CHAPTER II

REVIEW OF THE LITERATURE

Cardiorespiratory fitness is the single most important component of health-related physical fitness. The exception occurs among older adults, for whom muscular strength is particularly important. A person does need a certain amount of muscular strength and flexibility to engage in normal daily activities. Nevertheless, one can get by without high level of strength and flexibility, but cannot do without a good cardiorespiratory fitness (ACSM, 2005; Baumgartner and Jackson, 1995; McArdle et al., 1996).

Aerobic exercise is especially important in preventing cardiovascular disease. A poorly conditioned heart, which has to pump more often just to keep a person alive, is subject to more wear and tear than a well-conditioned heart. In situations that place strenuous demands on the heart, such as doing yard work, lifting heavy objects or weights, or running to catch a bus, the unconditioned heart may not be able to sustain the strain. Regular participation in cardiorespiratory fitness activities also help a person achieve and maintain recommended body weight, the fourth component of health-related physical fitness (David et al.,1999; McArdle et al., 1996).

Physical activity, unfortunately, is no longer a natural part of the existence in many societies. Current technological developments have driven most people in developed countries into sedentary lifestyles. For instance, when many people need to go to the store, most drive their automobiles and then spend a couple of minutes driving around the parking lot to find a spot closer to the store's entrance. They do not even have to carry out the groceries any more. A youngster working at the store usually takes them out in the cart and places them in the vehicle. Similarly, during a visit to a multi-level shopping mall, almost everyone chooses to ride the escalators instead of taking the stairs. Automobiles, elevators, escalators, telephones, intercoms, remote controls, electric garage door openers-all are modern–day commodities that minimize the amount of movement and effort required of the human body.

One of the most harmful effects of modern-day technology is an increase in chronic conditions related to a lack of physical activity. These include hypertension, heart disease, chronic low-back pain and obesity (ACSM, 2000; Golding,1989; McArdle et al., 1996). They are referred to as hypokinetic diseases. The term "hypo" means low or little, and "kinetic" implies motion. Lack of adequate physical activity is a fact of modern life that most people can avoid no longer. To enjoy modern-day commodities and still expect to live life to its fullest, however, a personalized lifetime exercise program must become a part of daily living (David et al., 1999; Edwardo, 1992).

Basic Cardiorespiratory Physiology

Cardiorespiratory fitness is a measure of how efficiently the bodies work. The pulmonary (lungs), cardiovascular (heart and blood vessels), and muscular systems work together during cardiorespiratory activities (ACSM, 2000; Baumgartner et al., 1995; McArdle et al., 1996; Triin, 2004).

As a person breathes, part of the oxygen in the air is taken up by the alveoli in the lungs. As blood passes through the alveoli, oxygen is picked up by hemoglobin and transported in the blood to the heart. The heart then is responsible for pumping the oxygenated blood through the circulatory system to all organs and tissues of the body.

At the cellular level, oxygen is used to convert food substrates through aerobic metabolism into adenosine triphosphate (ATP). This compound provides the energy for physical activity, body functions, and maintenance of a constant internal equilibrium. During physical exertion, more ATP is needed to perform the activity. As a result, the lungs, heart, and blood vessels have to deliver more oxygen to the muscles to supply the required energy.

During prolonged exercise, an individual with a high level of cardiorespiratory fitness is able to deliver the required amount of oxygen to the tissues with relative ease. The cardiorespiratory system of a person with a low level of endurance has to work much harder, the heart has to work at a higher rate, less oxygen is delivered to the tissues and consequently , the individual fatigues faster. Hence, a higher capacity to deliver and utilize oxygen (oxygen uptake or VO_2) indicates a more efficient cardiorespiratory system. Measuring oxygen uptake is therefore an important way to evaluate the cardiorespiratory health.

Aerobic Exercise can Improvement Cardiorespiratory Fitness

Cardiorespiratory activities often are called aerobic exercises. Examples of cardiorespiratory or aerobic exercises are walking, jogging, swimming, cycling, cross-country skiing, water aerobics, rope skipping and aerobics. The intensity of anaerobic exercise is so high that oxygen cannot be delivered and utilized to produce energy. Because energy production is limited in the absence of oxygen, these activities can be carried out for only short periods of 2 to 3 minutes. The higher the intensity of the activity, the shorter the duration.

Activities such as the 100, 200 and 400 meters in track and field, the 100 meters in swimming, gymnastics routines and strength training are good examples of anaerobic activities. Anaerobic activities do not contribute much to development of the cardiorespiratory system. Only aerobic activities will help increase cardiorespiratory fitness (David et al., 1999; McArdle et al., 1981)

Benefits of aerobic training (McArdle et al., 1981)

1. A higher maximal oxygen uptake (VO_2max).
2. An increase in the oxygen-carrying capacity of the blood.
3. A decrease in resting heart rate and an increase in cardiac muscle strength.
4. A lower heart rate at given workloads.
5. An increase in the number and size of the mitochondria.
6. An increase in the number of functional capillaries.
7. A faster recovery time.
8. Lower blood pressure and blood lipids.
9. An increase in fat-burning enzymes.

Unit of VO_2max

Cardiorespiratory fitness or aerobic capacity is determined by the maximal amount of oxygen the human body is able to utilize (that is, the oxygen uptake) per minute of physical activity (VO_2max). This value can be expressed in liters per minute (l/min) or milliliters per kilogram per minute (ml/kg/min). The relative value in ml/kg/min is used most often because it considers total body mass (weight) in kilograms. When comparing two individuals with the same absolute value, the one with the lesser body mass will have a higher relative value, indicating that more oxygen is available to each kilogram of body weight. Because all tissues and organs of the body need oxygen to function, higher oxygen consumption indicates a more efficient cardiorespiratory system (ACSM, 2000; Baumgartner, 1995; Keren et al. 1980).

Components of oxygen uptake (VO_2)

The amount of oxygen that is actually used by the body during rest or hard workout-that is, either submaximal (VO_2) or maximal (VO_2max) physical activity-is determined by the heart rate, the stroke volume and the amount of oxygen removed from the vascular system (ACSM, 2005; David et al., 1999; McArdle et al., 1972; Smothermon, 1996).

Heart rate

Normal heart rate may range from about 40 bpm during resting conditions in trained athletes to 200 bpm or higher during maximal exercise. The maximal heart rate that a person can achieve starts to drop by about 1 beat per year beginning at about 12 years of age (ACSM,2005; Olgun, 1980). Maximal heart rate in trained endurance athletes is sometimes slightly lower than in untrained individuals (David et al.,1999). This adaptation to training is thought to allow the heart greater time to effectively fill with blood so as to produce a greater stroke volume (Smothermon, 1996).

Stroke volume

Stroke volume ranges from 50 ml per beat (stroke) during resting conditions in untrained individuals to 200 ml at maximum in endurance-trained athletes. Following endurance training, stroke volume increases significantly (David et al.,1999). Some of the increase is due to a stronger heart muscle, but it is also related to an increase in total blood volume and a greater filling capacity of the ventricles during the resting phase (diastole) of the heart cycle (ACSM, 2000; McArdle et al., 1972). As more blood enters the heart, a greater amount can be ejected with each heartbeat (systole). The increase in stroke volume is primarily responsible for the increase in VO_2 seen with endurance training.

Amount of oxygen removed from blood

The amount of oxygen removed from the vascular system is known as the arteriovenous oxygen difference (a-VO_2 diff). The oxygen content in the arteries at sea level is typically 20 ml of oxygen per 100 cc of blood (ACSM, 2000; McArdle et al., 1972). The oxygen content in the veins during a resting state is about 15 ml per 100 cc. Thus, the a-VO_2 diff-that is, the amount of oxygen in the arteries minus the amount in the veins-at rest is 5 ml per 100 cc (David et al.,1999). The arterial value remains constant during both resting and exercise conditions but, during maximal exercise, the venous oxygen content drops to about 5 ml per 100 cc; yielding an a-VO_2 diff of 15 ml per 100 cc. The latter value may be slightly higher in endurance athletes.

These three factors are used to compute VO_2 using the following equation:

$$VO_2 \text{ in l/min} = (HR*SV* \text{a-}VO_2 \text{ diff})/ 100,000$$

For example, the resting VO_2 (also know as "resting metabolic rate") of an individual with a resting heart rate of 76 bmp and a stroke volume of 79 ml would be

$$VO_2 \text{ in l/min} = (76*79* 5)/ 100,000 = 0.3 \text{ l/min}$$

Likewise, the VO_2max of a person exercising maximally who achieves a heart rate of 190 bmp and a maximal stroke volume of 120 ml would be

$$VO_2\text{max in l/min} = (190*120* 15)/ 100,000 = 3.42 \text{ l/min}$$

To convert l/min to ml/kg/min, multiple the l/min value by 1,000 and divide by body weight in kilograms. In the above example, if the person weighed 70 kilograms, the VO_2max in ml/kg/min would be (3.42*1,000/70) = 48.9 ml/kg/min.

Factors that affect aerobic capacity

State of training

The VO_2max difference between trained and untrained individuals is between 5-20% (Hagberg and Schneider, 1978; Ben et al.,1997). Endurance training can increase aerobic capacity by 15-30% during an initial three-month training period and by as much as 50% over a two-year period (Foster et al., 1997). Training improves the body's ability to extract oxygen from blood (Smothermon, 1996). This improvement results in an increase in arteriovenous difference and more effective distribution of the cardiac output. Improvement in the mitrochondrial oxidative capacity is primary responsible for improvement in aerobic capacity (ACSM, 2000; Frank, 2004; Smothermon, 1996).

Heredity

The genetic effect on an individual's VO_2max is between 10-30%, 50% for maximal heart rate and 70% for physical working capacity (Smothermon, 1996). Endurance training improves an individual's aerobic capacity, but genetic endowment limits this improvement. Due to genetic limits of aerobic performance, it is impossible to predict an individual's response to training regimen (Frank, 2004; McArdle et al., 1996; Smothermon, 1996).

Gender

The VO_2max for females is 15-30% lower than for males (Barbara,1980). These gender differences are generally attributed to differences in body composition and hemoglobin concentrations (David et al.,1999). Males generally have more fat free mass than woman and are able to generate more aerobic energy (Smothermon, 1996). Males have a 10-14% greater concentration of hemoglobin and are able to circulate more oxygen during aerobic exercise. Males and females exhibit equal adaptation to aerobic training (ACSM, 2000; Frank, 2004; McArdle et al., 1981; Smothermon, 1996).

Age

After age 25, VO_2max declines steadily at a rate of approximately 1% (~0.5 ml/kg) per year (Olgun, 1980). An inactive individual's rate of decline may be doubled (Ritchie et al.,2005). Evidence indicates that an individual's activity level over time has a far greater effect on the rate of decline than aging alone. For an individual whose level of physical activity and body composition remain constant over time the rate of decline may be only 0.5% (~0.25 ml/kg) per year. As much as 50% of the steady decline may be attributable to a decrease in stroke volume (Barbara,1980; Frank, 2004; Olgun, 1980; Smothermon, 1996).

Altitude

Aerobic capacity is not measurably altered at altitudes below 1,500 meters. Above 1,500 meters there is a 10% linear decline in VO_2max per 1,000 meters increase in altitude (Smothermon, 1996). The decrement of aerobic capacity past 1,500 meters is due largely to hypoxia. A reduction in barometric pressure decreases the hemoglobin oxygen saturation and oxygen partial pressure, creating hypoxia and ultimately limiting VO_2max (Frank, 2004; Smothermon, 1996).

Body composition

Differences in body composition cause an estimated 69% variation in VO_2max scores among individuals. This large estimated variability has led to the common practice of expressing oxygen uptake measures in terms of body weight (Edwado,1992; Mark et al., 2004). The level of aerobic capacity is ultimately related to the percent and trained state of fat free mass. An individual with higher levels of body fat will have a lower level of VO_2max (Edwardo, 1992; Frank, 2004; Smothermon, 1996).

Mode of exercise

An important determinant in the measurement of VO_2max is the quantity of the muscle mass stressed when performing the task or mode of exercise used to elicit maximal oxygen uptake. The greater the amount of muscle mass employed during exercise the greater the consumption of oxygen (Hermansen and Saltin,1969; Mark et al., 2004). The highest VO_2max values are usually obtained during treadmill running (Keren, 1980; Meyer et al,, 2002; Micha et al., 2005). Bench stepping produce higher VO_2max values than cycling and is 5-15% less when compared to a maximal treadmill (Ryhming,1954; Smothermon, 1996; Golding,1989; Santo and Laerence,2003; Sykes and Roberts,2004; Satipati et al.,2005; Karen ,2006). VO_2max measured during submaximal cycling is 8-27% less when compared to a maximal treadmill (Astrand, 1953; Hermansen and Saltin, 1969; Keren et al., 1980; Edwado,1992; Park et al.,1997; Mark et al.,2004; Matthew et al., 2004). Arm ergometry is 30% less and swimming is 20% less when compared to a maximal treadmill (Edwardo, 1992; Frank, 2004; Keren et al., 1980; Hermansen and Saltin, 1969; Mark et al.,2004; Thomas; Smothermon, 1996).

Maximal oxygen uptake (VO_2max) can be determined from either maximal or submaximal exercise. At maximal exercise level, VO_2max is measured directly from expired gases or estimated from exercise intensity. The person being tested breathes into a metabolic cart that measures the difference in oxygen content between the person's exhalation and the atmosphere. Modern automated systems provide ease of use and a detailed printout of test results that save time and effort. However, attention to detail relative to calibration is still essential to obtain accurate results. Because of the costs associated with equipment, space and personnel needed to carry out these tests, direct measurement of VO_2max is generally reserved for research or clinical settings.

When direct measurement of VO_2max is not feasible or desirable, a variety of submaximal exercise tests can be used to estimate VO_2max from heart rate response to the exercise tests (ACSM, 2000; Patton et al., 1982; Keren et al., 1980).

Maximal versus submaximal exercise testing

The decision to use a maximal or submaximal exercise test depends largely on the reasons for the test, the type of subject to be tested and the availability of appropriate equipment and personnel. VO_2max can be estimated with reasonable accuracy during conventional exercise test protocols, by considering test duration at a given grade and speed on a treadmill or power output on a cycle ergometer, using the prediction equations. Maximal tests have the disadvantage of requiring participants to exercise to the point of volitional fatigue and might require physician supervision and emergency equipment. Maximal exercise testing, however, offers increased sensitivity in the diagnosis of coronary artery disease in asymptomatic individuals (ACSM,2000).

Because maximal exercise testing is not a feasible method of assessing cardiorespiratory fitness for the vast majority of health fitness practitioners, submaximal exercise tests are commonly used. The basic aim of submaximal exercise testing is to determine the heart rate (HR) response to one or more submaximal work rates and used the results to predict VO_2max. Submaximal exercise tests make several assumptions (Keren et al., 1980)

- A steady-state heart rate is obtained for each exercise work rate.
- A linear relationship exists between heart rate and work rate.
- The maximal heart rate for a given age is uniform.
- Mechanical efficiency is the same for everyone.

Some of these assumptions are easily met, while others introduce unknown errors into the prediction of VO_2max. Although submaximal exercise testing is not as precise as maximal exercise testing, it provides a reasonably accurate reflection of an individual's fitness at a lower cost and reduced risk and requires less time and effort on the part of subject. When an individual is given repeated submaximal exercise tests over a period of weeks or months and the heart rate response to a fixed work rate decreases over time, it is likely that the individual's cardiorespiratory fitness has improved, independent of the accuracy of the VO_2max prediction (ACSM, 2000).

Maximal exercise tests

The criterion measure, or "gold standard", of aerobic capacity is the direct measurement of VO_2max. The objective of a maximal test is to increase systematically exercise intensity until the subject reaches exhaustion. One of the methods is to estimate VO_2max from maximum power output (ACSM, 2000; Baumgartner and Jackson, 1995; McArdle et al., 1996). However, the most accurate method is to measure oxygen uptake by indirect calorimetry, that is, to measure expired gases during the exercise test.

Indirect calorimetry

Maximal oxygen uptake (VO_2max) is most accurately determined by measuring expired gases during maximal exercise. This method is conceptually simple but it is the most difficult method to use and requires trained technicians with expensive equipment. The objective is to increase power output at linear rate until the individual reaches exhaustion. Expired gases are collected during all stages of exercise. The volume of oxygen used at this exhausting level is VO_2max (ACSM, 2000; McArdle et al., 1996). The parameters needed to compute VO_2max are oxygen and carbon dioxide concentrations of room and expired air and volume of air expired per minute. Standard methods are available for calculating O_2 consumption.

Metabolic equipment

Expired gas was analyzed breath by breath via an automated computer inter faced metabolic system (Ben et al., 1996; Chuang et al.,2004). Metabolic equipment has more accuracy and is relatively simple than other methods, because gas exchange measurements (VO_2), VCO_2, and minute ventilation (VE) were computed breath by breath and online computer displays the data real time (Chuang et al.,2004).

Despite of its great benefits, the direct measurement of VO_2max is expensive in terms of needed equipment and personnel. For these reasons, the direct determination is typically done in a research setting.

Maximum power output estimates

VO_2max can be measured from maximal treadmill or cycle ergometer exercise. Maximal treadmill or cycle ergometer tests are highly reproducible (r = 0.95-0.98) with a standard error of the estimate (SEE) of 1-3 ml/kg/min (McArdle et al., 1996). The next hierarchy of tests are maximal treadmill or cycle ergometer tests, which estimate VO_2max from exercise time or maximal power output and correlate highly with actual VO_2max (r = 0.90-0.95, SEE 3-5 ml/kg/min) (McArdle et al., 1996).Many people are not accustomed to riding a cycle ergometer and find it difficult to reach their maximum; their legs fatigue prior to reaching maximal exercise. So, maximal tests are more often administered on a treadmill. Power output systematically increase by time in a treadmill protocol. The elapsed time to reach exhaustion is an index of maximum work capacity. About 71% of all tests given in the United States follow the Bruce protocol and about 10% use the Balke (ACSM, 2000; Golding, 2000).

Disadvantages to maximal testing include requiring participants to go to volitional maximum, considerable requirements of time, personnel, and resources, and test performance limited by local muscle fatigue or pain rather than cardiorespiratory insufficiency. These disadvantages make maximal testing unfeasible for large populations and is usually reserved for diagnostic or research purposes.

Submaximal exercise tests

Exercising to VO_2max is physical exhausting, time-consuming, and requires medical supervision when testing high-risk subjects. Submaximal tests provide a less accurate. But quick and easy to administer, need little equipment, and do not require subjects to work to exhaustion(Ryhming, 1954; Smothermon, 1996; Golding, 1989; Santo and Lawrence,2003; Sykes and Roberts,2004; Satipati et al.,2005; Karen et al.,2006). Older individuals and unfit or unconditioned subjects can be tested without the hazards associated with maximal testing. It safer method of estimating VO_2max(Ryhming,1954; Golding,1989; Smothermon, 1996; Karen et al.,2006). The measurement objective of submaximal tests is to define the slope of the individual's heart rate response to exercise and use the slope to estimate VO_2max from submaximal parameters. VO_2max may be estimated from a single reading (single-stage model) or several submaximal heart rates (multi-stage model) (Astrand, 1953; Hermansen and Saltin, 1969; Keren et al., 1980; Golding,1989; Matthew et al., 2004; Satipati et al.,2005).

A submaximal test estimates VO_2max from submaximal exercise heart rate and power output. Power output can be regulated with treadmill, cycle ergometer, and bench stepping. Walking and jogging tests is another method of regulating power output. The walking and jogging tests described next allow the person to travel at a self-determined pace. VO_2max is estimated from movement time, and heart rate response to the exercise. Listed next are common submaximal cycle ergometer protocols and step test (ACSM, 2000; Baumgartner and Jackson, 1995; McArdle et al.,1996; Thomas).

Submaximal step tests

Development

The step test, one of the first froms of physical work capacity testing, has been used to test physical fitness parameters for many years. A good review of development of step test has been reported by Smothermon (1996). Smothermon concluded the first step test by Collis and Pembrey designed a one minute pluse-ratio test. Afterwards Hunt and Pembrey (1921) experimented with effects of running and walking up and downstairs on heart rate. From their experimentation the Two-point Pulse Test was devised. Their purpose was to design a simple test of functional heart efficiency suitable for testing army recruits and life insurance and pension applicants. In 1922, Hambley, Hunt, Parker, Pembrey, and Warner revised this method. A 13 inch step was used with stepping frequencies from 6 to 36 steps/min. The researchers concluded that heart rate after exercise was the best single indicator of physical condition. Later, Campbell (1925) modified the technique designed by Hunt and Prembrey (1921). Using a 13 inch step and 28 steps/min frequency, he tested 80 medical students of varying fitness levels. Testing lasted 3 minutes. He concluded that this modified step test was acceptable for distinquishing fitness levels between unfit, average, and athletic men. Tuttle (1931) introduced a modofication of Hambley and Hunt's Two-Point Pulse Ratio test to the United States. He found the heart rate increase to be directly proportional to the increase in work. He reported a correlation of 0.93 for 124 pulse-ratio tests on ten subjects. A pre-determined standard heart rate of 2.5 was utilized for comparison with subjects' heart rate results. This test became known as the Pulse Ratio Test.

Probably the best know and most often used step test was developed at the Harvard University by Brouha (1943). Brouha's purpose was to design a technique that would test the cardiovascular fitness of young males. Brouha's premise was that "a satisfactory estimate of a man's fitness can be obtained by exposing him to a standard exercise that no one can perform in a 'steady state' for more than a few minutes and taking into account two factors: the length of time he can sustain it and the deceleration of his heart rate after exercise". The factors he utilized to develop this test were: a constant rate of movement proportional to body weight, movement that required no unusual skill, and exercise sufficient to put the cardiovascular and respiratory systems under stress by involving large muscle groups. The Harvard Step Test utilized a 20 inch bench, stepping frequency of 30 cycles per minute, and duration of 5 minutes or until exhaustion. Recovery heart rate was used to determine fitness levels. The recovery pulse was counted for three 30 second intervals after work was completed. This test has been modified by several researchers to fit different populations: girls and women

(Skubic and Hodgkins, 1963), women (Sloan, 1959), college age women (McArdle et al., 1972), and college age men (Katch et al., 1977).

DeVries and Klafs (1965) were the first investigators to validate the Harvard Step Test with a maximal criterion measure. The purpose of their research was to evaluate six submaximal tests commonly used to predict maximal physical work capacity. A modification of the bicycle ergometer method described by Taylor, Buskirk, and Henschel was used for the maximal testing. The subjects were 16 physically active but not highly trained male Physical Education majors aged 20 to 26 years. The correlation between the bicycle ergometer procedure and the Harvard Step Test when onrmalized for weight was 0.766; significance was recorded at the $p<.01$ level. Pearson correlations are considered to be more meaningful when the group tested is homogenous. DeVries and Klafs concluded that for active college aged men VO_2max can be predicted with a reasonable error from the Harvard Step Test.

In 1966, Kasch, Phillips, Ross, Carter, and Boyer designed a maximal step test using male and female subjects. The subjects were two females aged 7 and 42 years and ten males aged 15 to 57 years. There was great disparity between the subjects in regards to training activities. The test procedure required sudjects to step up and down on 12 inch bench with an initial step rate of 24 steps per minute. Stepping rate was increased every 3 to 6 minutes until exhaustion. Step results were correlated with VO_2max obtain using a treadmill maximal test (Robinson protocol). Treadmill VO_2max ranged from 40.2 to 54.1 ml/kg/min with a mean and standard deviation of 46.25 and 4.5 ml/kg/min respectively. Step VO_2max values were 37.2 to 56.0 ml/kg/min, with a mean of 48.01 and standard deviation of 5.1 ml/kg/min. A correlation of $r = 0.95$ was found which led investigators to conclude that this protocol would be useful in obtaining estimates of maximal oxygen uptake.

In 1989, Golding et al. modified the technique designed by Kasch and Boyer (1966). The YMCA step test uses a single-stage work period that requires an individual to step up and down on a 12 inch bench at a rate of 24 steps per minute for three minutes. An individual's level of fitness is determined by recovery heart rate. Heart rate is measured for the first minute after cessation of work. The 1-minute recovery heart rate is the score for the test and compared to norms to estimate level of fitness and VO_2max.

Three minute step test

Validation and reliability of three minute step test

In 1989, Golding present validity of the three minute step test (r = 0.92) for all subjects. The YMCA reports normative databases based on over 125,000 subjects, but no data exists to support the findings (Golding, 1989).

In 1998, Donahue and Judy Investigate whether the 3 minute step test was more effective indicator of cardiorespiratory fitness for 34 female students (age 18-23 years) than the 1.5 mile run test. Results of this study showed correlations of 0.70 for step test and 0.58 for 1.5 mile run test. The 3 minute step test was more highly correlated than the 1.5 mile run test.

In 2003, Santo and Golding examined the relationship between measured VO_2max and heart beat counts obtained from the modified YMCA 3 minute step test, Heart beat counts at 15s and 1 min were significant in predicting VO_2max and resulted in similar r and SEE values from 15s (r = 0.73, SEE = 6.9 ml/kg/min) and 1 min (r = 0.75, SEE = 8.76 ml/kg/min). There was no significant different between using a 15s and 1 min heart beat counts.

Strength and weakness

The 3 minute step test can be used very successfully in mass-testing situations. This is an excellent cardiorespiratory test not only for mass testing but it inexpensive, also as a self-test or as an addition to a test battery and requires no electricity or calibration. The three minute step test not suitable who have balance problem. The error of estimation VO_2max induce the steps in time with the beat, stands erect on the top step, and places both feet flat on the ground at the end of each stepping cycle.

Other step tests

The Harvard Step Test utilized a 20 inch bench, stepping frequency of 30 cycles per minute, and duration of 5 minute or until exhaustion. Recovery heart rate was used to determine fitness levels. The recovery pulse was counted for three 30 second intervals after work was completed. In 1954, Irma R. Modified Harvard step test for the evaluation of physical fitness. They found a greater correlation for 16% adjusted bench height when compared with the original Harvard Step Test.

In 1976, Baily developed the Canadian Aerobic Fitness Test and reported middle to high correlation (r = 0.79) with GXT. But it not familiar for the international submaximal test and lower correlation with GXT than 3 min step test.

In 2004, Kevin and Alison examined the relationship between measured VO_2max and the Chester Step Test. They used a bench height of 30 cm. step rate 15 steps per minute for 2 minutes and then increased to 20 steps per minute for a further 2 minutes. The maximum test duration was 10 minutes. The results revealed a high correlation (r = 0.92) between the VO_2max values SEE of 3.9 ml/kg/min. Thus, the Chester Step Test was shown to be a valid test for the estimation of aerobic capacity within this sample group.

In 2003, Satipati et.al., Examined the difference between the mean VO_2max values directly measured and indirectly Queen's College Step Test were significant correlation (r = 0.95, p< 0.001) in young Indian men. The Queen's College Step Test used a bench height of 16.25 inches with step rate 24 step per minute, total time duration 3 minutes.

Factors affecting step test results

Step height : In 1989, Golding developed the Kasch Recovery Heart Rate Step Test by adjusting step height from 11.25 inches to 12 inches. This modification resulted in a greater correlation value. Baily (1976) developed the Harvard Step Test and found that leg length influenced the results from step test. Adjusting the bench height to the participant's stature considers the biomechanical efficiency of stepping in participants with different leg lengths (Santo and Lawrence,2003). In 1978, Shahnawaz et al. concluded that adjusting the bench height to the participant's leg length could enhance the validity of any type of step test.

Step rate : Step test protocols have varied of step rate between 22 – 30 steps per min. (Queen's college step test used 22 steps per min for women and 24 steps per min for men. Three minute step test and home step test used 24 steps per min, while the rate of 30 steps per min was used in Harvard step test. Culpepper and Francis (1987) report different correlation for different step frequencies. Francis and Brasher (1992) also reported similar values of $r = 0.77,0.81$, and 0.81 for stepping frequencies of 22, 26, and 30 steps per min. Additionally, the subject's ability to maintain the correct stepping tempo and technique is important. The tester should ensure that the subject maintained the correct stepping rate, since deviations from these pre-set rhythms affect the exercise oxygen cost (Sykes and Roberts, 2004). Most subjects had no difficulty in keeping to the metronome beat, a smaller number need closes monitoring and the tester should also verbally emphasised the correct rhythm.

Time duration : Step test protocols have varied of time duration between 3 – 10 minutes. Three minute step test, Queen's college step test, and home step test used 3 minutes, while Harvard step test used a 5 minutes test duration. The longest duration of 10 minutes belonged to the Chester step test. Each protocol provides different correlation.

Body weight : Body weight of subject is the workload of step test (Irma Rhyming, 1954). Individulas with different body composition may impact the result obtained during submaximal exercise testing. Thus, individual difference in body weight may limit the prediction of VO_2max (Santo and Lawrence,2003).

Heart rate : Accurate reading and recording of heart rate are necessary. It was important for the tester to carefully monitor the heart rate to ensure that the correct counting was recorded (Sykes and Roberts, 2004). Anxiety can elevate heart rate and can reduce rate of recovery heart rate (Park et al., 1997). Thus, the ability of the subject to control oneself's anxiety may also affect the test result.

Submaximal cycle ergometer

Mechanical and electronically braked cycle ergometers are used to measure VO_2max. Exercise intensity on a mechanically braked bike is increased by placing more resistance on the flywheel; increasing pedaling speed; or both. The most common method is to have the subject pedal at a constant rate, usually 50 revolutions per minute, and power output is increased by placing more resistance on the flywheel.

Development

The Astrand-Ryhming cycle ergometer test is a single-stage test lasting 6 minutes. The suggested work rate is based on gender and an individual's fitness status, for age (because maximal HR decreases with age) by multiplying the VO_2max value by the correction factors.

The original Astrand-Ryhming nomogram was introduced in 1954. The original nomogram was developed from 58 subjects (18-30 yr, 27 males, 31 females) who performed a submaximal test on a cycle ergometer and a maximal test on either a treadmill or a cycle ergometer.

Astrand-Ryhming reported a variability of 6.7% (0.023+/-0.059 L/min) for males at a 1200 kgm/min workload and 9.4% (0.010+/-0.051 L/min) for females at a 900 kgm/min. at lower workloads of 900 kgm/min for males and 600 kgm/min for females the variability increase to 10.4% and 14.4%, respectively, when compared to maximal treadmill tests. In 1960, Astrand tested 144 additional subjects (100 males, 44 females), modified the nomogram, and introduced an age correction factor. He determined $r = 0.86$ for males and $r = 0.81$ for females when comparing a submaximal cycle test to a maximal cycle test. The standard error was 10-15%.

In contrast to the single-stage test, Maritz et al. measured HR at a series of submaximal work rates and extrapolated the response to the subject's age-predicted maximal heart rate. This has become one of the most popular assessment techniques to estimate VO_2max, and the YMCA cycle ergometer test is a good example. The YMCA protocol uses two to four, 3-minute stages of continuous exercise. The test is designed to raise the steady-stage HR of the subject to between 110 beats$\cdot$min^{-1} and 85% of the age-predicted maximal HR for at least two consecutive stages. An important point to remember is that two consecutive HR measurements must be obtained within this HR range to predict VO_2max. in the YMCA protocol, each work rate is performed for 3 minutes, and heart rate are recorded during the final 15 to 30 seconds of the second and third minutes. If these heart rates are not within 6 beats$\cdot$min^{-1} of each other, then that work rate is maintained for an additional minute. The heart rate measured during the last minute of each stage is plotted against work rate. The line generated from the plotted points is then extrapolated to age-predicted maximal heart rate, and a perpendicular line is dropped to the x-axis to estimate the work rate that would have been achieved if the person had worked to maximum. VO_2max can be estimated from the maximum work rate. Part of the error involved in estimating VO_2max from submaximal HR responses occurs because the formula (220-age) can provide only an estimate of maximal HR.

YMCA cycle test

Validation and reliability of YMCA cycle test

In 1970, Graan and Grayson performed a comparison study between the Bushmen cycle test and step test. It was found that the Bushmen cycle test gave better submaximal results than step test (Graan and Grayson, 1970).

In 2004, Matthew et. al., cross-validated the YMCA cycle test to predict VO_2max. There was a moderate to high correlation between treadmill VO_2max and predicted VO_2max from the YMCA test ($r = 0.77$, $p < 0.05$, SEE = 8.9 ml/kg/min). There was also a moderate to high correlation between measured VO_2max by cycle and predicted VO_2max from the YMCA test ($r = 0.79$, $p < 0.05$, SEE = 7.6 ml/kg/min) (Matthew et al., 2004). There was a significantly high correlation between treadmill VO_2max and cycle VO_2max ($r = 0.94$, $p < 0.05$). A similar cross-validation analysis inditicated that the YMCA test slightly, but significantly overpredicted treadmill VO_2max in men, whereas in women the mean difference did not differ from zero.

In 2005, John et. al., found that VO_2max estimated from the YMCA cycle test provided a more accurate estimate of VO_2max as compared to the Astrand-Rhyming test.

Consummation, the YMCA cycle test had high correlation when compare with GXT and more accurate estimate of VO_2max than the Astrand-Rhyming.

Strength and weaknesses

The YMCA cycle test is one of the most frequently used submaximal cycle ergometer tests (ACSM, 2005; Golding, 2000). The protocol uses heart rate, which is easy to measure.

Limitations of the test include the YMCA recommened to used Monark cycle (Golding, 1989), the margin of error in the predicted VO_2max values. The protocol can elicit lower extremity discomfort in some people, which may invalidate the results.

Factors effecting cycle test results

Length of pedal : Different lengths of the pedal crank give different mechanical mechanical efficiency. The ordinary length, 18 cm, of the crank suits most people, but some may want a longer and others a shorter crank. When riding uphill a longer crank may be of adventage (Astrand,1954).

Pedal rate : Different pedal rate is a variable to predict VO_2max (Ben et al.,1996). The pedal rate become a more important source of variation when the researcher could not control constant pedal rate for all participants (Beekly et al.,2004).

Seat height and body dimension : Seat height and lower extremity dimension of the body cause a variation of VO_2 due to different in technique or mechanics. Variation in VO_2 can be as much as ± 6 % (McArdle et al.,1991). Seat height was standardized and controlled throughout to minimize position effects on efficiency, and ultimately, HR (Astrand, 1986).

Stage of training : Skill or stage of training can provide a good result in cycle test. In 1978, Hagberg and Schneider presented that cyclists can achieve VO_2max by cycle better than treadmill. Estimated VO_2max from subjects unfamiliar with the mechanics of cycling would be expected to be lower than the true VO_2max (Hagberg and Schneider, 1978).

Anxiety : Anxiety can elevate heart rate, the estimated VO_2max from unusually high heart rate would provide an underestimate of VO_2max (Park et al,1997). Thus, the ability to control oneself's anxiety is an important factor affecting the VO_2max estimation.