conclusions

The study validated the workload standardised step test against the VO_2max test. A multivariate regression equation comprising step test variables and physical characteristics of participants was developed for the prediction of VO_2max. The equation has the capacity to predict maximal oxygen consumption as depicted by the coefficient of determination ($R^2 = 0.75$). The next study was a cross validation study which evaluated accuracy of the prediction equation using an independent sample.

CHAPTER 7

CROSS VALIDATION STUDY

7.1 Introduction

The process of developing a test for cardiorespiratory fitness started with the determination of step test variables, step height, stepping rate, test duration and the workload. Three step test configurations that had the same external workload but differed in stepping rates of 16, 20 and 24 steps per minute, were tested. Physiological responses to the three configurations were significantly different. The differences were attributed to different exercise intensities. In the next study the repeatability of the standardised step test was tested. The step test was highly repeatable. The validation study had participants perform the step test on one day and a VO_2max test on another day. Regression analysis was done first between the physical characteristics of participants and VO_2max results, and then between step test outcomes and the VO_2max. Physical characteristics of participants and step test outcomes were then combined in a regression analysis. The significant variables were further analysed to develop the selected prediction equation. The last stage of verifying the prediction equation is through a cross validation study. Cross validation is the evaluation of the accuracy of the prediction equation on an independent sample with characteristics similar to those of the development population. Ideally, a prediction model should be tested on an independent sample to confirm or confute its validity. The cross validation study determines the relationship between VO_2max measured directly on a treadmill, and VO_2max predicted from the equations established in Chapter 6.

7.2 Methods

Fifty participants aged 20 to 60 years were recruited for the cross validation study. The recruitment procedure was the same as that used in the validation study. Participants completed the informed consent form and responded to the Global Physical Activity Questionnaire. Stature, body mass and skinfold were measured.

On the first visit participants performed the workload standardised step test. Heart rate was measured during the test and two minutes after the test using a heart rate monitor (Suunto Oy, Vantaa, Finland). Perception of effort was recorded each minute. On the second visit participants did a VO_2max test running on a treadmill (Motor driven treadmill, Quinton Instruments, Seattle, WA, USA). Gas exchange during the test was measured by an Oxycon (Jaeger Pro®, VIASYS health care, Hoechberg, Germany). The Oxycon was calibrated before each testing session using a three litre syringe (SensorMedics®, Milan, Italy) and a reference gas of known composition (16% oxygen, 5% carbon dioxide, balance nitrogen). Heart rate was measured using a Suunto T6 chest heart rate transmitter and wrist monitor (Suunto Oy, Vantaa, Finland). Heart rate data were downloaded and recorded at two seconds intervals. Temperature and humidity were maintained relatively constant for the two testing episodes in air-conditioned laboratories.

7.2.1 Participants

Participants were recruited according to sex, age and physical activity levels to match the validation sample. Each sub-cell had two participants except the 20 to 30 age groups which had three participants for both sexes (Table 46). The recruitment strategy was the same, fliers, emails, word of mouth, visits, staff and students.

Table 46 Participants in each cell defined by age and level of physical activity (n = 50)

	Males				Females			
Age (years)	**below**	**achieved**	**above**	**Total**	**below**	**achieved**	**above**	**Total**
20-30	2	2	3	7	2	2	3	7
31-40	2	2	2	6	2	2	2	6
41-50	2	2	2	6	2	2	2	6
51-60	2	2	2	6	2	2	2	6
Total	8	8	9	25	8	8	9	25

below: below the recommended level of physical activity
achieved: achieved the recommended level of physical
above: above the recommended level of physical activity

7.2.2 Statistical Analysis

The participants' characteristics were summarised with descriptive statistics. The means and standard deviations of step test outcome measures and VO_2max outcome measures were used to analyse participant performance and response to exercise. Predicted VO_2max scores derived from the equation developed in Chapter 6 were plotted against measured VO_2max scores in Prism

(Prism 5, GraphPad Software, Inc., CA, USA). Regression analysis was done using Prism 5 to determine the Pearson's product moment correlation coefficient (r) between predicted and measured VO_2max. Standard error of estimate (SEE) values were used to determine the degree of error associated with prediction equations developed from statistics. Paired student's *t* test compared measured and estimated VO_2max. To test the validity, Pearson's correlation coefficient statistic was calculated to determine the direction and strength of the association between measured VO_2max and VO_2max predicted by the step test. The Bland and Altman analysis [214] was done to assess agreement between measured and predicted VO_2max.

7.3 Results

The results were tabulated in four sections, physical characteristics of participants, step test components, outcome measures of the step test and outcome measures of the VO_2max test.

7.3.1 Physical Characteristics of Participants

The physical characteristics of participants are presented as means and standard deviations (Table 47 and Table 48). The recruitment process was structured to get a balance in age between males and females. Whilst stature tended to increase in men with increasing age, there was no particular trend in women. Body mass did not define any pattern with age for both men and women. The 51 to 60 age groups for both sexes had the largest percentages of body fat. The youngest age group in women were the most active whilst the 31 to 40 men age group was the most active.

Table 47 Mean and standard deviation of anthropometric measures (Males). The sample size for each cell is shown in brackets ().

Variable	20-30 years	31-40 years	41-50 years	51-60 years	All
Age (years)	26 ± 3 (7)	34 ± 3 (6)	44 ± 3 (6)	55 ± 3 (6)	39 ± 11 (25)
Stature (cm)	172.9 ± 5.2 (7)	177.6 ± 5.3 (6)	181.6 ± 8.8 (6)	181.5 ± (4.5) 6	178.2 ± 6.9 (25)
Mass (kg)	72.2 ± 16.8 (7)	89.2 ± 17.7 (6)	87.1 ± 15.4 (6)	83.0 ± 7.3 (6)	82.4 ± 15.6 (25)
BMI (kg/m^2)	24.1 ± 5.4 (7)	28.2 ± 5.1 (6)	26.3 ± 3.1 (6)	25.3 ± 2.6 (6)	25.9 ± 4.3 (25)
Body fat %	14.3 ± 5.7 (7)	21.4 ± 4.8 (6)	19.6 ± 4.2 (6)	23.1 ± 3.8 (6)	19.4 ± 5.6 (25)
Sum of 7	76.3 ± 41.5 (7)	108.7 ± 40.8 (6)	82.3 ± 24.6 (6)	98.4 ± 21.4 (6)	90.8 ± 34.3 (25)
METS	2234 ± 2009 (7)	2360 ± 2648 (6)	1880 ± 1020 (6)	1547 ± 1195 (6)	2014 ±1757 (25)

Table 48 Mean and standard deviation of anthropometric measures (Females). The sample size for each cell is shown in brackets ().

Variable	20-30 years	31-40 years	41-50 years	51-60 years	All
Age (years)	27 ± 2 (7)	36 ± 3 (6)	46 ± 2 (6)	57 ± 4 (6)	41 ± 12 (25)
Stature (cm)	163.7 ± 6.4 (7)	161.6 ± 3.7 (6)	166.1 ± 7.1 (6)	160.1 ± 5.2 (6)	162.9 ± 5.9 (25)
Mass (kg)	72.9 ± 16.3 (7)	61.8 ± 6.0 (6)	66.6 ± 13.3 (6)	68.1 ± 9.5 (6)	67.6 ± 12.1 (25)
BMI (kg/m^2)	27.1 ± 5.9 (7)	23.8 ± 2.8 (6)	24.3 ± 5.8 (6)	26.0 ± 3.6 (6)	25.4 ± 4.7 (25)
Body fat %	29.4 ± 5.8 (7)	26.3 ± 4.4 (6)	30.2 ± 4.7 (6)	35.6 ± 2.4 (6)	30.3 ± 5.4 (25)
Sum of 7	142.6 ± 54.8 (7)	109.3 ± 34.0 (6)	113.5 ± 8.5(6)	141.4 ± 22.8 (6)	127.3 ±40.7 (25)
METS	2669 ± 2460 (7)	1319 ± 1041 (6)	1276 ±1159(6)	1140 ± 947 (6)	1643 ± 1623(25)

The physical characteristics of participants for the validation and cross validation samples were graphed (Figure 7, Figure 8 and Figure 9). The two groups were similar in all characteristics.

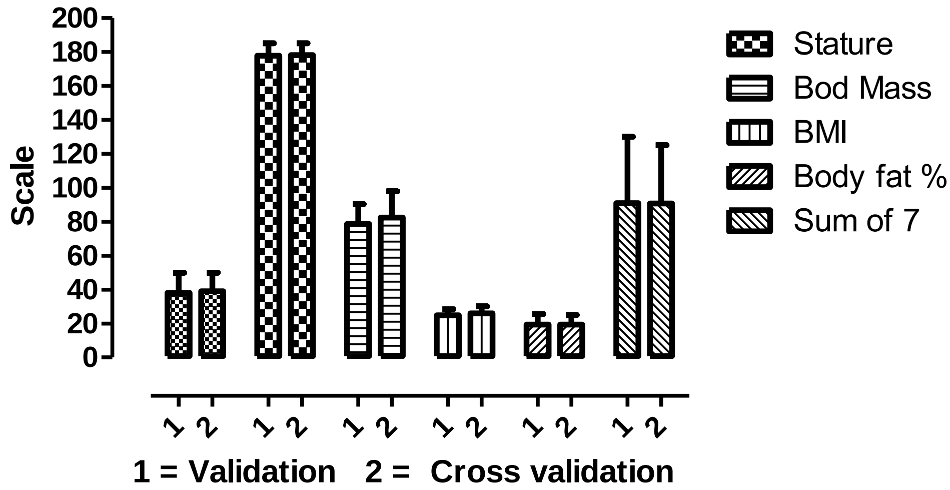

Figure 7 Validation and cross validation physical characteristics (Males). The data are represented as mean and standard deviation (the units of the Y axis are general units representing the different measurements).

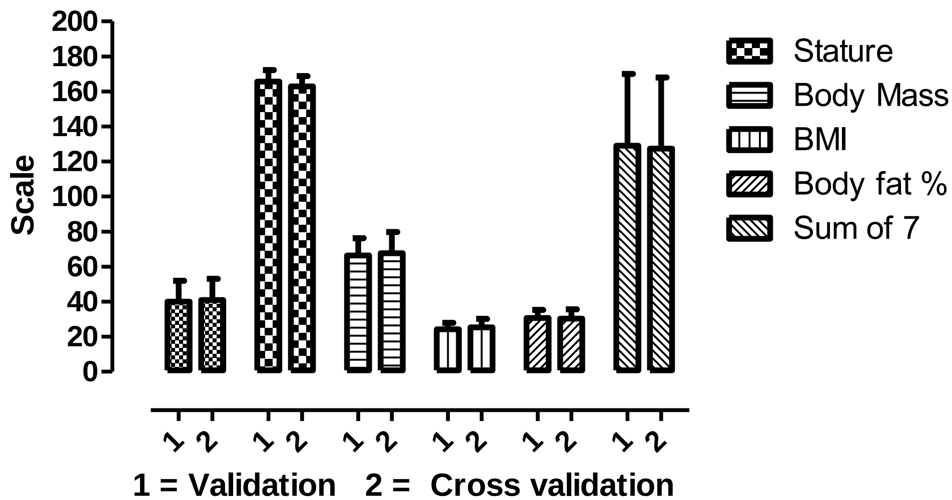

Figure 8 Validation and cross validation physical characteristics (Females). The data are represented as mean and standard deviation (the units of the Y axis are general units representing the different measurements).

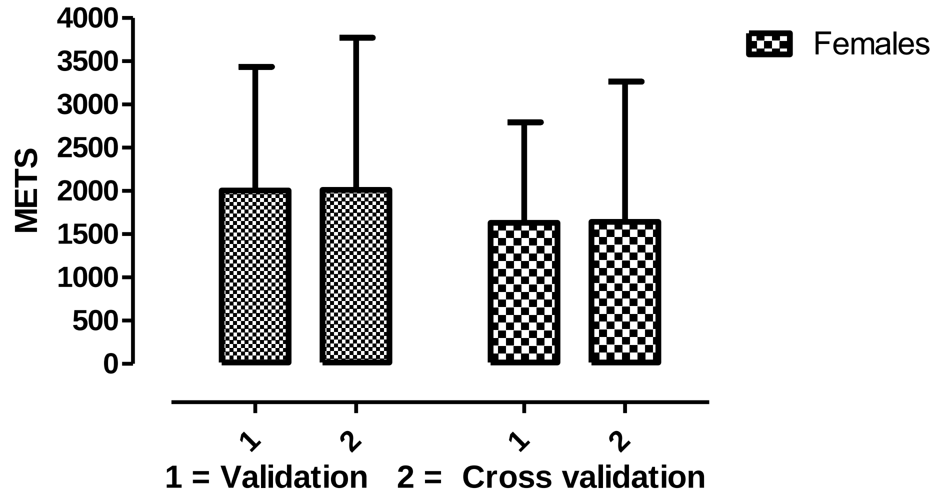

Figure 9 Validation and cross validation METS for males and females. The data are represented as mean and standard deviation.

7.3.2 Step Test Components

The mean step height for men was three centimetres higher than that for women (Table 49 and Table 50). On average the women's test was two minutes and twenty-eight seconds longer than the men's test.

Table 49 Mean and standard deviation of step test components (Males). The sample size for each cell is shown in brackets ().

Variable	20-30 years	31-40 years	41-50 years	51-60 years	All
Step height(cm)	32 ± 3 (7)	34 ± 1 (6)	35 ± 2 (6)	34 ± 1 (6)	33 ± 2 (25)
Duration (min)	8.47 ± 1.92 (7)	6.57 ± 1.25 (6)	6.50 ± 1.16 (6)	6.75 ± 0.55 (6)	7.13 ± 1.53 (25)

Table 50 Mean and standard deviation of step test components (Females). The sample size for each cell is shown in brackets ().

Variable	20-30 years	31-40 years	41-50 years	51-60 years	All
Step height(cm)	31 ± 1 (7)	30 ± 1 (6)	31 ± 2 (6)	30 ± 1 (6)	30 ± 1 (25)
Duration (min)	8.99 ± 2.15 (7)	10.33 ± 0.95 (6)	9.52 ± 1.79 (6)	9.61 ± 1.64 (6)	9.59 ± 1.68 (25)

The validation sample step height for men and women (Table 30 and Table 31 respectively) were one centimetre higher than the cross validation sample step height for men and women (Table 49 and Table 50 respectively). Step test duration for women was the same for both the validation (Table 31) and cross validation sample (Table 50). The men's test duration for the validation sample (Table 30) was sixteen seconds more than that for the cross validation sample (Table 50).

7.3.3 Outcome Measures of the Step Test

Maximum heart rate decreased with increasing age for men. Women also followed the same trend except the 51 to 60 years age group, which had the highest values. There was no defined trend for both males and females for the rest of the outcome measures of the step test, heart rate recovery, step test maximum heart rate as a percentage of VO_2max maximum heart rate, average heart rate, total heart beats and rating of perceived exertion (Table 51 and Table 52). Step test heart rate measures and perception of effort for the validation sample (Table 32 and Table 33) were comparable with those for the cross validation sample (Table 51 and Table 52).

Table 51 Mean and standard deviation of step test outcome measures (Males). The sample size for each cell is shown in brackets ().

Variable	20-30 years	31-40 years	41-50 years	51-60 years	All
HRR (beats)	33 ± 8 (7)	34 ± 15 (6)	29 ± 11 (6)	36 ± 6 (6)	33 ± 10 (25)
MHR (bpm)	144 ± 20 (7)	143 ± 32 (6)	138 ± 13 (6)	137 ± 15 (6)	141 ± 20 (25)
% of MHR	79 ± 10 (7)	77 ± 15 (6)	77 ± 6 (6)	80 ± 10 (6)	78 ± 10 (25)
Av HR (bpm)	125 ± 23 (7)	126 ± 30 (6)	121 ± 10 (6)	119 ± 13 (6)	123 ± 20 (25)
Min HR (bpm)	87 ± 17 (7)	92 ± 26 (6)	90 ± 6 (6)	78 ± 14 (6)	86 ± 17 (25)
Heart beats	1114 ± 373 (7)	853 ± 213 (6)	812 ± 157 (6)	843 ± 83 (6)	914 ± 259 (25)
RPE	10 ± 3 (7)	13 ± 4 (6)	13 ± 1 (6)	13 ± 4 (6)	12 ± 3 (25)

Table 52 Mean and standard deviation of step test outcome measures (Females). The sample size for each cell is shown in brackets ().

Variable	20-30 years	31-40 years	41-50 years	51-60 years	All
HRR (beats)	30 ± 11 (7)	30 ± 5 (6)	30 ± 7 (6)	32 ± 10 (6)	30 ± 8 (25)
MHR (bpm)	157 ± 24 (7)	152 ± 21 (6)	151 ± 12 (6)	160 ± 23 (6)	155 ± 20 (25)
% of MHR	87 ± 15 (7)	85 ± 8 (6)	87 ± 7 (6)	93 ± 12 (6)	88 ± 11 (25)
Av HR (bpm)	138 ± 18 (7)	137 ± 19 (6)	135 ± 11 (6)	135 ± 14 (6)	136 ± 15 (25)
Min HR (bpm)	88 ± 23 (7)	95 ± 10 (6)	95 ± 12 (6)	88 ± 23 (6)	91 ± 18 (25)
Heart beats	1254 ± 220 (7)	1442 ± 163 (6)	1326 ± 253 (6)	1334 ± 278 (6)	1335 ± 228 (25)
RPE	14 ± 4 (7)	14 ± 2 (6)	13 ± 3 (6)	14 ± 4 (6)	14 ± 3 (25)

7.3.4 Outcome Measures of the VO_2max Test

VO_2max decreased with increasing age for both men and women. Maximum heart also decreased with age for women. For men, VO_2max for the 31 to 40 age group was higher than the previous age group, distorting the trend. The rest of the outcome measures of the VO_2max test for both men and women followed no particular direction.

Table 53 Mean and standard deviation of VO_2max outcome measures (Males). The sample size for each cell is shown in brackets ().

Variable	20-30 years	31-40 years	41-50 years	51-60 years	All
VO_2max	52.9 ± 12.9 (7)	47.7 ± 10.1 (6)	47.6 ± 6.6 (6)	42.5 ±5.9 (6)	47.9 ± 9.7 (25)
RER	1.26 ± 0.08 (7)	1.22 ± 0.10 (6)	1.29 ± 0.06 (6)	1.26 ± 0.04 (6)	1.26 ±0.07 (25)
Duration (min)	12.39 ±2.81(7)	13.31 ±3.99(6)	12.18 ±1.56(6)	11.40 ±1.79(6)	12.32 ± 2.63(25)
MHR (bpm)	183 ± 17 (7)	184 ± 12 (6)	179 ±5 (6)	173 ± 11 (6)	180 ± 12 (25)
Av HR (bpm)	134 ± 13 (7)	138 ± 13 (6)	129 ± 4 (6)	129 ± 14 (6)	133 ± 12 (25)
Min HR (bpm)	94 ± 10 (7)	91 ± 17 (6)	90 ± 5 (6)	93 ± 16 (6)	92 ± 12 (25)
RPE	17 ± 3 (7)	19 ± 1 (6)	18 ± 2 (6)	18 ± 4 (6)	18 ± 3 (25)

Table 54 Mean and standard deviation of VO_2max outcome measures (Females). The sample size for each cell is shown in brackets ().

Variable	20-30 years	31-40 years	41-50 years	51-60 years	All
VO_2max	42.2 ± 13.0 (7)	40.0 ± 8.8 (6)	37.7 ± 7.9 (6)	35.4 ± 8.9 (6)	38.9 ± 9.7 (25)
RER	1.18 ± 0.08 (7)	1.21 ± 0.15(6)	1.24 ± 0.02 (6)	1.22 ± 0.08 (6)	1.21 ± 0.09 (25)
Duration (min)	10.89 ±2.55(7)	11.26 ±1.16(6)	10.89 ±1.42(6)	11.43 ±3.09(6)	11.11 ± 2.09(25)
MHR (bpm)	180 ± 11 (7)	178 ± 16 (6)	174 ± 6 (6)	171 ± 8 (6)	176 ± 11 (25)
Av HR (bpm)	141 ± 9 (7)	141 ± 18 (6)	137 ± 10 (6)	135 ± 6 (6)	138 ± 11 (25)
Min HR (bpm)	97 ± 12 (7)	102 ± 17 (6)	92 ± 18 (6)	97 ± 9 (6)	97 ± 14 (25)
RPE	18 ± 2 (7)	19 ± 2 (6)	19 ± 2 (6)	17 ± 4 (6)	18 ± 2 (25)

7.3.5 Prediction of VO_2max from the Equation

Equation xxi: $VO_2max\ (ml.kg^{-1.}min^{-1}) = -0.10911\ (age) - 0.06178\ (body\ mass) - 0.75481\ (body\ fat\ \%) + 0.00208\ (METS) + 0.11636\ (HRR) – 0.019551\ (MHR) + 0.07955\ (Av\ HR) + 83.34846$ from the validation study was used to predict VO_2max in the cross validation sample.

Pearson's correlation coefficients showed a strong, positive relationship between directly measured VO_2max and VO_2max predicted from the standardised step test, r = 0.87 (Figure 10).

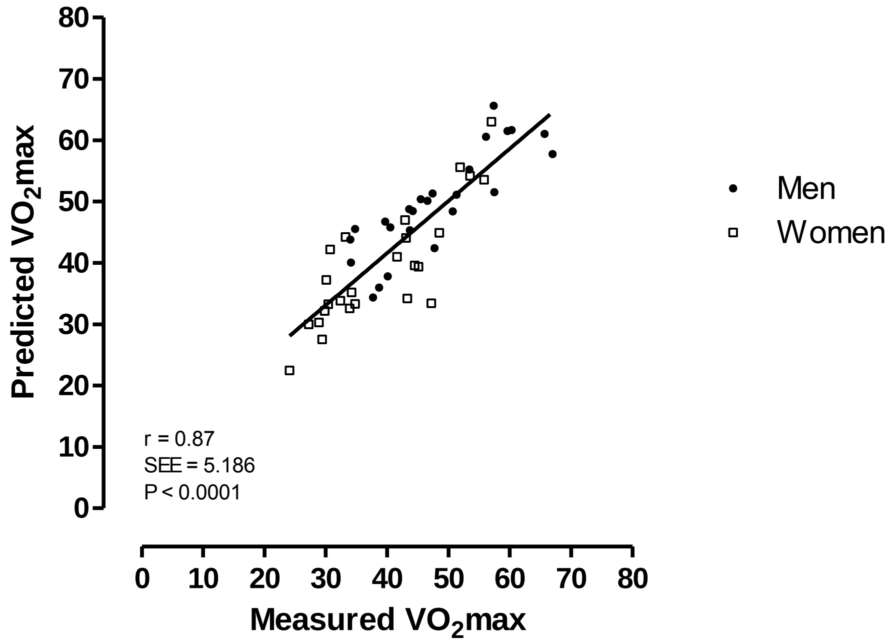

Figure 10 Measured VO_2max against predicted VO_2max in $ml.kg^{-1}.min^{-1}$

A paired *t* test analysis was done between the measured VO_2max and predicted VO_2max. There were no significant differences between the means ($P = 0.16$). The pairing was significant ($P < 0.0001$).

Two more prediction equations had their prediction capacity tested. The first was the equation that used all physical characteristics and all outcome measures of the workload standardised step test.

VO_2max ($ml.kg^{-1.}min^{-1}$) = -2.11227 (sex) - 0.12934 (age) + 0.01404 (stature) - 0.18904 (body mass) - 0.60733 (body fat %) + 0.00203 (METS) + 0.12266 (HRR) - 0.20209 (MHR) + 0.12695 (Av HR) - 0.00460 (heart beats) - 0.11955 (RPE) + 91.95516 (Equation xxii)

Where METS is metabolic equivalents, HRR is heart rate recovery, MHR is maximum heart rate, Av HR is average heart rate and RPE is rating of perceived exertion.

The correlation coefficient between predicted VO_2max and measured VO_2max was 0.88 and the standard error of estimate was 5.049 ml.kg^{-1}.min^{-1}. The relationship between measured VO_2max and predicted VO_2max is shown in Figure 11. The equation increased the prediction capacity by only 0.01. Since it included many non-significant variables it was not chosen as the best equation.

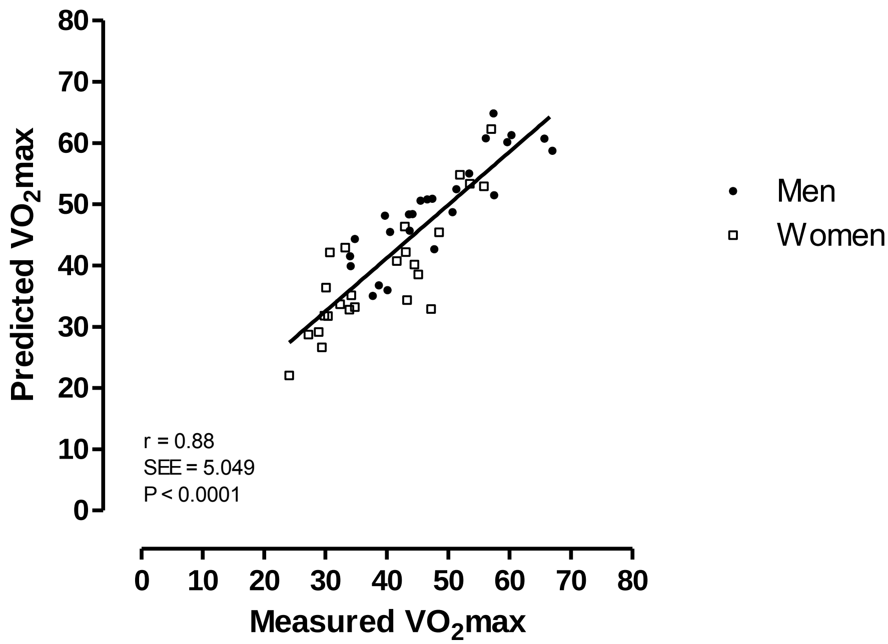

Figure 11 Measured VO_2max against predicted VO_2max in ml.kg^{-1}.min^{-1}

The second equation had average heart rate removed from the equation of significant variables since it had turned non-significant.

VO_2max (ml.kg^{-1}·min^{-1}) = -0.11655 (age) - 0.06480 (body mass) - 0.75081 (body fat %) + 0.00210(METS) + 0.11287 (HRR) - 0.12834 (MHR) + 84.23101 (Equation xxiii)

Where METS is metabolic equivalents, HRR is heart rate recovery and MHR is maximum heart rate.

Figure 12 is the graphic presentation of the relationship between measured and predicted VO_2max. The correlation coefficient remained 0.87 so the equation with average heart rate remained the preferred equation.

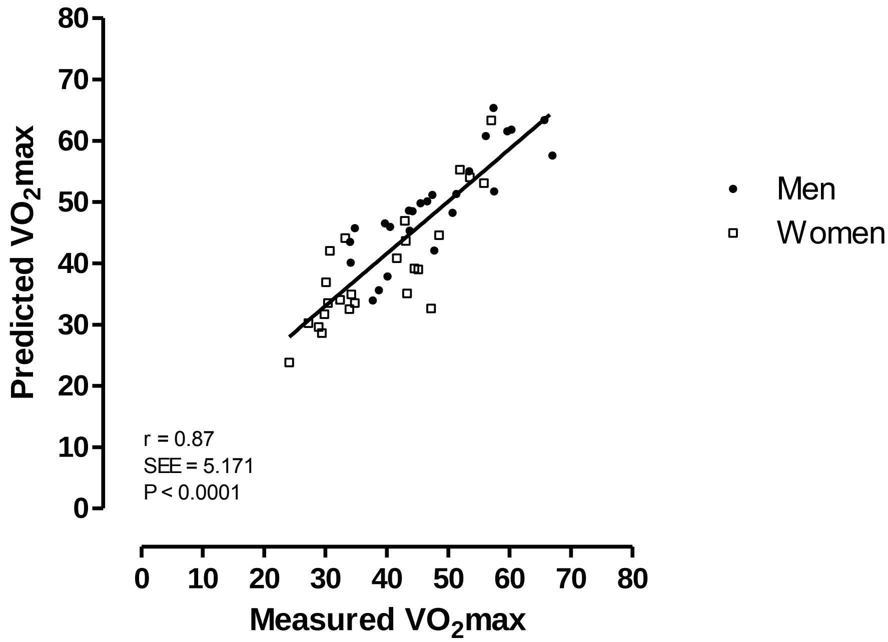

Figure 12 Measured VO_2max against predicted VO_2max in $ml.kg^{-1}.min^{-1}$

To assess the agreement between the measured VO_2max and VO_2max predicted using equation xxii which was considered the best equation, the Bland and Altman analysis was done. Figure 13 is the plot showing the limits of agreement.

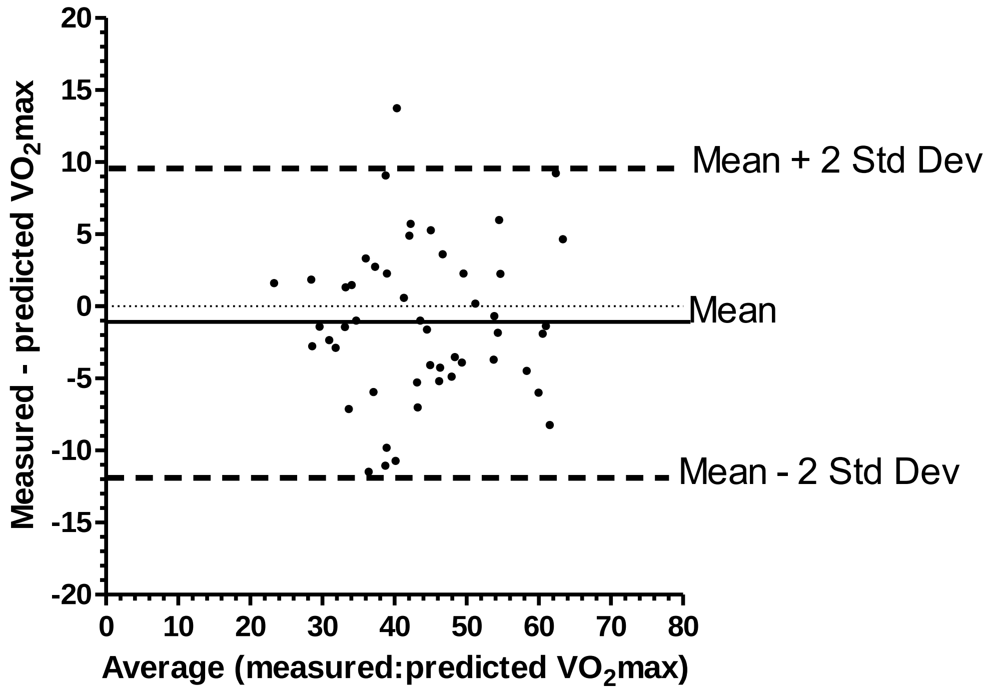

Figure 13 Difference against mean for measured and predicted VO_2max

The limits of agreement are 9.65 $ml.kg^{-1}.min^{-1}$ above the mean and 11.84 $ml.kg^{-1}.min^{-1}$ below the mean; 95% of the measurements lie within these limits.

7.4 Discussion

The predicted VO_2max values correlated significantly with measured VO_2max values ($r = 0.87$, $P < 0.0001$), a result that compares favourably with previous findings of r = 0.85 [70], r = 0.87 and r = 0.85 for men and women respectively [73]. Cross validation of a VO_2max prediction equation that used age, sex, body mass, heart rate and time for the track walk resulted in r = 0.88 [72]. The Pearson correlation coefficient r is used for validity and accuracy of prediction. It indicates how well the estimated measure relates to the true criterion measure; $r = 1$ is a perfect correlation, $r \geq 0.5$ represents a strong correlation, $r \geq 0.3$ moderate, $r \geq 0.1$ small, and $r = 0$ is no correlation at all. According to Cohen statistics a correlation coefficient of 0.88 is considered a strong association [184]. A predictive test is considered valid if it has a validity coefficient ≥ 0.80 [215].

The use of standard error of estimate (SEE) is preferred over correlation coefficient when comparing prediction equations generated from different samples. The SEE measures the accuracy of the prediction by providing an estimate of the dispersion of the prediction errors. A standard error of estimate of 5.2 $ml.kg^{-1}.min^{-1}$ is small, hence the model can predict VO_2max accurately. The SEE is similar in magnitude to that reported in an earlier cross validation analysis of the one mile track of 4.4 $ml.kg^{-1}.min^{-1}$ [72]. The workload standardised step test predicts VO_2max more accurately than the widely used ACSM equation (r = 0.64, SEE = 6.18 [216]) Therefore the submaximal standardised step test has a measurement error for maximal oxygen consumption that is aligned to previously used procedures.

The coefficient of determination from the validation sample ($R^2 = 0.75$) was compared with that from the cross validation sample ($R^2 = 0.76$). A shrinkage of 0.0018 revealed that the prediction equation was successful in predicting VO_2max [75].

The product moment correlation coefficient (r) measures the strength of the relationship between two variables. The high product moment correlation coefficient between measured and predicted means there is a strong linear relationship between the prediction and measurement of VO_2max. The Bland and Altman plot [214] was used to assess the limits of agreement between the measured and predicted VO_2max. This calculation showed that the limits of agreement are between -11.84 $ml.kg^{-1}.min^{-1}$ and 9.65 $ml.kg^{-1}.min^{-1}$. The limits of agreement are narrow enough that the workload standardised step test can be confidently used confidently for the prediction of VO_2max in the studied population. In other words, 95% of the differences between measured and predicted VO_2max lie between these limits.

The VO_2max prediction equation (Equation xxi) was developed on a large sample (n = 273) and cross validated on fifty participants. The recruitment process for the cross validation group considered sex, age and physical activity levels to ensure the validation and cross validation samples were similar.

The validation sample is more than five times larger than the samples used for most submaximal tests [99,109,81,82,111,112,83,123]. Large sample sizes are essential for the development and cross validation of prediction equations.

The workload standardised step test satisfied all the requirements of clinimetrics. Some previous tests of cardiorespiratory fitness were not validated. Those that were validated had aspects that limited their VO_2max prediction accuracy. For example, both the Chester step test and the Cambridge step test used age predicted maximum heart rate, a variable that has since been proven to be an inaccurate predictor of maximum heart rate [129]. The Cambridge step test also assumes that age predicted maximum heart rate coincides with VO_2max. The Chester step test is based estimated VO_2 for each stage of the test. All the variables used in the prediction equation of the workload standardised step test were measured, reducing the error of prediction and improving validity. The variables were in the marginal category of comparison of measurement error and the smallest worthwhile difference.

In summary, the validation study generated several equations for the prediction of VO_2max. Three of the equations, with a similar accuracy of predicting VO_2max, were used to predict VO_2max on the cross validation sample. One equation (Equation xxi), based on predictive ability and ease of measuring the output variables was then chosen as the optimal equation to use with the workload standardised step test. The use of more than one physiological variable improves accuracy of prediction. Since the equation was derived and tested on participants of all physical activity levels from the most active to the inactive, the prediction equation can be generalised for participants of all categories. However, the prediction equation is specific to treadmill measured VO_2max and may not work for cycling VO_2max.

We conclude that the workload standardised step test can predict VO_2max with good precision (SEE $\approx$ 5 $ml.kg^{-1}.min^{-1}$) in a heterogeneous healthy population with individuals of both sexes, and varying ages and levels of physical activity.

CHAPTER 8

SUMMARY AND CONCLUSIONS

8.1 Summary

Cardiorespiratory fitness describes the capacity of the cardiovascular and respiratory systems to provide muscles with oxygen during sustained or intense exercise. Cardiorespiratory fitness is a component of health related fitness. The maximal rate at which oxygen can be processed by muscle cells [70], maximum oxygen uptake (VO_2max), involves the integration of functions of the neuromuscular, cardiovascular, and pulmonary systems. VO_2max is used to classify individuals into categories of cardiorespiratory fitness and is frequently used as the basis for exercise prescription. Other reasons for measuring VO_2max are; determine a person's current fitness status, create an exercise programme and prescribe exercise, provide feedback on a participant's progress during training, identify limitations that can affect an exercise programme and evaluate cardiovascular responses to exercise. Although VO_2max can be measured from standardised protocols using the treadmill, cycle ergometer, or arm ergometer, it is sometimes not possible. These tests are expensive and require laboratories and trained personnel and some people cannot do maximal tests for health reasons. Furthermore the laboratory protocols are time consuming and cannot be used for testing large numbers. In response to these challenges, submaximal tests of cardiorespiratory fitness have been developed to test fitness and to predict VO_2max. These tests involve different forms of exercise. Step testing is often considered the preferred choice as the mode of exercise does not require skill to perform, the test does not require expensive equipment, and it is easy to implement. Most of the step tests that are available have limitations and have not been validated.

This study sought to develop a submaximal test of aerobic capacity in the form of stepping that could accurately predict VO_2max. The test had to cater for a heterogeneous group (with reference to gender, age and levels of physical activity), be relatively easy to administer, and not depend on expensive equipment. After reviewing the literature it became clear that the existing step tests did not control the absolute workload, making the interpretation of results difficult. As a consequence a method was developed which standardised the external workload of the step test, exposing the participants to the same amount of work. The reasoning behind this approach was that the differences in the outcome measures would more likely reflect changes in cardiorespiratory fitness between participants than if the workload was not standardised.

The thesis was developed in accordance with the principles of clinimetrics to ensure that each component of the test was understood. The first stage was general step test development examining the components of the test that were subject to manipulation. Step height was determined using previous studies that calculated step height using participant height. Stepping rate and workload were determined after theoretical exercises and pilot studies. Step test duration was calculated from the other components. This was followed by two reliability studies, the development of a multivariate equation to predict VO_2max, and then a cross validation study to test the accuracy of the equation.

The first study tested the reliability of three configurations of the step test using 16, 20 and 24 steps per minute. There were significant differences among all three step tests for all the variables measured except heart rate recovery between 16 and 20 steps per minute. Energy expenditure was highest at 16 steps per minute and steadily decreased with increasing stepping frequency. This study showed that a step test using different cadences but standardised for external workload can elicit different physiological responses to exercise. This was attributed to varying cadences resulting in different exercise intensities and test duration. Three step tests, all 45 kJ but different parameters (stepping rate and duration) produced significant differences ($p < 0.05$) in energy expenditure and heart rate recovery in participants. This study showed that relative exercise intensity needs be considered, even if the external workload is standardised.

The next study tested the repeatability of the step test. We also determine the preferred cadence, if a participant was given a choice. Energy expenditure, heart rate recovery and peak respiratory exchange ratio (RER) were not different between trials. Generally there was high intraclass correlation among all measured variables with maximum heart rate, maximum heart rate as a percentage of age predicted maximum heart rate, total heart beats and rating of perceived exertion all $R \geq 0.95$.

The third study sought to establish if the outcome measures of the standardised step test (i.e. heart rate recovery, maximum heart rate achieved during the test, total heart beats for the test, average heart rate and perception of effort) could be used to predict VO_2max either on their own or in combination in a heterogeneous group of males and females. The variables measured during the step test, such as heart rate recovery, maximum heart rate, step test maximum heart rate as a percentage of age predicted maximum heart rate, total heart beats during the test, average heart rate and rating of perceived exertion all contributed to the predictions equation as there was not much difference between the typical error of measurement and the smallest worthwhile difference. However, after considering the variables that contributed to the prediction of VO_2max and the practicality of the measurements, the following equation was selected as being the most accurate and practical to predict VO_2max was:

$$VO_2max = -0.10911\ (age) - 0.06178\ (body\ mass) - 0.75481\ (body\ fat\ \%) + 0.00208\ (METS) + 0.11636\ (HRR) - 0.019551\ (MHR) + 0.07955\ (Av\ HR) + 83.34846 \qquad \text{(Equation xxi)}$$

Where; METS is Metabolic equivalents, HRR is Heart rate recovery, MHR is Maximum heart rate and Av HR is Average heart rate.

The last study was the cross validation of the equation developed in the previous study to predict VO_2max. In this study another sample (n = 50) of participants with similar characteristics to the participants in the validation sample were tested. There was a strong, positive relationship between directly measured VO_2max and VO_2max predicted from the standardised step test, r = 0.87. The SEE of the equation was 5.2 $ml.kg^{-1}.min^{-1}$.

8.2 Conclusions

The workload standardised step test and the prediction equation are practical alternatives to maximal exercise testing. The test is submaximal, lasts between five and fifteen minutes and caters for differences in body mass (50 to 100 kg) and height (150 to 200 cm). The prediction equation below has potential to predict VO_2max in a heterogeneous population with individuals of both sexes, varying ages (20 to 60 years), physical activity levels and fitness levels.

$$VO_2max\ (ml.kg^{-1}.min^{-1}) = -\ 0.10911\ (age) - 0.06178\ (body\ mass) - 0.75481\ (body\ fat\ \%) + 0.00208\ (METS) + 0.11636\ (HRR) - 0.019551\ (MHR) + 0.07955\ (Av\ HR) + 83.34846$$

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APPENDICES

Appendix 1 American College of Sports Medicine (ACSM) Pre-participation Screening Questionnaire

Asses your health needs by marking all *true* statements

History

You have had:
- a heart attack
- heart surgery
- cardiac catheterisation
- coronary angioplasty (PTCA)
- pacemaker/implantable cardiac defibrillator/rhythm disturbance
- heart valve disease
- heart failure
- heart transplantation
- congenital heart disease

Symptoms

- You experience chest discomfort with exertion
- You experience unreasonable breathlessness
- You experience dizziness, fainting, or blackouts
- You take heart medications.

Other health issues

- You have diabetes.
- You have asthma or other lung disease.
- You have burning or cramping sensation in your lower legs when walking short distances.
- You have musculoskeletal problems that limit your physical activity
- You have concerns about the safety of exercise.
- You take prescription medication(s).
- You are pregnant.

If you marked any of the statements in this section, consult your physician or other appropriate health care provider before engaging in exercise. You may need to use a facility with a ***medically qualified staff***

Cardiovascular Risk Factors

- You are a man older than 45 years.
- You are a woman older than 55 years, have had a hysterectomy, or are postmenopausal.
- You smoke, or quit smoking within the previous 6 months.
- Your blood pressure is > 140/90 mm Hg.
- You do not know your blood pressure
- You take blood pressure medication.
- Your blood cholesterol level is > 5.2 $mmol.l^{-1}$.
- You do not know your cholesterol level
- You have a close blood relative who had a heart attack or heart surgery before age 55 (father or brother) or age 65 (mother or sister).
- You are physically inactive (i.e., you get < 30 minutes of physical activity on at least 3 days per week)
- You are > 20 pounds (9 kg) overweight.

If you marked two or more of the statements in this section, you should consult your physician or other appropriate healthcare provider before engaging in exercise. You might benefit by using a facility with a professionally qualified exercise staff to guide your exercise programme.

- None of the above is true.

You should be able to exercise safely without consulting your physician or other appropriate health care provider in a self-guided programme or almost any facility that meets your exercise programme needs.

Participant name	
Signature	Date

Appendix 2 Global Physical Activity Questionnaire (GPAQ) (Abridged)

Physical Activity

I am going to ask you about the time you spend doing different types of physical activity in a typical week. Please answer these questions even if you do not consider yourself to be a physically active person.

Think first about the time you spend doing work. Think of work as the things that you have to do such as paid or unpaid work, study/training, household chores, harvesting food/crops, fishing or hunting for food, seeking employment. [Insert other examples if needed]. In answering the following questions 'vigorous-intensity activities' are activities that require hard physical effort and cause large increases in breathing or heart rate, 'moderate-intensity activities' are activities that require moderate physical effort and cause small increases in breathing or heart rate.

	Questions	Response	Code
Activity at work			
1	Does your work involve vigorous-intensity activity that causes large increases in breathing or heart rate like [carrying or lifting heavy loads, digging or construction work] for at least 10 minutes continuously? [INSERT EXAMPLES] (USE SHOWCARD)	Yes 1 No 2 If No, go to P 4	P1
2	In a typical week, on how many days do you do vigorous-intensity activities as part of your work?	Number of days □	P2
3	How much time do you spend doing vigorous-intensity activities at work on a typical day?	Hours□:minute□	P3 (a-b)
4	Does your work involve moderate-intensity activity that causes small increases in breathing or heart rate such as brisk walking [or carrying light loads] for at least 10 minutes continuously? [INSERT EXAMPLES] (USE SHOWCARD)	Yes 1 No 2 If No, go to P 7	P4
5	In a typical week, on how many days do you do moderate-intensity activities as part of your work?	Number of days □	P5
6	How much time do you spend doing moderate-intensity activities at work on a typical day?	Hours□:minutes□	(a-b)

Travel to and from places

The next questions exclude the physical activities at work that you have already mentioned.
Now I would like to ask you about the usual way you travel to and from places. For example to work, for shopping, to market, to place of worship. [insert other examples if needed]

7	Do you walk or use a bicycle (pedal cycle) for at least 10 minutes continuously to get to and from places?	Yes 1 No 2 If No, go to P 10	P7
8	In a typical week, on how many days do you walk or bicycle for at least 10 minutes continuously to get to and from places?	Number of days □	P8
9	How much time do you spend walking or bicycling for travel on a typical day?	Hours □ :Minutes□	P9 (a-b)

Recreational activities

The next questions exclude the work and transport activities that you have already mentioned.
Now I would like to ask you about sports, fitness and recreational activities (leisure), [insert relevant terms].

10	Do you do any vigorous-intensity sports, fitness or recreational (leisure) activities that cause large increases in breathing or heart rate like [running or football,] for at least 10 minutes continuously?	Yes 1	P10

	[INSERT EXAMPLES] (USE SHOWCARD)	No 2 If No, go to P 13	
11	In a typical week, on how many days do you do vigorous-intensity sports, fitness or recreational (leisure) activities?	Number of days□	P11
12	How much time do you spend doing vigorous-intensity sports, fitness or recreational activities on a typical day?	Hours □:Minutes □	P12 (a-b)

Physical Activity (recreational activities) contd.

Questions		Response	Code
13	Do you do any moderate-intensity sports, fitness or recreational (leisure) activities that causes a small increase in breathing or heart rate such as brisk walking,(cycling, swimming, volleyball)for at least 10 minutes continuously? [INSERT EXAMPLES] (USE SHOWCARD)	Yes 1 No 2 If No, go to P16	P13
14	In a typical week, on how many days do you do moderate-intensity sports, fitness or recreational (leisure) activities?	Number of days □	P14
15	How much time do you spend doing moderate-intensity sports, fitness or recreational (leisure) activities on a typical day?	Hours □: Minutes□	P15 (a-b)

Sedentary behaviour

The following question is about sitting or reclining at work, at home, getting to and from places, or with friends including time spent [sitting at a desk, sitting with friends, travelling in car, bus, train, reading, playing cards or watching television], but do not include time spent sleeping.

[INSERT EXAMPLES] (USE SHOWCARD)

16	How much time do you usually spend sitting or reclining on a typical day?	Hours□: Minutes □	P16 (a-b)

MET values

For the calculation of physical activity the following MET values are used:

Domain	**METS value**
Work	□ Moderate MET value = 4.0 □ Vigorous MET value = 8.0
Transport	Cycling and walking MET value = 4.0
Recreation	□ Moderate MET value = 4.0 □ Vigorous MET value = 8.0

Analysis, Guidelines and Calculations

Total physical activity MET-minutes/ week (= the sum of the total MET minutes of activity computed for each setting)
Equation: Total Physical Activity = [(P2*P3*8) + (P5*P6*4) + (P8*P9*4) + (P11*P12*8) + (P14*P15*4)

Level of total physical activity	Physical activity cutoff value
High	IF:(P2 + P11) >= 3 days AND Total physical activity MET minutes per week >1500 **OR** IF: (P2 + P5 + P8 + P11 + P14) >= 7 days AND total physical activity MET minutes per week ≥ 3000
Moderate	IF: (P2 + P11) >= 3 days AND ((P2 * P3) + (P11 * P12)) >= 60 minutes **OR** IF: (P5 + P8 + P14) >= 5 days AND ((P5 * P6) + (P8 * P9) + (P14 * P15) ≥150 minutes **OR** IF: (P2 + P5 + P8 + P11 + P14)>= 5 days AND Total physical activity Minutes per week ≥ 600
Low	F: the value does not reach the criteria for either high or moderate levels of physical activity

Appendix 3 Global Physical Activity Questionnaire (GPAQ) Score sheet

Name: …………………………………………… Age: ……. Sex: ……………….

Question code	Response	Days	Hours	Minutes
P1				
P2				
P3				
P4				
P5				
P6				
P7				
P8				
P9				
P10				
P11				
P12				
P13				
P14				
P15				
P16				
Total				

Appendix 4 Rating of Perceived Exertion (RPE) Scale

Category Scale

6

7 Very, very light

8

9 Very light

10

11 Fairly light

12

13 Somewhat hard

14

15 Hard

16

17 Very hard

18

19 Very, very hard

20

Borg G. (1998) Borg's Rating of Perceived Exertion (RPE) and Pain Scales. Champaign, IL: Human Kinetics.

Appendix 5 Ethics Approval Studies A and B

UNIVERSITY OF CAPE TOWN

Health Sciences Faculty
Human Research Ethics Committee
Room E52-24 Groote Schuur Hospital Old Main Building
Observatory 7925
Telephone [021] 406 6338 • **Facsimile** [021] 406 6411
e-mail: shuretta.thomas@uct.ac.za

05 June 2012

HREC REF: 170/2012

Prof M Lambert
ESSM
Human Biology
Sport Science Institute

Dear Prof Lambert

PROJECT TITLE: THE ASSOCIATION BETWEEN CARDIORESPIRATORY FITNESS AND PERFORMANCE IN A SUBMAXIMAL STEPPING TEST STANDARDISED FOR ENERGY EXPENDITURE: RELIABILITY OF THE MEASUREMENTS.

Thank you for responding to the issues raised by the Faculty of Health Sciences Human Research Ethics Committee in your letter dated 28th May 2012.

It is a pleasure to inform you that the HREC has **formally approved** the above-mentioned study.

Approval is granted for one year till the 15th June 2013

Please submit a progress form, using the standardised Annual Report Form if the study continues beyond the approval period. Please submit a Standard Closure form if the study is completed within the approval period.
(Forms can be found on our website: www.health.uct.ac.za/research/humanethics/forms)

Please note that the ongoing ethical conduct of the study remains the responsibility of the principal investigator.

Please quote the HREC. REF in all your correspondence.

Yours sincerely

Signed

PROFESSOR M BLOCKMAN
CHAIRPERSON, HSF HUMAN ETHICS
Federal Wide Assurance Number: FWA00001637.

Institutional Review Board (IRB) number: IRB00001938
This serves to confirm that the University of Cape Town Human Research Ethics Committee complies to the Ethics Standards for Clinical Research with a new drug in patients, based on the Medical Research Council (MRC-SA), Food and Drug Administration (FDA-USA), International Convention on Harmonisation Good Clinical Practice (ICH GCP) and Declaration of Helsinki guidelines.
The Human Research Ethics Committee granting this approval is in compliance with the ICH Harmonised Tripartite Guidelines E6: Note for Guidance on Good Clinical Practice (CPMP/ICH/135/95) and FDA Code Federal Regulation Part 50, 56 and 312.

s.thomas

Appendix 6 Ethics Approval for Studies C and D

UNIVERSITY OF CAPE TOWN

Faculty of Health Sciences
Faculty of Health Sciences Human Research Ethics Committee
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Observatory 7925
Telephone [021] 406 6338 • **Facsimile** [021] 406 6411
e-mail: sumayah.ariefdien@uct.ac.za
www.health.uct.ac.za/research/humanethics/forms

12 April 2013

HREC REF: 161/2013

Ms L Huchu
c/o Prof M Lambert
Sports Science Institute
Newlands

Dear Ms Huchu

PROJECT TITLE: THE ASSOCIATION BETWEEN CARDIORESPIRATORY FITNESS AND PERFOMANCE IN A SUBMAXIMAL STEPPING TEST STANDARDISED FOR ENERGY EXPENDITURE.

Thank you for addressing the issues raised by the Human Research Ethics Committee.

It is a pleasure to inform you that the HREC has **formally approved** the above mentioned study.

Approval is granted for one year till the 15 April 2014.

Please submit a progress form, using the standardised Annual Report Form, if the study continues beyond the approval period. Please submit a Standard Closure form if the study is completed within the approval period.

Please add the UCT no fault insurance clause to the I/C Document.)
No Fault Clinical Trials Insurance
The University of Cape Town carries a No Fault Clinical Liability policy for participants who suffer a research-related injury in researcher-initiated clinical research:
http://www.health.uct.ac.za/usr/health/research/hrec/forms/No_Fault_2012.PDF

Please note that the ongoing ethical conduct of the study remains the responsibility of the principal investigator.

Please quote the REC. REF in all your correspondence.

sAriefdien

Appendix 7 Recruitment Poster

If so, the University of Cape Town invites you to take part in exciting research on the association between cardiorespiratory fitness and performance in a submaximal step test standardised for energy expenditure

What's in it for me?

- ✓ Pertinent personalised feedback relating to valuable measures of your health and fitness: VO_2max, BMI, body fat % and heart rate recovery.
- ✓ Corrective programmes based on your movement competence.
- ✓ General feedback at the end of the study about the validity of the step test.

What would I have to do?

- ✓ Commit to 2 visits to the Sports Science Institute of South Africa in Newlands
- ✓ Agree to heart rate and oxygen consumption measurements (no needles, promise!)

Visit 1	**ACSM screening, informed consent, body composition step test, evaluation of mobility and stability**
Visits 2	**VO_2max test**

What are the requirements for taking part?

- ✓ Generally healthy, injury-free and between the ages of 20 and 60 years
- ✓ Body mass between 50 kg and 100 kg

How can I sign up or find out more?

Please contact Lynnette Huchu: linet.huchu@uct.ac.za

Appendix 8 Informed Consent Form Study A and B

The association between cardiorespiratory fitness and performance in a submaximal stepping test standardised for energy expenditure: reliability of the measurements

Dear Participant

Thank you for your interest in participating in the study (*The association between cardiorespiratory fitness and performance in a submaximal stepping test standardised for energy expenditure: reliability of the measurements)* which is being conducted by the MRC/UCT Research Unit for Exercise Science and Sports Medicine. This study is divided into 2 parts: (A) The cardiorespiratory responses (measured by your heart rate and oxygen consumption) to a standardised step test and (B) Repeatability of a standardised step test. Through these studies we will establish the effect of manipulating external workload on physiological responses. This information will allow us to validate the step test and accurately predict cardiorespiratory fitness. The following description applies to both part A and part B of the study.

Brief description of the study

Before you can participate in the study you have to complete a pre-participation questionnaire that is designed to identify any factors which indicate a risk of you participating in exercise. This should take a few minutes and is designed to identify any factors that indicate a risk of you participating in exercise. If you satisfy the requirements of this test and fulfil the inclusion criteria for participation, you will be informed of the days you visit the laboratory for testing.

On the first day of testing we will measure your height, body mass and the thickness of 7 skinfolds. The skinfold measurement is not painful and will involve the researcher gently pinching the skin and underlying fat. You will then put a mask over your mouth and nose for the measurement of oxygen consumption. This does not restrict your breathing at all. A strap with a small heart rate transmitter will be attached around your chest and a monitor, the size of a watch will be attached to your wrist. The oxygen analyser will be switched on and the metronome set to either 16, 20 or 24 steps per minute depending on the test being conducted on that particular day. You will be informed of the duration of the test which depends on your weight and step height. This will range between 5 and 17 minutes. The researcher demonstrates stepping and you have 10 seconds to practise stepping to the metronome rhythm. During the test your oxygen consumption and heart rate will be measured continuously. The researcher will continually inform you about how much time you have to complete the test. The researcher informs you when you are half way in the test so you can change the leading leg when stepping. At the end of the test you have to provide a rating of your perception of effort before standing motionless for 2 minutes while oxygen consumption and heart rate are recorded. After the test a researcher will assist you in removing the mask and heart rate monitor.

You will come back to the laboratory twice within 5 working days at the same time as the first day for the remaining step test protocols. If you are participating in Study A the stepping cadence will be altered (one of 16, 20 or 24 steps per minute allocated in a random order). If you are participating in study B the stepping cadence will be kept the same.

Either before the start of the trial or within 1 week of the last step test you will do the 12 minute motion test. After an adequate warm-up of walking and stretching you will be asked to cover as much distance as possible in 12 minutes by either walking or jogging. This test will be done on a track in the Fitness Centre of the Sports Science Institute.

Possible risks of participation

The step test used in this study poses very low risk to the participants, similar to the risks associated with stepping when walking or jogging at a moderate intensity for 12 minutes.
Should there be any unexpected event such a tripping or straining a muscle while participating in this trial, on-site medical care will be provided by one of the medical personnel in the building who are always on call via an emergency system that is in place.

Benefits

There is no direct benefit to individuals, however, after the results have been analysed we will inform you of the significance of our findings. We will also provide you with a comprehensive assessment of your performance tests. You will also receive in invitation to our annual research evening for research participants which will be held in November.

Ethics and insurance

The study will be performed in accordance with the principles of the Declaration of Helsinki, ICH Good Clinical Practice and the laws of South Africa.

Please note that UCT does offer a no-fault insurance that will cover all participants in the event that something may go wrong. This insurance will provide prompt payment of compensation for any trial-related injury according to the Association of the British Pharmaceutical Industry (ABPI) guidelines (1991). These guidelines recommend that UCT, without any legal commitment, should compensate you without you having to prove that UCT is at fault. An injury is considered trial-related if, and to the extent that, it is caused by study activities. You must notify the study investigators immediately of any injuries during the trial, whether they are research-related or other related complications. UCT reserves the right not to provide compensation if, and to the extent that, your injury came about because you chose not to follow the instructions that you were given while taking part in the study. Your right in law to claim compensation for injury where you prove negligence is not affected.

Statement of understanding and consent:

I confirm that the exact procedure and techniques, and possible complications of the above tests have been thoroughly explained to me. I am free to withdraw from the study at any time, should I choose to do so. I understand that I may ask questions at any time during the testing procedure. I know that the personal information required by the researchers and derived from the testing procedure will remain strictly confidential and will only be revealed as a number in statistical analysis.

I have carefully read this form and understand the nature, purpose and procedures of this study. I agree to participate in this research project of the MRC / UCT Research Unit for Exercise Science and Sports Medicine.

Name of volunteer: ……………………………………………………......

Signature: ……………….………………………………………………..

Name of investigator: ……………………………………………….………….

Signature: ………………………………………….………………......

Date: **…...**

==

Contact details

Principal investigator: Ms Linet Huchu
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Co-investigator: Professor Mike Lambert
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Appendix 9 Participant information sheet Study A and B

The association between cardiorespiratory fitness and performance in a submaximal stepping test standardised for energy expenditure: reliability of the measurements

Dear Participant

Thank you for your interest in participating in the study (*The association between cardiorespiratory fitness and performance in a submaximal stepping test standardised for energy expenditure: reliability of the measurements*) which is being conducted by the MRC/UCT Research Unit for Exercise Science and sports Medicine. This study is divided into 2 parts: (A) The cardiorespiratory responses (measured by your heart rate and oxygen consumption) to a standardised step test (B) Repeatability of a standardised step test protocol. These studies are important because they will enable us to understand the effect of standardising step test work on cardiorespiratory responses. The information will be fundamental for the accurate prediction of cardiorespiratory fitness using a step test and for the subsequent validation of the step test protocol.

Brief description of the study

For you to participate in the study you have to complete the pre-participation questionnaire that is designed to identify any factors which indicate a risk of you participating in exercise. This takes a few minutes. You may be asked to get cleared by your medical doctor if you have any risk factors. If you satisfy the requirements of this test and fulfil the inclusion criteria for participation, you will be recruited into the study. The study will be explained to you and you ask questions after which you sign the informed consent form.

On the first day of testing we will measure the thickness of 7 skinfolds on your torso, arms and legs. This is not painful and will involve the researcher gently pinching the skin and underlying fat to record the measurement. We also measure and record you height and body mass. You are required to maintain a constant diet and physical activity programme during the testing days.

Part A

On the first day of testing you do a step test at either 16, 20 or 24 steps per minute in random order. The researcher demonstrates stepping and you are allowed time to practise after which testing begins. Test duration is determined by your body mass, stepping rate and step height. Heart rate, oxygen consumption and respiratory exchange ratio are measured during the test and 2 minutes after the test. You will come to the laboratory twice within 5 working days to do the remaining tests at the same time of day and under similar testing conditions.

Part B

You will visit the laboratory 3 times in 5 working days to do the same step test. On the first day the 3 step test protocols are explained and demonstrated. You are allowed time to try them after which you choose the test you are most comfortable with. Test duration depends on the protocol chosen, your body mass and step height. Heart rate, oxygen consumption and respiratory exchange ratio are measured during the test and 2 minutes after the test.

Either before the start of the trial or within 1 week of the last step test you will do the 12 minute motion test. After an adequate warm-up of walking and stretching you will be asked to cover as much distance as possible in 12 minutes by either walking or jogging on a track in the Fitness Centre of the Sports Science Institute.

Possible risks of participation

The step test used in this study poses very low risk to the participants, similar to the risks associated with stepping when walking or jogging at a moderate intensity for 12 minutes.

Should there be any unexpected event such a tripping or straining a muscle while participating in this trial, on-site medical care will be provided by one of the medical personnel in the building who are always on call via an emergency system that is in place.

Benefits

At the end of the study we will provide you with a comprehensive assessment of your performance tests. After the results have been analysed we will inform you of the significance of our findings

Ethics and insurance

The study will be performed in accordance with the principles of the Declaration of Helsinki, ICH Good Clinical Practice and the laws of South Africa.

Please note that UCT does offer a no-fault insurance that will cover all participants in the event that something may go wrong. This insurance will provide prompt payment of compensation for any trial-related injury according to the Association of the British Pharmaceutical Industry (ABPI) guidelines (1991). These guidelines recommend that UCT, without any legal commitment, should compensate you without you having to prove that UCT is at fault. An injury is considered trial-related if, and to the extent that, it is caused by study activities. You must notify the study investigators immediately of any injuries during the trial, whether they are research-related or other related complications. UCT reserves the right not to provide compensation if, and to the extent that, your injury came about because you chose not to follow the instructions that you were given while taking part in the study. Your right in law to claim compensation for injury where you prove negligence is not affected.

Appendix 10 Informed Consent Form Study C and D

The association between cardiorespiratory fitness and performance in a submaximal stepping test standardised for energy expenditure

Dear Participant

Thank you for your interest in participating in the study (*The association between cardiorespiratory fitness and performance in a submaximal stepping test standardised for energy expenditure)* which is being conducted by the MRC/UCT Research Unit for Exercise Science and Sports Medicine. This is a validation study which uses measurements from the step test (i.e. heart rate during the test and heart rate recovery after the test) to predict performance measured during a treadmill protocol.

Brief description of the study

To participate in the study you have to complete a pre-participation questionnaire that is designed to identify any factors which indicate a risk of you participating in exercise. This should take a few minutes. If you satisfy the requirements of this test and fulfil the inclusion criteria for participation, you will be recruited into the study. You will then answer questions from a questionnaire designed to predict your physical activity level.

On the first day of testing we will measure your height, body mass and the thickness of 7 skinfolds. The skinfold measurement is not painful and will involve the researcher gently pinching the skin and underlying fat. You will then perform a step test and a functional participation screen in random order. For the step test a strap with a small heart rate transmitter will be attached around your chest and a monitor, the size of a watch will be attached to your wrist. The metronome will be set at 24 steps per minute. You will be informed of the duration of the test which varies between 5 and 15 minutes depending on your weight and step height. The researcher will demonstrate stepping and you have an opportunity to practise stepping to the metronome rhythm. During the test heart rate will be measured continuously. The researcher will continually inform you about how much time you have to complete the test. The researcher informs you when you are half way in the test so you can change the leading leg when stepping. At the end of the test you will stand motionless for 2 minutes while heart rate is recorded. You then remove the heart rate monitor.

On the same day as the step test you will perform the functional participation screen. You warm up by doing dynamic stretching followed by 5 minutes of submaximal cycling on a stationary ergometer. You then do 7 screen tests designed to test movement pattern. The movements will be explained and demonstrated by the researcher. The testing protocol takes about 12 minutes. All tests are scored out of three, with the possibility of scoring from 0 – 3 depending on how accurate your performance is and whether or not you feel pain.

You will come back to the laboratory after 2-3 days to do a maximal effort test on a treadmill. The test protocol will be explained and you warm up for 6 minutes. The researcher will put a mask over your mouth and nose for the measurement of oxygen consumption. This does not restrict your breathing. The oxygen analyser will be switched on and the test begins at a treadmill speed of 2.74 km/ h and 10% gradient. Speed and incline will be increased every 3 minutes until you cannot continue with the test. You will be verbally encouraged throughout the test to produce a maximum effort performance. After the test the researcher will assist you in removing the mask.

Possible risks of participation

The step test used in this study poses very low risks to participants similar to that of brisk walking. The risks associated with the maximal working level test are similar to that of self-limiting, vigorous intensity exercise. Only those persons meeting American College of Sports Medicine criteria for low risk will be included in the study. All the functional participation screen test movements are slow and controlled and only use body weight as the load. In terms of effort they may be equated to the types of exercises done in a yoga class. The researchers will ensure that the instructions are clear so that participants will do the tests strictly according to the protocol to reduce any risk of injury.

Benefits

There is no financial remuneration for participation in this study. However, after the results have been analysed we will inform you of the significance of our findings. We will also provide you with a comprehensive assessment of your performance tests. You will also receive an invitation to our annual research evening for research participants which will be held in November.

Ethics and insurance

The study will be performed in accordance with the principles of the Declaration of Helsinki, ICH Good Clinical Practice and the laws of South Africa. Please note that UCT has a no-fault insurance policy that will cover participants in the event of some untoward event occurring during the study.

Statement of understanding and consent:

I confirm that the exact procedure and techniques, and possible complications of the above tests have been thoroughly explained to me. I am free to withdraw from the study at any time, should I choose to do so. I understand that I may ask questions at any time during the testing procedure. I know that the personal information required by the researchers and derived from the testing procedure will remain strictly confidential and will only be revealed as a number in statistical analysis.

I have carefully read this form and understand the nature, purpose and procedures of this study. I agree to participate in this research project of the MRC / UCT Research Unit for Exercise Science and Sports Medicine.

Name of volunteer: ……………………………………………….

Signature:………………………………………………………….

Name of investigator: ………………………………………………

Signature: ………………………………………………………….

Date: ……………………………………………………………..

==

Contact details

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Professor Marc Blockman
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Faculty of Health Sciences Human Research Ethics Committee
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Appendix 11 Participant information sheet study C and D

The association between cardiorespiratory fitness and performance in a submaximal stepping test standardised for energy expenditure

Dear participant

Thank you for your interest in participating in the study (*The association between cardiorespiratory fitness and performance in a submaximal stepping test standardised for energy expenditure*) which is being conducted by the MRC/UCT Research Unit for Exercise Science and Sports Medicine. This is a validation of the step test using heart rate during the test and heart rate recovery after the test to predict performance measured during a treadmill protocol

Brief description of the study

To participate in the study you have to complete the pre-participation questionnaire that is designed to identify any factors which indicate a risk of you doing exercise. This takes a few minutes. You may be asked to get cleared by your medical doctor if you have any risk factors. If you satisfy the requirements of this test you will be recruited into the study. The study will be explained to you and you ask questions after which you sign the informed consent form. You will answer questions from a questionnaire designed to predict your physical activity level.

On the first day of testing we will measure the thickness of 7 skinfolds on your torso, arms and legs. This is not painful and will involve the researcher gently pinching the skin and underlying fat to record the measurement. We also measure and record you height and body mass. You are asked to maintain a constant diet and physical activity programme during the testing days.

Step test

On the first day of testing you will be asked to perform a step test at 24 steps per minute that will elicit 45 kJ. The researcher will demonstrate stepping and you will be allowed time to practise after which testing will begin. Test duration will be determined by your body mass and step height. Heart rate will be measured during the test and 2 minutes after the test.

The Functional Participation Screen

On the same day as the step test you will be asked to perform a series of functional participation screening tests to determine general functional strength and flexibility. You first warm up by stretching and cycling on a stationary ergometer for 5 minutes. Then you perform 7 screen tests designed to test movement pattern. The movements will be explained and demonstrated. The testing protocol takes about 12 minutes. All tests are scored out of three, with the possibility of scoring from 0 – 3.

VO_2max test

On your next visit, after 2-3 days, you will perform a test that causes maximal exhaustion on a treadmill. You warm up for 6 minutes. The test begins at a treadmill speed of 2.74 km/ h and 10% gradient. Speed and incline are increased every 3 minutes until you cannot continue with the test. You will be verbally encouraged throughout the test to produce a maximum effort performance. During the test oxygen consumption and respiratory exchange ratio are measured using an Oxycon. Maximal working level will be defined as the highest oxygen consumption measured for 30 s during the test.

Possible risks of taking part

The step test used in this study poses very low risks to participants similar to that of brisk walking. The risks associated with the maximal effort test are similar to that of self-limiting, vigorous intensity exercise. Only those persons meeting American College of Sports Medicine criteria for low risk will be included in the study. All the functional participation screen test movements are slow and controlled and only use body weight as the load. In terms of effort they may be equated to the types of exercises done in a yoga class. The researchers will ensure that the instructions are clear so that participants will do the tests strictly according to the protocol to reduce any risk of injury.

Benefits

At the end of the study we will provide you with a report of your data (maximal working level, heart rate and body composition). After the results have been analysed we will inform you of the significance of our findings.

Ethics and insurance

The study will be performed in accordance with the principles of the Declaration of Helsinki, ICH Good Clinical Practice and the laws of South Africa. Please note that UCT has a no-fault insurance policy that will cover participants in the event of some untoward event occurring during the study.

Contact details

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Appendix 12 VO$_2$max score sheet

VO$_2$max Score Sheet

Name: ______________________Male/Female: __________Age:________

Height: ______________Weight:______________Sport:___________

Hand Dominance: RHS/LHS Foot Dominance: RHS/LHS

Time	Workload	HR	RPE	VO$_2$ (ml.kg^{-1}.min^{-1})
0	2.74 km.h^{-1} @ 10%			
1				
2				
3	4.02 km.h^{-1} @ 12%			
4				
5				
6	5.47 km.h^{-1} @ 14%			
7				
8				
9	6.76 km.h^{-1} @ 16%			
10				
11				
12	8.05 km.h^{-1} @ 18%			
13				
14				
15	8.85 km.h^{-1} @ 20%			
16				
17				
18	9.65 km.h^{-1} @ 22%			
19				
20				
21	10.46 km.h^{-1} @			

Time achieved: …………………… . mins and sec

Maximum heart rate: ………………. .bpm

Maximum workload: ………………. km.h^{-1} ….. %

Appendix 13 Participant Report (Men)

ANTHROPOMETRY

Height:	**metres**
Mass:	**kilogrammes**
BMI:	
Skin folds	
Biceps	**mm**
Triceps	**mm**
Subscapular	**mm**
Suprailiac	**mm**
Abdominal	**mm**
Thigh	**mm**
Med. Calf	**mm**
Sum of skinfolds:	**mm**
Predicted body fat percentage (±1%) (Durnin & Womersley)	**%**
Fat mass	**kg**
Fat-free mass	**kg**

Physiological Results

VO_2max (ml/kg/min)	VO_2max (l/min)
LT Heart Rate (bpm)	**LT Heart Rate Range (bpm)**
Crossover Point Heart Rate (bpm)	**Crossover point HR Range (bpm)**
Peak RER	**Maximal heart rate (bpm)**
Treadmill Speed ($km.h^{-1}$)	**Treadmill Incline (%)**
Heart Rate Recovery (Step Test) ↓ in beats in the first minute after exercise	**Time to Exhaustion**

VO_2max: Maximal measured rate of oxygen uptake. This figure is displayed as an absolute and relative value.

Respiratory Exchange Ratio (RER): The relationship between O_2 and CO_2 inhalation and Expiration, this indicates how hard you were able to push yourself. This result is influenced by training and fatigue

Lactate Threshold (LT): The point at which lactate starts to accumulate, the goal of training is to push this point closer to your maximum

BPM: The number of times the heart beats per minute

VO_2MAX RESULTS

The requirement of O_2 by the various tissue cells of the body is met by the combined cardiovascular and pulmonary systems, which function as a unit termed the O_2 transport system of the body. There is a normative data table below for athletic populations. Higher scores indicate a greater propensity for increased oxygen delivery and uptake which may be associated with higher levels of endurance performance.

MALE VO_2 NORMS

Age	Low Score	Below Average	Average	Above Average	High Score
20-29	<35	35-45	45-55	55-65	>65
30-39	<32.5	32.5-42.5	42.5-52.5	52.5-62.5	>62.5
40-49	<30	30-40	40-50	50-60	>60
50-59	<27.5	27.5-37.5	37.5-47.5	47.5-57.5	>57.5
+60	<25	25-35	35-45	45-55	>55

H

EART RATE RECOVERY

Heart Rate Recovery looks at the decrease in heart rate within the first few minutes, after the cessation of exercise. The faster the rate of recovery the higher the fitness level of an individual. A heart rate recovery of less than 12 beats is associated with heart related risk of mortality. A value higher than 12 indicates reduced risk of developing heart related risk factors associated with coronary heart disease.

Heart Rate Recovery

BODY MASS INDEX

The body max index (BMI) is used to assess weight relative to height and is calculated by dividing body weight in kilograms by height in meters squared (kg/m^2). Obesity related health problems increase beyond a BMI of 25. This Measurement does not, however, take into consideration the composition (fat vs. fat free) of your body mass and therefore can give inaccurate classifications. Therefore body composition is calculated

Classification	Risk	BMI
Underweight	Moderate	< 18.5
Normal	Very Low	18.5-24.9
Moderately Overweight	Low	25-29.9
Overweight	Moderate	>30

BODY FAT PERCENTAGE

Body fat percentage is measured by way of skinfold callipers, 7 different skinfolds sites are measured and then used to calculate total percentage body fat. This figure also increases with age as can be seen with the increased fat percentages within the next increase in age group. There is also a trend to calculate the sum of the pinches of skin (mm) from the seven sites. The changes in this figure do not take into consideration age.

MALE BODY FAT NORMS

Age	Low Score	Below Average	Average	Above Average	High Score
20-29	>22.4	17.4-22.4	9.4-17.4	7.1-9.4	<7.1
30-39	>24.2	20.5-24.2	13.9-20.5	11.3-13.9	<11.3
40-49	>26.1	22.5-26.1	16.3-22.5	13.6-16.3	<13.6
50-59	>27.5	24.1-27.5	24.1-17.9	15.3-17.9	<17.9
+60	>28.5	25.0-28.5	18.4-25.0	15.3-18.4	<15.3

TRAINING ZONES

Zone:	Heart Rate (bpm)	Target
Zone 1	< 167	Rest
Zone 2	167 - 187	(Fat burning / Recovery)
Zone 3	187 - 197	(Aerobic conditioning)
Zone 4	197 – 207	(LT)
Zone 5	> 207	(High intensity)

The training zones are based on your body's physiological response to exercise intensity. These zones are individually dependant on your personal physiology and should all be trained to gain the optimal results from your training.

Thank you for being a participant, your assistance is greatly appreciated

Appendix 14 Participant Report (Women)

ANTHROPOMETRY

Height:	**metres**
Mass:	**kilogrammes**
BMI:	
Skin folds	
Biceps	**mm**
Triceps	**mm**
Subscapular	**mm**
Suprailiac	**mm**
Abdominal	**mm**
Thigh	**mm**
Med. Calf	**mm**
Sum of skinfolds:	**mm**
Predicted body fat percentage (±1%) (Durnin & Womersley)	**%**
Fat mass	**kg**
Fat-free mass	**kg**

PHYSIOLOGICAL RESULTS

VO_2max (ml/kg/min)	VO_2max (l/min)
LT Heart Rate (bpm)	**LT Heart Rate Range (bpm)**
Crossover Point Heart Rate (bpm)	**Crossover point HR Range (bpm)**
Peak RER	**Maximal heart rate (bpm)**
Treadmill Speed ($km.h^{-1}$)	**Treadmill Incline (%)**
Heart Rate Recovery (Step Test) ↓ in beats in the first minute after exercise	**Time to Exhaustion**

VO_2max: Maximal measured rate of oxygen uptake. This figure is displayed as an absolute and relative value.

Respiratory Exchange Ratio (RER): The relationship between O_2 and CO_2 inhalation and Expiration, this indicates how hard you were able to push yourself. This result is influenced by training and fatigue

Lactate Threshold (LT): The point at which lactate starts to accumulate, the goal of training is to push this point closer to your maximum

BPM: The number of times the heart beats per minute

VO_2MAX RESULTS

The requirement of O_2 by the various tissue cells of the body is met by the combined cardiovascular and pulmonary systems, which function as a unit termed the O_2 transport system of the body. There is a normative data table below for athletic populations. Higher scores indicate a greater propensity for increased oxygen delivery and uptake which may be associated with higher levels of endurance performance.

FEMALE VO_2 NORMS

Age	Low Score	Below Average	Average	Above Average	High Score
20-29	<25	25-35	35-45	45-55	>55
30-39	<22.5	22.5-32.5	32.5-42.5	42.5-52.5	>52.5
40-49	<20	20-30	30-40	40-50	>50
50-59	<17.5	17.5-27.5	27.5-37.5	37.5-47.5	>47.5
+60	<15	15-25	25-35	35-45	>45

HEART RATE RECOVERY

Heart Rate Recovery looks at the decrease in heart rate within the first few minutes, after the cessation of exercise. The faster the rate of recovery the higher the fitness level of an individual. A heart rate recovery of less than 12 beats is associated with heart related risk of mortality. A value higher than 12 indicates reduced risk of developing heart related risk factors associated with coronary heart disease.

Heart Rate Recovery

BODY MASS INDEX

The body max index (BMI) is used to assess weight relative to height and is calculated by dividing body weight in kilograms by height in meters squared (kg/m^2). Obesity related health problems increase beyond a BMI of 25. This Measurement does not, however, take into consideration the composition (fat vs. fat free) of your body mass and therefore can give inaccurate classifications. Therefore body composition is calculated

Classification	Risk	BMI
Underweight	Moderate	< 18.5
Normal	Very Low	18.5-24.9
Moderately Overweight	Low	25-29.9
Overweight	Moderate	>30

BODY FAT PERCENTAGE

Body fat percentage is measured by way of skinfold callipers, 7 different skinfolds sites are measured and then used to calculate total percentage body fat. This figure also increases with age as can be seen with the increased fat percentages within the next increase in age group. There is also a trend to calculate the sum of the pinches of skin (mm) from the seven sites. The changes in this figure do not take into consideration age.

FEMALE BODY FAT NORMS

Age	Low Score	Below Average	Average	Above Average	High Score
20-29	>27.7	23.7-27.7	17.1-27.7	14.5-17.1	<14.5
30-39	>29.3	24.9-29.3	18.0-24.9	15.5-18.0	<15.5
40-49	>32.1	28.1-32.1	21.3-28.1	18.5-21.3	<18.5
50-59	>35.9	31.6-35.9	25.0-31.6	21.9-25.0	<25.0
+60	>36.6	32.5-36.6	25.1-32.5	21.1-25.1	<21.1

TRAINING ZONES

Zone:	Heart Rate (bpm)	Target
Zone 1	< 104	Rest
Zone 2	104 - 124	(Fat burning / Recovery)
Zone 3	124 - 147	(Aerobic conditioning)
Zone 4	147 - 157	(LT)
Zone 5	> 157	(High intensity)

The training zones are based on your body's physiological response to exercise intensity. These zones are individually dependant on your personal physiology and should all be trained to gain the optimal results from your training.

Thank you for being a participant, your assistance is greatly appreciated

Appendix 15 Step test duration calculation

Gravity	9.81	m/s	Work done	45000	Joules
Step height	0.3	metres			
Stepping rate	24	Steps per minute			

Participant	Mass	Duration
1	50	12.7421
2	55	11.58373
3	60	10.61842
4	65	9.801615
5	70	9.1015
6	72	8.84868
7	74	8.609527
8	76	8.38296
9	78	8.168013
10	80	7.963812

Appendix 16 Workload determination

Gravity	9.81	m/s		
Step height	0.3	metres		
Stepping rate	20	24	28	Steps per minute
Mass	50 kg		80 kg	100 kg

Duration	**Work 16**	**Work 20**	**Work 24**	**Work 16**	**Work 20**	**Work 24**	**Work 16**	**Work 20**	**Work 24**
5	14715	17658	20601	23544	28252.8	32961.6	29430	35316	41202
6	17658	21189.6	24721.2	28252.8	33903.36	39553.92	35316	42379.2	49442.4
7	20601	24721.2	28841.4	32961.6	39553.92	46146.24	41202	49442.4	57682.8
8	23544	28252.8	32961.6	37670.4	45204.48	52738.56	47088	56505.6	65923.2
9	26487	31784.4	37081.8	42379.2	50855.04	59330.88	52974	63568.8	74163.6
10	29430	35316	41202	47088	56505.6	65923.2	58860	70632	82404
11	32373	38847.6	45322.2	51796.8	62156.16	72515.52	64746	77695.2	90644.4
12	35316	42379.2	49442.4	56505.6	67806.72	79107.84	70632	84758.4	98884.8
13	38259	45910.8	53562.6	61214.4	73457.28	85700.16	76518	91821.6	107125.2
14	41202	49442.4	57682.8	65923.2	79107.84	92292.48	82404	98884.8	115365.6
15	44145	52974	61803	70632	84758.4	98884.8	88290	105948	123606
16	47088	56505.6	65923.2	75340.8	90408.96	105477.1	94176	113011.2	131846.4
17	50031	60037.2	70043.4	80049.6	96059.52	112069.4	100062	120074.4	140086.8
18	52974	63568.8	74163.6	84758.4	101710.1	118661.8	105948	127137.6	148327.2
19	55917	67100.4	78283.8	89467.2	107360.6	125254.1	111834	134200.8	156567.6
20	58860	70632	82404	94176	113011.2	131846.4	117720	141264	164808

Appendix 17 Anthropometry

Name: **Date:** **Mass(kg):**
Gender: male = 1, female = 2 **Age:**

SKINFOLDS **(mm)**

triceps
biceps
subscapular
suprailiac
calf
thigh
abdominal

DIAMETER **(cm)**

humerus	0.0
femur	0.0

GIRTH (cm)

con arm	0.0
calf	0.0
sub-gluteal	0.0
mid-thigh	0.0
above knee	0.0
forearm	0.0

HEIGHT (cm)

stature
sub-gluteal to knee

RESULTS

SOMATOTYPE	
endomorphy	-0.7
mesomorphy	4.5
ectomorphy	#DIV/0!

lean thigh volume (cc)	0

DURNIN/WOMERSLEY	
%fat =	#NUM!
fat mass (kg) =	#NUM!
LBM (kg) =	#NUM!

Sum of Skinfolds	0.000

MUSCLE	
% Muscle Mass	#DIV/0!
muscle (kg) =	-2.4

BODY MASS INDEX =	#DIV/0!

Appendix 18 Cooper test ratings

Male Athletes

Age	Excellent	Above Average	Average	Below Average	Poor
13-14	>2700m	2400-2700m	2200-2399m	2100-2199m	<2100m
15-16	>2800m	2500-2800m	2300-2499m	2200-2299m	<2200m
17-19	>3000m	2700-3000m	2500-2699m	2300-2499m	<2300m
20-29	>2800m	2400-2800m	2200-2399m	1600-2199m	<1600m
30-39	>2700m	2300-2700m	1900-2299m	1500-1999m	<1500m
40-49	>2500m	2100-2500m	1700-2099m	1400-1699m	<1400m
>50	>2400m	2000-2400m	1600-1999m	1300-1599m	<1300m

Female Athletes

Age	Excellent	Above Average	Average	Below Average	Poor
13-14	>2000m	1900-2000m	1600-1899m	1500-1599m	<1500m
15-16	>2100m	2000-2100m	1700-1999m	1600-1699m	<1600m
17-20	>2300m	2100-2300m	1800-2099m	1700-1799m	<1700m
20-29	>2700m	2200-2700m	1800-2199m	1500-1799m	<1500m
30-39	>2500m	2000-2500m	1700-1999m	1400-1699m	<1400m
40-49	>2300m	1900-2300m	1500-1899m	1200-1499m	<1200m
>50	>2200m	1700-2200m	1400-1699m	1100-1399m	<1100m

Cooper, K.H. (1968) A means of assessing maximal oxygen intake. *JAMA*. 203, p. 135-138