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Using heart rate recovery rate to predict vo_2max

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USING HEART RATE RECOVERY RATE TO PREDICT VO_{2max}

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CERTIFICATE OF APPROVAL

MASTER OF SCIENCE THESIS

This is to certify that the Thesis of

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ABSTRACT

The purpose of this study was to determine if the heart rate recovery rate (HrRr) following a maximum exercise test can be used to accurately predict maximum oxygen consumption (VO_{2max}). To that end, 30 subjects (aged 20.6 ± 1.6 years) completed three exercise tests: two maximum treadmill tests and one 20-meter shuttle run. VO_{2max} was measured during one maximum treadmill test via open circuit spirometry. After each test, the subject immediately assumed a supine position, and heart rate was measured immediately and every min thereafter for 5 min. Differences among the HrRr from each test were assessed with a 3 x 6 ANOVA. There was no significant difference noted between the three tests. A stepwise regression was used to develop a prediction equation for VO_{2max} from HrRr at min 1, 2, 3, 4, and 5 post-exercise. Only treadmill speed (r^2 = 0.374, p = 0.000) and shuttle run end speed (r^2 = 0.521, p = 0.000) but not HrRr were moderately good predictors of VO_{2max}. Several factors may have contributed to the inability to predict VO_{2max} from HrRr, such as subject posture following the test and the genetic component. This study also established that headgear used during indirect spirometry has no effect on HR during or after testing. It was also observed that the 20-meter shuttle run test underestimated VO_{2max} by approximately 10 $ml \cdot kg^{-1} \cdot min^{-1}$ in novice subjects running individually. The ACSM metabolic equation for running provided an excellent method for estimating VO_{2max} (r^2 = 0.995). In conclusion, HrRr was not useful for predicting VO_{2max} given the parameters that defined this study.

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DEDICATION

I dedicate this project to everyone that assisted in my achieving this milestone in life.

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Chapter 1

INTRODUCTION

Recovery heart rate has recently gained a lot of attention, as a slow heart rate recovery rate (HrRr) after exercise is a powerful independent predictor of mortality (Cole, Blackstone, Pashkow, Snader, & Laurer, 1999). Accordingly, HrRr provides prognostic information during a treadmill exercise test and it should be considered during test interpretation (Nishime, Cole, Blackstone, & Pashkow, 2000).

There is a good relationship between mortality and endurance capacity (Blair et al., 1996). Therefore, HrRr may also be useful to predict endurance capacity (i.e. VO_{2max}) (Kline et al., 1986). The direct measurement of VO_{2max} is preferred, but the need for special equipment, trained personnel, and a motivated subject frequently lead to the use of a submaximum test from which VO_{2max} is predicted. Many submaximal tests use recovery heart rate following stepping to predict VO_{2max}. The Harvard Step Test, for example, measures heart rate at three 30-second periods post-exercise and yields correlations of 0.55-0.77 with direct measures of VO_{2max} (Brouha, Graybiel, & Heath, 1943; Burke, 1976; DeVries & Klafs, 1965; Glassford, Baycroft, Sedgwick, & MacNab, 1965). Similarly, McArdle and Katch (1983) showed that measuring heart rate every 5 s for 15 s after a step test yields predicted VO_{2max} values for young adults that are highly correlated ($r = 0.72$-0.92) with direct measures of VO_{2max}. Other step tests that used the recovery heart rate have also shown high correlations with direct measures of VO_{2max} (Francis, 1990; Shapiro, Shapiro,& Magazanik , 1976; Tuxworth & Shahnawaz, 1977).

In addition to using HR recovery, exercise scientists have also used the heart rate response to exercise to predict VO_{2max}. In the Rockport walking test (1987), for example, the exercise heart rate during the last minute of each quarter mile was used to predict VO_{2max}, and yielded a high correlation with a direct measure ($r = 0.92$). In addition, single stage walking treadmill tests were also highly correlated ($r = 0.88$ to 0.96) with direct VO_{2max} measures (Ebbeling, Ward, Pulea, Widrick, & Rippe, 1991; George, Vehrs, Allsen, Fellingham, & Fisher, 1993). Likewise, a branching submaximal treadmill test in which the % of age predicted maximum heart rate was used to predict VO_{2max} was also highly correlated ($r = 0.96$) with direct measures of VO_{2max}. As with these aforementioned treadmill tests, the HR measure during cycle ergometery can also be used to estimate VO_{2max} (Astrand & Ryhming, 1954; Golding, Lawrence, Myers, & Clayton, 1989). Therefore, it is clear that HR measures are useful in estimating VO_{2max}.

Whereas the HR response to exercise has been used to predict VO_{2max}, the rate of change in the heart rate recovery has not. Given that HrRr takes into account both maximum heart rate and heart rate recovery, it may be a more robust predictor of VO_{2max} than mere HR recovery. Moreover, since HrRr is an indicator of cardiac neural function, and provides prognostic information, it is wise to routinely measure HrRr with every clinical test. Hence, the primary purpose of the study was to investigate the ability of the HrRr to predict VO_{2max} following a maximal treadmill exercise test.

If HrRr measured in the lab is a good predictor of VO_{2max} then, the need for special equipment (e.g. treadmill & metabolic cart) still persists, thereby potentially limiting the applicability of this procedure. This issue may be resolved with the use of a field test. The second purpose of this study, therefore, was to see if it is possible to accurately predict VO_2max from HrRr following a 20-meter shuttle run test.

Scope of the Problem

This study examined the relationship between the HrRr and directly measured VO_{2max} in college-aged males. In addition, the HrRr measured following a 20-meter shuttle run test was examined to see if it could predict VO_{2max}. The current study is the only one to date to examine the ability of the HrRr to predict VO_{2max}. Showing that HrRr predicts VO_{2max} will increase the prognostic value of HrRr, which is already a good predictor of mortality. If HrRr from the shuttle-run successfully predicts VO_{2max}, one could simply determine this variable from a simple running test in the gym with no need for a treadmill or other expensive equipment.

Statement of the Problem

The purpose of this study was to identify if VO_{2max} could be predicted from a simple recovery heart rate measure following maximal running exercise. Accordingly, data collected from a heart rate monitor and metabolic cart were analyzed in attempt to answer the following question: Can HrRr predict VO_{2max} after a treadmill test and can this result be duplicated using a 20-meter shuttle run test?

Hypothesis

The following directional hypotheses were made:

1. The HrRr can be used to predict VO_{2max} in college-aged men.
2. The HrRr following a maximum 20-meter shuttle run test can be used to predict VO_{2max} as accurately as the lab test.

Assumptions of the Study

The following assumptions were made:

1. HrRr provides an indication of parasympathetic function, which improves with cardiovascular training level.
2. The subjects gave maximal effort during all exercise tests.
3. Rating of perceived exertion (RPE) is a good estimator of the level of subject motivation during exercise.

Definition of Terms

The following definitions clarify the meaning of terms used:

1. HrRr - the rate at which the heart recovers following maximum exercise at a certain point in time (e.g., 1-min post-test).
2. VO_{2max} - the maximum oxygen uptake measured during maximal exercise and expressed in either liters·min^{-1} or ml·kg^{-1}·min^{-1}.
3. Trained participants - subjects that have participated in regular physical endurance exercise (at least three times a week for a period of at least 20 min per session) for a minimum of past six months.
4. Untrained participants - subjects that have not participated in regular endurance exercise in the past six months.
5. Treadmill test 1 - the VO_{2max} test conducted on the treadmill using the metabolic cart in which VO_{2max}, RPE, and HR were recorded.
6. Treadmill test 2 - the maximum exercise test conducted on the treadmill in which only the HR and RPE were measured and recorded.

7. Maximum HR - the maximum heart rate measured immediately after exercise with the subject in the supine position.

Delimitations

The following were the delimitations of this study:

1. This study involved only male subjects between the ages of 18 and 25 years.
2. The study used only maximum running exercise tests either on the treadmill or during a 20-meter shuttle run test.
3. The HrRr was only measured at 1, 2, 3, 4, and 5 minute time intervals post-exercise.
4. No cool down period was allowed during the HrRr measurement.
5. The subject lay supine during the HrRr measurement.

Limitations

The following were the limitations of this study:

1. The results of this study may only be applicable to college-age males between the ages of 18 and 25.
2. The results are for running exercise and may not be generalizable to other forms of exercise.
3. The results may not be generalizable to other HrRr time points during the post-exercise period.
4. The results may not be generalizable if a cool down period is employed or a different subject position is used post-exercise.

Chapter 2

REVIEW OF LITERATURE

In this chapter the literature related to the study is discussed. The following topics are addressed: (a) Mortality and HrRr, (b) Cardiovascular fitness and mortality, (c) Cardiovascular physiology in exercise recovery, (d) Predicting VO_{2max}, (e) Relevant factors that may affect heart rate, and (f) Summary.

Mortality and HrRr

The fall in heart rate immediately after exercise is considered to be a function of the reactivation of the parasympathetic nervous system. Because increased vagal activity has been associated with a reduction in the risk of death (Schwartz, La Rovere, & Vanoli, 1992), it was hypothesized by Cole et al. (1999) that the HrRr immediately after exercise might be an important prognostic marker. This hypothesis was tested on a group of subjects free from cardiovascular disease (Cole et al.,1999). The patients underwent a symptom-limited maximum exercise test in which HrRr was measured. Abnormal HrRr was defined as a recovery of ≤ 12 bpm from peak HR in the first minute of the cool down period at 1.5 miles an hour and on 2.5% grade. A six-year follow up showed that HrRr was a good predictor of mortality, as the majority (56%) of the patients who died had an abnormally low HrRr. Data also showed that HrRr was a predictor of mortality in a number of subgroups including the elderly, women, patients with normal chronotropic response during exercise, and those taking beta-blockers.

In a follow up study, the prognostic value of HrRr after submaximal exercise was examined in subjects (N=8681) that had no evidence of cardiovascular disease (Cole, Foody, Blackstone, & Lauer, 2000). In this study, HrRr was defined as the change from peak heart rate to that measured two minutes later in the seated position. A HrRr ≤ 42 beats in 2 min was the cutoff for poor recovery. During a 12-year follow up, 325 died (6.2%) which included 10% of subjects with abnormal HrRr and 4% of subjects with normal HrRr. These data also showed that abnormal HrRr was a good predictor of mortality. Nishime et al. (2000) compared the ability of the Duke treadmill score and HrRr after a symptom limited exercise test to predict mortality in 9454 patients referred for exercise ECG. Similar to the study done by Cole et al. (1999), abnormal HrRr was defined as a recovery of 12 beats from the peak exercise heart rate during a cool down period of at least 2 minutes at 1.5 miles an hour and a 2.5% grade. Abnormal HrRr and treadmill scores were found in 20% and 21% of patients respectively. During a 5 year follow-up period, there were 312 deaths with 148 of these deaths predicted by the HrRr. Therefore, HrRr had a similar prognostic value as the Duke treadmill score. It was suggested that combining these scores would enhance their predictive value, as patients that had an intermediate to poor Duke score were found to have even higher mortality if abnormal HrRr was also present. These data were consistent with other data with one exception: HrRr was not predictive of mortality among patients on beta-blockers as was indicated by Cole et al. (1999).

In a study conducted by Watanabe, Thamilarasan, Blackstone, Thomas, & Laver (2001), HrRr was measured immediately after exercise in 5438 patients using supine recovery with no cool down period. This procedure allowed for an echocardiogram, which requires a supine position after exercise. The purpose of this study was to determine whether the predictive value of HrRr persisted after considering estimated left ventricular ejection fraction. Abnormal HrRr was defined as a recovery of ≤ 18 bpm; and was seen in 805 patients, of whom 72 died during the 3 year follow up. In this study cohort, 9% of subjects with abnormal HrRr died during follow up versus 2% that had normal HrRr. To conclude, all studies showed that slow HrRr after exercise is a robust independent predictor of mortality suggesting that this measurement should be made routinely during exercise test interpretation.

Cardiorespiratory Fitenss and Mortality

Blair et al. (1996) examined the relationship of fitness to cardiovascular disease and to other predictors such as body mass index, blood pressure, blood cholesterol levels, and smoking. The study included 25341 men and 7080 women (aged 20 to 88 years). VO_{2max} was predicted from a submaximal treadmill test in which the subject reached at least 85% of their age predicted maximal HR. The tests were conducted in 1970 and follow up continued until 1989. During this period, 601 men and 89 women died. Low fitness, elevated systolic blood pressure, elevated serum cholesterol, cigarette smoking, and poor general health were associated with cardiovascular disease and mortality in men. Only low fitness and cigarette smoking were associated with cardiovascular disease and mortality in women. Men with high fitness and two or three other predictors have a 15% lower death rate than unfit counterparts, while high fitness women with two or three other predictors had a 50% lower death rate than unfit counterparts. It was concluded that moderate and high levels of cardiorespiratory fitness provides protection against combinations of other mortality predictors.

Cardiovascular Physiology in Exercise Recovery

It is well known that endurance training induces resting bradycardia (Blomqvist & Satlin, 1983). Data show that resting bradycardia is due both to an increase in parasympathetic tone and a decrease in sympathetic tone (Blomqvist & Satlin, 1983; Dixon, Kamath, McCartney, & Fallen, 1992; Goldsmith, Bigger, Steinman, & Fleiss, 1992). The effect of age and training status on heart rate recovery after peak exercise has been studied by Darr et al. (1988). They measured HR every 15 s during the first min and every 30 s thereafter for 7 min. It was concluded that trained subjects in both younger and older age groups showed more rapid heart rate recovery than untrained counterparts at similar workloads.

Arai et al. (1989) stated that immediate post-exercise HR recovery is mainly attributed to vagal activation. If adaptation in cardiac autonomic modulation is a major contributing factor in the reduction of resting and post-exercise HR after endurance training, then changes in cardiac autonomic nervous system (ANS) modulation during training periods should correspond to changes in HR reduction (Yamamoto, Miyachi, Saitoh, Yoshioka, & Onodera, 2001). This hypothesis was tested on a group of healthy male college students (N = 12), seven of which underwent intense six week cycle-endurance training. The remaining five served as a control group. Heart rate and indices of ANS variability were measured five times for the training group (before training, and on the 4th, 7th, 28th, and 42nd days of training) and four times (before training, and on the 7th, 28th, and 42nd days) for the control group. For the training group, resting heart rate was measured prior to each training session for a period of 5 min, whereas post-exercise HR was measured for 5 min at the 10th and 20th minutes of recovery. Decreased HR and increased indices of parasympathetic functions were seen both at rest and immediately post-exercise in the trained subjects. Endurance training resulted in no significant changes in any parameters measured during the post-exercise recovery periods from the

7^{th} to 42^{nd} day of training period despite the continued changes that occurred in the resting measures during that period. It was concluded that adaptability of the cardiac autonomic control to endurance training occurs sooner in the immediate post-exercise recovery period than at rest. The amount of change in HR during the post-exercise period for the first seven days of the training program corresponded to the adaptations in resting HR that occurred over 42 days.

Predicting VO_{2max}

VO_{2max} is considered the most accurate tool for measuring cardiorespiratory physical fitness (Kline et al., 1986). Although direct measurement during a maximal exercise test is best, it requires expensive and not widely available equipment. In addition, highly trained personnel are needed to operate the equipment. For these reasons, researchers have developed different methods for estimating VO_{2max}. In the following sections the various methods that have been used to predict VO_{2max} will be discussed.

Step Tests

The Harvard Step Test was designed in 1943 as a single-stage step test that required the subject to step up and down a 20-inch bench at a rate of 30 steps per min for 5 min or until exhaustion. Heart rate recovery was measured three times for 30 s at 1, 2, and 3 min post-exercise. The score was obtained by dividing 100 x the duration of exercise in seconds by 2 x the sum of pulse counts in recovery. Correlations between the Harvard Step Test score and actual measurements of VO_{2max} were found to be between 0.55 and 0.77 indicating a moderate correlation (Smith, Pethybridge, & Duggan, 1988). The Harvard Step Test has limitations, however, such as the uncontrolled level of exertion for untrained and older subjects (Francis, 1987). Moreover, the test often stresses leg endurance more than the cardiovascular endurance in shorter individuals (Francis, 1987). In addition, there were reports of soreness in the calf muscles and Achilles tendon, considerable local fatigue, pain in the knee joints, and soreness throughout the thigh and groin that persisted for days in a group of marathoners that took the test (Smith et al., 1988). Other groups reported discomfort in the quadricep muscle group (Smith et al., 1988). Many researchers have modified one or more aspects of the Harvard Step test in an attempt to improve its application.

Shapiro et al. (1976), for example, had the subject step up and down a 12.8-inch step at the rate of 25 beats per minute for 6 min. They counted the number of heart beats for 10 s starting 5 s post-exercise with 23 beats or more indicating poor fitness and 18 beats or less indicating excellent fitness. The recovery heart rate between the 5th and 15th seconds after the end of their step test was used to correlate with VO_{2max}. Although they found a high r-value of 0.80, their results were flawed because they matched step test results against a submaximal estimation of VO_2 rather than a maximal and direct measurement of VO_{2max}.

Tuxworth and Shahnawaz (1977) decreased used a step height of 15.7 inches and a step rate of 25 steps per minute for 5 min. Recovery heart rate was recorded as it was in the Harvard Step test and the HR data were then inserted into an equation that included the subject's weight. The score of the test correlated highly (r = 0.88) with the VO_{2max} measured on the cycle ergometer.

A simple modification was made by Banerjee and Chatterje (1983) who only lowered step height to 18.11 inches. In a group of Indian subjects, they found a 0.70 correlation with the VO_{2max} measured on a treadmill. Another step test that used the recovery heart rate as an indicator of VO_{2max} was developed by McArdle and Katch (1983). They had subjects step for 3 min on a 16.5 in step at a rate of 24 and 22 steps per min for young males and females, respectively. The recovery heart rate was measured for 15 s starting 5 s after the end of the test. The recovery heart rate in beats per minute was used in a formula (a different formula was used for men and women) to estimate VO_{2max}. The correlation to open circuit spirometry was 0.72 and 0.92 for men and women, respectively.

A test adjusted for subject height was introduced by Francis (1990) who set step height so that 73.3 degrees of hip flexion would occur during stepping. In this test, subjects completed 26 steps per min for 3 min. The recovery heart rate was determined for 15 s starting 5 s after the end of the test. This test had a 0.80 correlation with directly measured VO_2. Even though this height-adjusted, single-stage step test predicted VO_{2max} in a clinical setting, it is inconvenient, as one has to calculate the results (Francis, 1990).

Field Tests

The heart rate response to exercise was used as an indicator of physical fitness in the Rockport Walking Test (Kline et al., 1986). In this test, subjects walked 1 mile around a track and their HR was measured during the last minute of each quarter mile. Generalized and gender-specific equations were developed using a cross-validation analysis. Reliability coefficients of $r = 0.92$ and $r = 0.88$ were found for predicting VO_{2max} ($l \cdot min^{-1}$ and $ml \cdot kg^{-1} \cdot min^{-1}$ equations, respectively) which compared favorably with other available equations. Since the validation and cross-validation were homogeneous and relatively large, the data were robust (Kline et al., 1986). In addition, the equations are valid over a wide age range. The test can be completed by elderly people, which increases the applicability of the test relative to others that require subjects to run (Kline et al., 1986).

The 12-minute Run Test is one of the most popular field tests. In this test, subjects run for a period of 12 min and the distance covered is correlated with VO_{2max} (Cooper, 1968). This test yielded correlations ranging from $r = 0.13$ to $r = 0.90$ (Burke, 1976; Cooper, 1968; Jessup, Tolson, and Terry, 1974). Jessup et al.(1974) attributed low r values ($r = 0.13$ to $r = 0.34$), relative to Cooper ($r = 0.90$), to the narrow age range and VO_{2max} of their subjects. Burke (1976) stressed that motivation played an important role in good results. Cooper (1968) discussed the importance of subject motivation in the 12 minute run test if it is to serve as an accurate predictor of VO_{2max}. The results found by Burke (1976) tended to agree, as the subjects were well motivated.

Another commonly used field test is a timed 1.5 mile run. Myles, Brown, and Pope (1980) investigated the ability of this test to measure cardiorespiratory fitness in the Canadian Forces. They compared the 1.5-mile run to direct VO_{2max} measurements and examined two alternatives, which were a three-mile run and a submaximal bicycle ergometer test. Both 1.5 mile and three-mile run correlated well with the measured VO_{2max} having r-values of - 0.88 and - 0.83, respectively. It was concluded that the 1.5 mile timed run is a good measure of cardiorespiratory fitness. The authors also stressed that motivation is a key in achieving good results with such tests as was stated earlier by Cooper (1968). Aspiration toward a permanent career in the Canadian military was a key motivational factor in this study. It was also stated that lack of motivation was the reason why several studies have found poor correlations between test results and direct measurements of VO_{2max}. McNaughton, Hill, and Cooley (1998) compared the 1.5 mile run, Cooper's 12-minute run, a progressive shuttle test, and a submaximal treadmill test with direct measurements of VO_{2max} using a treadmill protocol in a group of active, untrained college students. Cooper's 12 minute run test had the strongest correlation with the actual measurement ($r = 0.87$) with the 1.5 mile run test reported to come in second although it showed the same correlation ($r = 0.87$), and then the shuttle run ($r = 0.82$). The weakest correlation was found with the (recently developed) submaximal treadmill test. The authors explained the strong correlation with the field tests is due to the fact that the subjects were motivated and had the ability to gauge intensity of performance as they all had an active lifestyle. Whether the field test is a set time measuring distance or a set distance measuring time, it appears motivation is a key factor if good results are to be anticipated from these running field tests.

Cycle Ergometer Tests

The Astrand-Ryhming cycle ergometer test (1954) is a well known submaximal test that is commonly used to predict VO_{2max}. The subject pedals for 6 min at 50 rpm at a work rate that is based on gender and fitness level. The subject's heart rate is measured at the 5^{th} and 6^{th} min. The two heart rates are averaged and used to estimate VO_{2max} with a nomogram. If the two heart rates are not within five beats of each other then the subject continues to pedal for another two to three min until a steady state HR is reached. The HR value is then adjusted for age by multiplying it with a predetermined correction factor. Astrand and Ryhming (1954) compared the estimated and true values for VO_{2max}, mean difference ranged from 0.023 – 0.043 and 0.010 – 0.137 $l \cdot min^{-1}$ for males and females, respectively.

Davies (1968) re-examined the relationship between heart rate and VO_2 on 80 subjects aged 20-50 using prediction nomograms. He found that there was a bias toward underestimation of VO_{2max} with heart rates greater than 120 bpm and less than 150 bpm. Using the Astrand nomogram under these conditions resulted in a predicted VO_{2max} value within 1.22 $l \cdot min^{-1}$ of the observed value. Thus for a predicted value of 3.5 $l \cdot min^{-1}$ the true VO_{2max} may lie between 2.89 to 4.11 $l \cdot min^{-1}$, which is a very raw estimate of VO_{2max}. It was suggested that the estimates would be improved significantly if the heart rates attained were greater than 165 bpm, if two heart rate measures were between 130-170 bpm, or if the calculated regression of the VO_2 on heart frequency was used. With these modifications, the 5% probability limits an estimated VO_{2max} of 3.5 $l \cdot min^{-1}$ would lie between actual values of 3.2 to 3.8 $l \cdot min^{-1}$, a much better estimate.

The YMCA Submaximal Cycle Test which is described in a text by Golding et al. (1989) is conceptually similar to the Astrand-Ryhming cycle ergometer test, but it uses multi-stage protocol. The subject starts pedaling at 50 rpm with a 0.5 kg resistance. Each stage of the test is three minutes. The heart rate is taken in the last 15-30 seconds of the second and third min (it is measured for 10 seconds and then multiplied by six). The subject progresses to the next stage only if a steady state is reached (the two heart rate measures are less than six beats apart). The resistance in the next stage is determined by the heart rate response of the subject in the previous stage. The procedure is repeated until steady state heart rates are reached that lie between 110 to 150 bpm in two different stages. The results of the two final heart rates that are in this range are plotted on a nomogram to estimate VO_{2max}. For the test to be valid, the two heart rates used must be greater than 110 bpm and less than 85% of the individual's age-predicted maximal heart rate.

Lockwood, Yoder, and Deuster (1997) compared the U.S Air Force cycle ergometry test (a modified Astrand – Rhyming submaximal test) to the progressive cycle ergometry test in a group of duty personnel consisting of 109 male and 71 females aged 20 to 59. The subjects conducted a maximum treadmill test, the progressive cycle ergometer test, and three Air Force ergometer tests. Overall, 80.9% of the subjects passed the treadmill test (were shown to be fit) compared with 56.4% for the Air Force test. The Air Force test underestimated VO_{2max} by an average of 6.5± 0.8 $ml \cdot kg^{-1}$. Coefficient of variation for the three Air Force tests was 13.1%. One single Air Force test was shown to be unreliable. The intraclass correlation coefficient for the reliability of a single test was 0.26. The estimate of the reliability of the mean of the three tests was significantly better but less than desirable ($r = 0.61$). Concerning the progressive cycle ergometer test, it had a good predictability but had a poor sensitivity, as only 23% had a predicted VO_{2max} within 5% of the measured values. It was concluded submaximal cycle ergometer tests should be interpreted with caution.

Treadmill Tests

Although maximum treadmill tests are well known, Ebbeling et al. (1991) stated that no submaximal treadmill tests that estimate VO_{2max} have been developed. They cross validated a new test on 77 males and 89 females of various ages and fitness levels. A single-stage, submaximal treadmill-walking test was developed, from which an equation predicting VO_{2max} was derived. The test consisted of three, four-minute submaximal stages (0, 5, and 10% grade) at a constant walking pace of 2.0, 3.0, 4.0 or 4.5 mph. The subjects were divided into two groups, an estimation group (n=118) and a cross-validation group (n=22). Data from the first group were used to develop the equation using multiple regression. The second group was used to cross-validate the model. Finally an equation using the gender, speed, heart rate, and speed x age was developed. It was reported that the estimated VO_{2max} correlated highly ($r = 0.93$ and $r = 0.96$ for males and females, respectively) with observed measures. Therefore, VO_{2max} could be estimated from a walking treadmill test.

George, Vehrs, Allsen, Fellingham and Fisher (1993) also stated that no submaximal treadmill running test to estimate VO_{2max} existed and the researchers designed and tested a submaximal treadmill test on a group of 129 subjects (84 males, 45 females) aged 18 to 29 years. The treadmill-jogging test required subjects to sustain a submaximal jogging pace until a steady state HR was achieved. HR was measured every 30 s and was considered steady when two consecutive measures differed by less than or equal to three bpm after at least three minutes of jogging at a constant speed. Steady state HR was restricted to less than or equal to 180 bpm. The treadmill speed was controlled by the test administrator who manipulated it until a comfortable jogging pace was achieved. Maximum speed was less than or equal to 7.5 mph for males and 6.5 mph for females. A regression equation was developed using gender, body mass, speed, and heart rate as variables. The adjusted r-values and SEE between directly measured and estimated relative VO_{2max} data resulted in a $r_{adj} = 0.88$ and SEE = 3.1 $ml \cdot kg^{-1} \cdot min^{-1}$. Correspondent absolute VO_{2max} data resulted in a $r_{adj} = 0.94$ and SEE = 0.22 $l \cdot min^{-1}$. They concluded that the developed test provides a valid and convenient method for estimating VO_{2max} for individuals aged 18 to 29 years.

Swank et al. (2001) developed a branching submaximal treadmill test to predict VO_{2max}. They modified an earlier test by Town and Golding (1977) who used a three stage branching protocol and percent grade to change stages. Swank et al. modified the Town and Golding protocol first by changing the speed for two branches of the protocol and changes in percent of grade were added as a means of increasing the workload. Second, a percent of the age-predicted maximum heart rate was used to determine the subsequent workload rather than absolute HR values. They stated that this modification would ensure that the subjects are physically exhausted to the same relative extent independent of age. The subjects started walking at 2.7 mph and 2% grade then progressed to the next stage depending on the heart rate response. Less than 60%, from 60 – 70%, and greater than 70% of age-predicted maximum heart rate in the first stage progressed to 2.7 mph at 5.5% grade, 3.2 mph at 6.0% grade and 3.7 mph at 6.5% grade, respectively. If by the second workload the HR was less than 110 bpm, a fourth workload was added and if the HR was 90% or more of the age predicted maximum heart rate by the end of the second stage, the test was terminated. A regression equation including % of age-predicted maximum HR, speed, grade at stage three and age-predicted maximum heart rate being the variables was established and yielded a strong correlation ($r = 0.96$) between estimated and actual VO_{2max}. Cross-validation indicated validity of the model developed.

The validity of the ACSM prediction equation was evaluated by Foster et al. (1996). Their study included seventy subjects (44.6 ± 12.5 years) varying from debilitated patients to competitive athletes. One test was conducted in which subjects ran or walked to exhaustion on the treadmill. At the end of each stage (every minute) the speed was increased by 0.2 to 0.5 mph and grade by 2 to 5%. The amount of change was determined by the individual conducting the test following subject consultation. VO_{2max} was measured using open-circuit spirometry and was also estimated by the ASCM prediction equations. If the subject walked during the last stage the equation used was $VO_2 = 3.5 + (0.1 \times \text{velocity } (m \cdot sec^{-1}) + (\text{velocity} \times \text{grade} \times 1.8)$, if the subject ran during the last stage the equation used was $VO_2 = 3.5 + (0.2 \times \text{velocity } (m \cdot sec^{-1})) + (\text{velocity} \times \text{grade} \times 0.9)$. The relationship between measured and predicted values was well described by a linear regression equation ($r^2 = 0.995$). It was concluded that the ACSM prediction equations predicts VO_{2max} well, even when a specific testing protocol is abandoned.

<u>Shuttle-Run Test</u>

Leger and Lambert (1982) developed the 20-meter shuttle-run test to have a valid, reliable, safe, and inexpensive test that predicts VO_{2max} well and which can be efficiently administered to a large group. To achieve this goal, four series of tests were conducted to standardize a protocol and make sure the test was reproducible. The first series was conducted on 25 adult (23.8 ± 6.0 years) subjects (13 males, 12 females). The subjects underwent a maximum inclined walking treadmill test (Balke protocol) where direct measurement of VO_{2max} took place and two 20-meter shuttle-run tests on different surfaces (rubber floor and vinyl-asbestos). The shuttle-run protocol had the subjects start running between two points (20 meters apart) at a rate of 7.5 $km \cdot h^{-1}$ with rate increased by 0.5 $km \cdot h^{-1}$ every 2 minutes. The pace was set with audio signals (beep) emitted at specific frequencies using a prerecorded tape. Rate was increased until the subject was unable to keep the pace or felt they could not complete the stage. A strong positive correlation was found between the end running speed and VO_{2max} ($r = 0.93$). No difference was found when comparing genders or floor surfaces. Additional subjects (N = 66) performed the experimental 20-meter shuttle run test on a vinyl-asbestos floor in the second series and were added to series. The purpose of the second series was to obtain a larger sample size. A regression equation was obtained using the final speed and correlation of 0.84 and a standard error of the estimate of 5.4 $ml \cdot kg^{-1} \cdot min^{-1}$ were found. The third series was used to compare the test to a multistage running track test. The subjects (N=70) ran the 20-meter shuttle run test and a multistage running track test (Leger and Boucher, 1980). Only the predicted VO_{2max} scores from the shuttle run and track tests were compared. The correlation was $r = 0.923$ and standard error of the estimate was 2.63 $ml \cdot kg^{-1} \cdot min^{-1}$. Although the shuttle-run test yielded significantly lower values statistically, these values were not considered physiologically significant. In the fourth series of testing, 50 subjects (27 males, 23 females) ran two shuttle run tests one week apart to assess the reproducibility of the test. It was shown that the 20-meter shuttle run test was highly reproducible ($r = 0.975$). It was concluded that the 20-meter shuttle run test is valid and reliable in predicting VO_{2max} in males and females on most surfaces.

Leger, Mercier, Gadoury, and Lambert (1988) stated that the two-minute stages for the 20-meter shuttle-run test were psychologically boring for children, so the authors decided to design a 1-minute stage version of the 20-meter shuttle-run test and to validate it with children and adults. The subjects ran at a starting speed of 8.5 $km \cdot h^{-1}$ and the speed was increased by 0.5 $km \cdot h^{-1}$ every minute. A correlation of $r = 0.90$ and $r = 0.71$ was found between the end speed and directly measured VO_{2max} in adults and children, respectively. The test was found to be reliable on repeated trials with $r = 0.95$ and $r = 0.89$ for adults and children, respectively.

The validity of the 20-meter shuttle run test was reexamined by Ramsbottom, Brewer, and Williams (1988). Seventy-four volunteers (aged 19 to 36 years) ran a 20-meter shuttle-run, a 5 km time trial, and a maximal treadmill test (to directly measure VO_{2max}). Shuttle run performance was determined as the final running speed and VO_{2max} was predicted from the regression equation introduced by Leger and Lambert (1982). Predicated VO_{2max} from the shuttle run and the 5 km run time had a strong correlation with direct measurements of VO_{2max} ($r = 0.93$ & $r = -0.94$ respectively). Although both tests yielded similar correlations, there are many advantages to a shuttle-run with constant environmental conditions, a graded physiological response, and the absence of need for judgment of pace. The established correlations are similar to those of the two minute stage shuttle-run, thus, one minute stages are preferable as the test time is cut by half. Leger and Gadoury (1989) conducted a similar study assessing the validity of the 20-meter shuttle run test with 1-minute stages. However, in this study the speed was increased from 8.5 $km \cdot h^{-1}$ at a rate of 1 $km \cdot h^{-1}$ every minute. Again the 20-meter shuttle run test was found to have a high correlation ($r = 0.90$) with measures of VO_{2max} leading to the conclusion that it was a valid method of estimating VO_{2max}.

Relevant Factors that May Affect Heart Rate

VO_2 Breathing Apparatus and Heart Rate

The effect of the breathing apparatus (i.e., mouth piece and breathing valve) typically used to measure VO_2 on heart rate is not well studied. Ward, Wasserman, Davis & Whipp (1989) studied how a nose clip and a standard rubber mouthpiece attached to a low resistance, low dead space turbine volume-sensor affects arterial blood gases and acid base balance status in subjects during exercise. Although the effect on the heart rate was not the main purpose of the study, the heart rate was recorded. They reported that there was no effect on heart rate as the mean resting HR was 65.6 bpm for both unencumbered and encumbered measurements. The mean maximum HR was 175.7 bpm and 177.4 bpm with apparatus and without, respectively, during maximum exercise and therefore also was not significantly impacted. No other study has examined the effect of breathing apparatus on HR during exercise.

Temperature and Humidity

Comparison of metabolism, temperature, HR and ventilatory responses to extreme temperatures was studied by Claremont, Nagle, Reddan and Brooks (1975). Eight healthy men with the mean age of 32.2 years cycled for one hour in zero degrees Celsius and another day at 35 degrees Celsius. They reported a significant increase in HR, blood lactate, sweat loss and muscle, rectal and skin temperatures at 35 degrees. In another study, Galloway and Maughan (1997) studied the effect of different ambient temperatures on eight healthy males (age = 25 years) that cycled to exhaustion. The subjects cycled at 4, 11, 21, and 31 degrees Celsius with a RH of 70%. They reported that heart rate was not different at rest but was significantly higher during exercise at 31 degrees than during the other three trials, compared to the other temperatures. No difference existed between the 4, 11, and 21-degree exercise trials. In addition, in trials over 21 degrees, rectal temperature, skin temperature, and sweat rate were higher indicating greater thermal stress. This stress was not large enough to result in any differences in HR during the 21 degree trial.

Potteiger and Weber (1994) studied the rating of perceived exertion and HR as indicators of exercise intensity in different environmental temperatures of 30, 22 and 14 degrees Celsius on nine male cyclists. The participants underwent an incremental exercise test in the lab as well as three constant load environmental tests. During an incremental test to exhaustion, subjects started at an initial workload of 0 W which was increased by 29.4 W every 4 min. The test was conducted in a room with temperature of 22 degrees Celsius and humidity ranging between 32-38%. The subjects cycled until they reached OBLA with HR, RPE, and workload at OBLA recorded. During the constant workload tests the subjects warmed up for 5 min at one half the OBLA workload followed by an increase of workload to equal the OBLA. The subjects cycled until fatigue or their inability to maintain an 85 rev·min^{-1} pedaling rate. HR and RPE were determined at 5 min intervals and at fatigue. Both HR and RPE showed no significant difference at 30, 22, and 12 degrees Celsius. However, when comparing the measures to that of an incremental exercise test (in the lab), the researchers found a significant difference between RPE measured in the lab to that in the outside environment at all times. Heart rate only showed a significant difference during the first 5 minutes. They concluded that the HR values obtained from an incremental exercise test are more stable than RPE.

Summary

A slow HrRr has been shown to be an independent predictor of mortality. This has been concluded from several studies that measured HrRr following maximal and submaximal exercise conducted on patients referred for a nuclear stress test (Cole et al., 1999), subjects with no evidence of cardiovascular disease (Cole et al., 1999) , and patients referred for exercise ECG (Nishime et al., 2000). Low cardiorespiratory fitness also predicts mortality while moderate to high fitness protects against mortality (Blair et al., 1996). In addition, endurance trained individuals have a more rapid heart rate recovery after peak exercise than their untrained counterparts at similar workloads (Darr et al., 1988). Thus HrRr may be useful in predicting cardiorespiratory fitness. VO_{2max} is considered the most accurate tool for measuring cardiorespiratory physical fitness (Kline et al., 1986). VO_{2max} can be measured directly via metabolic cart or estimated by many different methods. Some of the popular methods for predicting VO_{2max} are field tests (e.g. 20-meter shuttle run test, Rockport walking test, 12-minute Run Test, one, two, three mile run tests), step tests (Harvard step test and its different modifications), cycle tests (e.g. Astrand and Ryhming, YMCA submaximal), and treadmill tests. For most tests, accuracy of HR measure is critical to estimation of VO_{2max}. Factors such as breathing apparatus and environmental conditions should be carefully considered when measuring HR. Although Ward et al. (1989) showed no effect of breathing apparatus on HR, their data were collected on HR during the test not during exercise recovery.

Chapter 3

METHODS

The following chapter outlines the methods used in the investigation. Sections on (a) Participants (b) Test sessions (c) Testing protocol and equipment (d) Statistical analysis and (e) Summary are presented.

Participants

Physical characteristics of the thirty male college students that participated in the study are shown in Table 1, averaging 20.6 ± 1.6 years of age participated in this study. Subjects were recruited with flyers and class announcements describing the research. Participants had different fitness levels ranging from endurance trained athletes to sedentary subjects who had not participated in purposeful physical activity for the past six months. Recruitment was aimed at getting a heterogeneous fitness sample to help generalize results to a larger population. The study was approved by the human subjects research committee at Ithaca College and all subjects signed an informed consent (Appendix A). The subjects' age and activity level were determined by a questionnaire that also included a health history eliciting information about medical conditions, alcohol use, smoking, exercise habits, and medications (Appendices B & C). Subjects who were not familiar with the treadmill were duly familiarized. All participants met the following criteria: (1) no history of heart disease, (2) no orthopedic injury that would alter their performance, and (3) willingness to exert a maximum effort both on the treadmill and in the gym.

Table 1.

Subject Characteristics

	Age (y)	Weight (kg)	Height (m)	VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$)	Maximum HR (bpm)
Mean	20.6	74.36	1.74	50.18	192.05
SD	1.6	11.72	0.07	6.00	1.28

Note

Maximum HR values are the combination of all three tests

Test Sessions

Prior to testing, the subjects had their height and weight measured. Afterwards, they performed three tests: two maximal treadmill exercise tests in the laboratory and one maximal 20-meter shuttle-run test in the gym or hallway. Maximum exercise tests were used as they are the most accurate indicators of VO_{2max} (Kline et al., 1986). The order of these tests was balanced as subjects were assigned to one of six possible testing sequences (Appendix D). The period between the tests ranged from at least 48 hours to no more than one week to allow for sufficient recovery between tests and avoid deconditioning that may occur with longer rest periods.

Testing Protocol and Equipment

A branching protocol was used for both maximal treadmill tests. During one treadmill test session, but not the other, the subjects wore a breathing valve (series 2700, Hans Rudolph. Inc. Kansas City, Missouri) and headgear (series 2726, Hans Rudolph. Inc. Kansas City, Missouri) for gas collection. The purpose of the second treadmill test, where expired air was not collected, was to determine if HrRr was similar for both tests. In either test, the subject started jogging at a comfortable speed (same speed used for both tests) and 0% grade. The grade was increased in succeeding stages every two min by 2.5% until volitional exhaustion. The maximum grade allowed by the treadmill (C954, Precore. Inc. Woodinville, Washington) was 12 %. If the subjects were still able to run beyond this grade, the treadmill speed was increased by 0.5 $m \cdot hour^{-1}$ every 2 min. Respiratory exchange ratio (RER), HR and RPE were measured at the end of each stage. HR was measured with a HR monitor (CardioChamp, Sensor Dynamics. Inc. Fremont, California), RPE with the modified Borg scale (Robertson, Goss, & Metz, 1998), and

RER and VO_2 were measured with indirect calorimetry (TrueMax 2400 Metabolic Measurement System, Salt Lake City, Utah). Immediately after each test, a supine recovery commenced, whereupon HR was taken at 0, 1, 2, 3, 4, and 5 min. HrRr was determined from the six HR measures. It was calculated by subtracting each HR from the maximum HR determined at 0 min immediately post-test. The ACSM prediction equation ($VO_2 = 0.2$ (speed in $m \cdot s^{-1}$) + 0.9 (speed in $m \cdot s^{-1}$) (fractional grade)) was used to estimate VO_{2max} following the treadmill test where no breathing apparatus was used.

The 20-meter shuttle run test (Romsbottlom et al., 1988) was conducted in an indoor gym or hallway using one-minute stages. The subjects ran back and forth between two lines 20 meters apart (Appendix E). The subjects were instructed to reach each line in the given time. In the first stage the subjects were allowed 9 s to run each 20 meters. This time gradually decreased by 0.5 s per stage as the stages progressed. The subjects continued to run until they were unable to continue or failed to reach the 20 meter marker three consecutive times. As the subjects ran, they were paced by an audio cassette tape and were instructed to reach each end line before the following beep. Prior to the test, the subjects were fitted with a heart rate monitor. During the test, RPE was taken at the end of each stage as the subjects either yelled out a number or held up a number of fingers. At the end of the test the subjects assumed a supine position, whereupon HR was measured as previously described for five minutes. Subjects were given special instructions to end the test at the line where the researcher stood, thus, avoiding a drop in HR before the researcher started monitoring the HR. Subjects were allowed to leave immediately after the fifth recovery minute if they recovered normally. VO_{2max} was predicted using the chart by Romsbottom et al. (1988).

Statistical Analysis

A two-way repeated measures (3 x 6) ANOVA was done to compare the six HR measures (HrRr measured five times and maximum HR) in the three different conditions (shuttle-run and two treadmill tests) using $\alpha = 0.05$. Two independent t-tests were conducted to investigate if there was a difference between measured VO_{2max} and VO_{2max} predicted from the treadmill and shuttle-run tests. A series of regression analyses were conducted to investigate if HrRr could be used to predict VO_{2max}. Finally, step-wise regression analyses were done using HrRr, maximum HR, treadmill speed, and shuttle-run end speed to investigate if a prediction equation could be developed to predict VO_{2max} from each of the three testing conditions.

Summary

The participants underwent three maximum exercise tests with two maximum on the treadmill and one being a maximum shuttle-run test. The HrRr was measured in the supine position following all three tests. One treadmill test was conducted without breathing apparatus to investigate if the HrRr is altered when such equipment is used. The relationship between HrRr and VO_{2max} was studied under the three testing conditions using a regression analyses.

Chapter 4

RESULTS

This chapter presents data and statistical analysis associated with the study. Raw data for HR on the two treadmill tests and shuttle run are found in Appendices F, G, and H. Raw data for measured VO_{2max}, VO_{2max} predicted from treadmill, and VO_{2max} predicted from shuttle run are found in Appendix I. Summaries of data and analyses for all variables of interest are presented below.

HrRr

A 3 x 6 ANOVA (Table 2) revealed no difference in HR measures (HrRr, HR max) between the three exercise tests with no significant test x time interaction observed ($p = 0.217$). This showed that recovery HR measures were consistent from one exercise test to the next. HR mean and SD (Table 3) clearly show this consistency between tests. Therefore, maximum HR was the same for all tests and HR recovery was also the same with or without breathing apparatus or after a maximum shuttle-run. There was, however, a significant main effect for recovery HR measured over time ($p = 0.000$). HrRr gradually increased from one minute to the next as the number of beats of HR recovery from maximum HR accumulated. This exercise recovery effect was expected and has no relevance to the main thesis of the study.

VO_{2max}

An independent t-test revealed a significant difference between measured VO_{2max} and that predicted from the shuttle run test (Figure 1). Predicted VO_{2max} from the shuttle run was significantly lower than direct measures ($t(28)= 0.000$: $p < 0.05_{2\text{-tail}}$). Shuttle run

Table 2.

3 x 6 ANOVA Summary Table For HR Measures

Source of Variation	SS	df	MS	F	P
Tests	614.33	2	307.17	2.64	0.0800
Error	6755.33	58	116.47		
HR (beats/min)	1124132.48	5	224826.50	2628.70	0.000*
Error	12401.51	145	85.53		
Tests x HR	121.44	10	12.14	1.32	0.2170
Error	2660.89	290	9.18		

Note. *$p < 0.05$

Table 3.

Recovery and Maximum HR From Three Maximum Exercise Tests

		HrRr1	HrRr2	HrRr3	HrRr4	HrRr5	HRmax
Treadmill Test 1	mean	47.50	73.27	83.73	87.87	89.40	193.20
	±	12.28	12.60	10.37	9.13	9.12	6.81
Treadmill Test 2	mean	47.80	72.07	82.17	86.87	88.80	192.27
	±	11.84	11.59	9.43	9.77	8.66	7.56
Shuttle Run Test	mean	47.07	70.93	80.60	84.00	86.33	190.67
	±	8.24	9.86	9.45	9.33	8.60	9.39

Note.

Values are means ± SD

HrRr1: number of beats recovered in the first minute

HrRr2: number of beats recovered in two minutes

HrRr3: number of beats recovered in three minutes

HrRr4: number of beats recovered in four minutes

HrRr5: number of beats recovered in five minutes

HRmax: number of beats at test termination

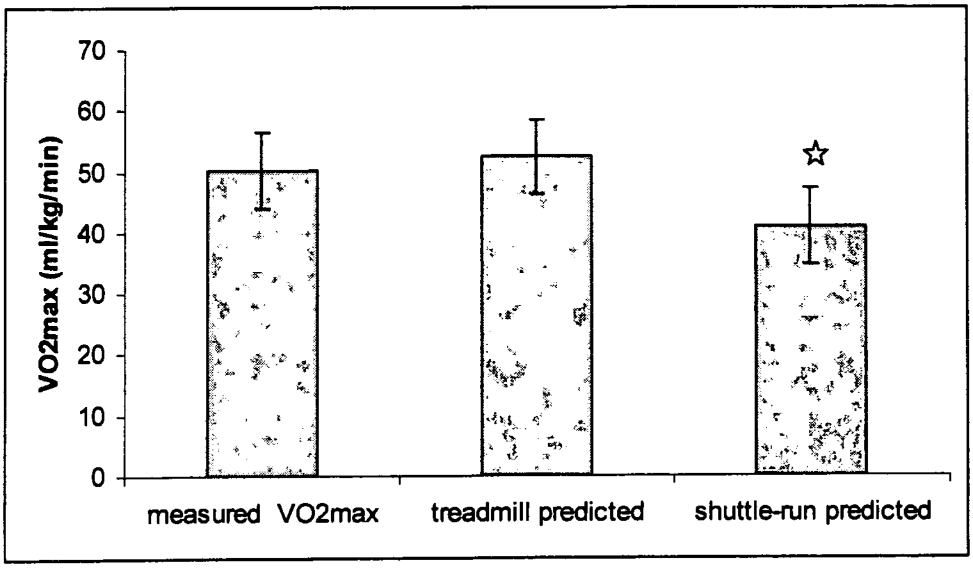

Figure 1. Comparison between measured, treadmill predicted, and shuttle run predicted VO_{2max}. Values are mean and standard deviation. No significant defference ($t(28)= 0.174$ $p> 0.05_{2\text{-tail}}$) was found between measured VO_{2max} and treadmill predicted VO_{2max}.☆ Indicates that predicted VO_{2max} from the shuttle run test is significantly lower than treadmill measured VO_{2max} ($t(28)= 0.000$: $p < 0.05_{2\text{-tail}}$).

predictions underestimated VO_{2max} by almost 25%. There was, however, no significant difference between measured VO_{2max} and that predicted from the treadmill (test with no breathing apparatus) run estimated by the ACSM equation ($t(28)= 0.174$: $p > 0.05_{2\text{-tail}}$).

Predicting VO_{2max} from HrRr

A series of simple regressions were used to determine if HrRr could be used to predict measured VO_{2max}. All HrRr measurements from the shuttle run and treadmill test (no breathing apparatus) were entered as variables in addition to treadmill speed, shuttle run end speed, and maximum HR from the shuttle run and treadmill test (no breathing apparatus). Results (Table 4) showed HrRr and maximum HR to be non significant predictors of VO_{2max}. However, treadmill speed ($R^2 = 0.374$, $p=0.000$) and shuttle run end speed ($R^2 = 0.521$, $p=0.000$) were shown to be moderate and significant predictors of VO_{2max}. A step-wise regression analysis selected shuttle run end speed as the sole factor useful in the prediction of actual VO_{2max}($R^2 = 0.521$, $p=0.000$). Thus, of the variables tested, only the shuttle run end speed could be used to produce a modest prediction of measured VO_{2max}. According to the step-wise regression analysis, treadmill speed, recovery HR, and maximum HR did not add to the prediction of actual VO_{2max}.

Table 4.

Series of Simple Regression Analyses To Predict VO_{2max}

Factor	R	R^2	Adjusted R^2	SEE	Sig
Treadmill HrRr1	0.067	0.005	-0.310	6.140	0.724
Treadmill HrRr2	0.117	0.014	-0.210	6.110	0.537
Treadmill HrRr3	0.253	0.064	0.031	5.950	0.177
Treadmill HrRr4	0.188	0.035	0.001	6.040	0.319
Treadmill HrRr5	0.289	0.084	0.051	5.889	0.121
Treadmill HR max	0.155	0.024	-0.011	6.078	0.414
Shuttle-run HrRr1	0.209	0.044	0.010	6.016	0.267
Shuttle-run HrRr2	0.286	0.082	0.049	5.895	0.125
Shuttle-run HrRr3	0.271	0.073	0.040	5.922	0.147
Shuttle-run HrRr4	0.335	0.112	0.081	5.797	0.070
Shuttle-run HrRr5	0.289	0.083	0.051	5.890	0.122
Shuttle-run HRmax	0.270	0.073	0.040	5.924	0.150
Treadmill Speed	0.612	0.374	0.352	4.867	0.000*
Shuttle run end speed	0.722	0.521	0.504	4.257	0.000*

Note. *$p < 0.05$

All treadmill HrRr refer to treadmill test with no breathing apparatus.

Chapter 5

DISCUSSION

The primary purpose of the present study was to determine if HrRr could be used to predict VO_{2max}. Previous studies were successful in using absolute recovery HR to predict VO_{2max}. Our expectations were that VO_{2max} could be predicted from HrRr, as recovery HR is often used to predict VO_{2max} (Bamerjee & Chatterje, 1983; Brouha et al., 1943; Francis,1987; McArdle & Katch, 1983; Shapiro et al.,1976; Tuxworth & Shahnawaz, 1977). In addition, HrRr is an independent predictor of mortality (Cole et al., 1999; Cole et al., 2000; Nishime et al., 2000; Watanabe et al., 2001) and poor VO_{2max} is an independent predictor of mortality (Blair et al., 1996; Nishime et al., 2000). It was therefore logical that there may be a relationship between HrRr and VO_{2max}. Contrary to these expectations, regression analyses showed that no relationship existed between HrRr and VO_{2max}. Hence, a useful prediction equation using HrRr to predict VO_{2max} was not established.

Several factors may explain why no meaningful relationship between HrRr and VO_{2max} was identified. One of the assumptions made in the present study is that HrRr is dependent on parasympathetic function and that parasympathetic activity is enhanced as fitness improves. However, the impact of fitness on parasympathetic function may have only a small influence on HrRr and design factors of the present study may have obscured this effect. It is possible that the subject sample was too homogenous or that the recovery posture should have been standing rather than supine. Alternatively, genetics may be an over riding variable that was not considered. These possibilities are discussed below.

Recruitment was aimed at getting a heterogeneous sample, however recruitment was based on subjects' report of activity level which was shown to be unreliable based on these results. The pool of subjects in this study had a mean of 50.18 ml·kg^{-1}·min^{-1} and SD of 6.0. Thus it was a somewhat homogenous sample. In the low fit group, for example, the lowest VO_{2max} was only 38.1 ml·kg^{-1}·min^{-1} which falls within the normal range of values for college age males, whereas in the high fit group, the highest VO2max was 63.3 ml·kg^{-1}·min^{-1}, a value that indicated a well-trained but not elite athlete. In short, there were no subjects from the extremes of the fitness spectrum. In addition to range of fitness levels, the number of subjects in each category may also be a key, especially for the low and high fitness groups which only had 6 and 5 subjects respectively.

To better understand sample effect and if fitness level impacted HrRr, a post-hoc difference analysis was conducted in which the subjects were divided into three groups according to fitness level: high fitness group ($n = 5$, $VO_{2max} \geq 55$ ml·kg^{-1}·min^{-1}); a moderate fitness group ($n = 19$, $45 < VO_{2max} < 55$ ml·kg^{-1}·min^{-1}); and a low fitness group ($n = 6$, $VO_{2max} \leq 45$ ml·kg^{-1}·min^{-1}). High fitness subjects tended to have a more rapid HrRr than lower fitness subjects at min 3, 4, and 5 of recovery from maximum exercise. But the difference in HrRr was only statistically significant when comparing high fitness with the moderate fitness group at min 3 and 4. All other comparisons were not significantly different although several approached significance. Perhaps having a larger sample in the high and low fitness groups may have provided a stronger statistical analysis and clarified if any differences in HrRr exists among fitness levels. The analysis would be even stronger if the high fitness group would be composed of subjects having a

$VO_{2max} \geq 70$ ml·kg^{-1}·min^{-1}) and the low fit group would be made up of subjects having $VO_{2max} \leq 30$ ml·kg^{-1}·min^{-1}.

Another factor that may have influenced parasympathetic function, and therefore, HrRr was subject posture immediately after exercise. In the present study, subjects assumed the supine position post-exercise whereas all previous studies attempting to predict VO_{2max} had subjects either sit or stand immediately after the test. The supine position diminishes sympathetic output perhaps lowering HR, stroke volume, cardiac output and blood pressure more quickly than in an upright posture (Wilmore & Costill, 1994). This postural effect may so enhance parasympathetic function that relatively small differences in autonomic function across persons of various fitness levels are overshadowed. It may have been a better methodological strategy to have exercise recovery in the standing posture thereby potentially challenging parasympathetic function. This may have allowed more fit subjects in the present study to demonstrate their potential for parasympathetic dominance and faster HrRr. This change in procedure may be useful in a future study.

To get a better understanding of how recovery posture may have influenced our study, a trial was conducted with three subjects, each of whom completed two shuttle run tests. One test was followed by recovery in supine position, while for the other it was measured with subjects in standing position. A two-tailed t-test (Table 5) showed that HrRr at all time periods except the first were significantly higher when the subjects were supine. Thus, had the subjects in our main study assumed a standing position after exercise, the results may have been different.

Table 5.

Mean HrRr For Standing and Supine Positions Following the Shuttle Run.

	HrRr1	HrRr2	HrRr3	HrRr4	HrRr5
Standing Position	43.67	64.67	71.67	76.67	79.670
Supine Position	55.33	77.00	85.33	88.67	91.000
p value	0.19	0.05*	0.01*	0.02*	0.049*

Note. *p < 0.05

HrRr1: number of beats recovered in the first minute

HrRr2: number of beats recovered in two minutes

HrRr3: number of beats recovered in three minutes

HrRr4: number of beats recovered in four minutes

HrRr5: number of beats recovered in five minutes

HRmax: number of beats at test termination

Although poor HrRr in the supine position predicts death (Watanabe et al., 2001), poor recovery was defined as a HrRr of less that 18 beats in the first minute. Perhaps there is a cut off point at which a subject's health is so poor that even the supine position is not as effective in rapidly reducing the sympathetic cardiorespiratory function. This study did not employ subjects with such a diminished health status.

Genetics may also play a key role in parasympathetic function although it is difficult to find reports supporting such a claim. While disease may greatly alter vagal activity in older individuals it may be genetics that plays the dominant role in determining autonomic balance in younger, healthy individuals. Relative to genetics, the effect of exercise training may again be small and therefore our examination of the effects of fitness on HrRr across healthy subjects was fruitless.

Other factors the may have contributed to the inability to predict VO_{2max} from HrRr include the specific timing of the measure and the fact that HrRr is influenced by both maximum heart rate and recovery heart rate and not simply recovery heart rate. It would be interesting to further examine such factors in a future study.

In addition to using recovery HR to predict VO2, previous studies also added additional factors into their prediction equations. These factors may account for the ability to predict VO_{2max} from recovery HR. For example, the addition of stepping duration or subject weight significantly improved the predictive ability of the Harvard Step Test (Brouha et al., 1943; Tuxworth & Shahnawaz, 1977). Regression analysis in our study showed that only shuttle-run end speed and treadmill speed predicted VO_{2max}. The shuttle-run end speed was slightly more predictive, which is not surprising as the 20-meter shuttle-run test is based on the linear relationship between O_2 consumption and maximum running speed (Romsbottom et al., 1988). Similarly, treadmill speed is also predictive of VO_{2max}, as subjects who ran at higher velocities had higher VO_{2max}. Among those subjects whose treadmill speed was the same, there were still differences in VO_{2max}, a finding related to the progressive nature of the treadmill test. Hence, predictive power of treadmill speed decreased compared to that of the shuttle-run because the treadmill test is also influenced by treadmill grade. To increase the predictive power of the treadmill test, speed and grade should be considered as one factor. This was not done in this study, as the main purpose was to determine if HrRr, and not workload, could predict VO_{2max}.

Treadmill data from this study were also used to estimate VO_{2max} using the ACSM metabolic equation, which uses both speed and grade. No difference was found between treadmill equation predicted and measured VO_{2max} in the present study. The ACSM metabolic equation for treadmill running proved to be a strong predictor of VO_{2max} measured by indirect calorimetry. This comes as no surprise, as treadmill tests have always shown good predictions of VO_{2max}. The ACSM equation (ACSM, 2000) was evaluated by Foster et al. (1996) who found an $r^2 = 0.995$ when compared with gas analysis measurements.

The second purpose of present study was to examine if VO_{2max} could be predicted using HrRr obtained following a 20-meter shuttle run test. Had we known that no relationship between HrRr following the treadmill test and VO_{2max} existed, this part of the study would not have been conducted. HrRr from the shuttle run were similar to the HrRr collected after the treadmill tests. Hence, it is appropriate to obtain HrRr following a shuttle run if needed for future studies though these data were not valuable for predicting VO_{2max}.

Leger and Gadoury (1989) introduced a regression equation that used shuttle-run end speed to predict VO_{2max}. This prediction equation underestimated VO_{2max} by approximately 10 $ml \cdot kg^{-1} \cdot min^{-1}$ using data collected from our study. Perhaps this is due to subjects' lack of familiarity with the shuttle-run test. Although explicit instructions were given prior to the test, subjects tended to exert unneeded effort at the beginning of the test, which may have contributed to early fatigue, and hence, test termination. Performance was not the purpose of this study, however, as it was most important to reach maximum HR, which was achieved. In our follow up trial study, subjects had a predicted VO_{2max} of about 3 $ml \cdot kg^{-1} \cdot min^{-1}$ higher on their second run. This is in agreement with Leger & Lambert (1982) who found that the second trial yielded higher values when validating the 20-meter shuttle run test.

Motivation may also have contributed to the underestimation of VO_{2max} by shuttle run score in the present study. Subjects in previous studies ran in groups, which may have increased the competitive nature of the trial, therefore increasing final velocity and hence VO_{2max} (Leger and Gadoury, 1989). In this study, subjects ran the shuttle-run alone. Even though subjects in this study may not have reached maximum running velocity in the shuttle-run because of methodological factors, they did achieve maximum HR, the primary objective.

In addition to our finding regarding HrRr, the present study found no significant effect of wearing a mouth piece and breathing valve on maximum HR and HrRr. This is in agreement with data from Ward et al. (1989), who reported similar maximum HR was achieved whether subjects wore or did not wear a mouth piece. The present study adds that recovery HR as measured with HrRr is also not affected by using a mouth piece during exercise though it was removed immediately after the test. In our study, discomfort and inability to breathe when wearing the breathing apparatus was reported by 25 of the 30 subjects. This discomfort, however, did not affect HR results. The duration of the treadmill test was also not affected by the headgear as test durations were similar with and without. Indeed, only one subject performed substantially longer (2.5 min) on the maximal treadmill test with no headgear. As a consequence, he reached a higher grade, and therefore, obtained a higher maximum HR. Hence, his first test (with head gear) represented a submaximal effort. Despite this difference in maximum HR between these two tests in this subject, HrRr was the same, suggesting that HrRr following a submaximal test may be the same as that following a maximal test. This is supported by HrRr data that show a submaximal exercise test can be used in the prediction of mortality as well as a maximal test (Cole et al., 2001). If HrRr becomes an important clinical measure, the use of a submaximal test to obtain these data would prove easier and more comfortable for subjects than a maximal effort.

This study showed that HrRr at min 1, 2, 3, 4, and 5 is not a good predictor of VO_{2max}. Further investigation is needed to determine if HrRr at different points in recovery could predict VO_{2max}. Additional investigation is also needed to determine if HrRr at min 1, 2, 3, 4, and 5 correlates with VO_{2max} in specific fitness groups. Different subject recovery positions (e.g., standing) should also be more fully investigated as posture after the test can clearly impact heart rate and recovery rate. Practitioners should continue to use other methods of VO_{2max} prediction. For example, a maximal treadmill test using the ACSM prediction equation was shown to be a good predictor of VO_{2max}.

The 20-meter shuttle-run test should be used carefully as it may underestimate VO_{2max} in isolated testing of novice subjects.

Chapter 6

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

VO_{2max} is the most accurate indicator of cardiorespiratory fitness. However, measuring VO_{2max} is expensive, as it requires special equipment and trained personnel. This leads scientists to seek alternative methods to predict VO_{2max}. In recent years, HrRr has gained a lot of attention, as a poor HrRr is an independent predictor of mortality. The rate of immediate post-exercise HR recovery is mainly due to vagal activation. Vagal activity is higher among subjects with better fitness. This led to the hypothesis that HrRr may also be a good predictor of VO_{2max}. Therefore, the purpose of this study was to investigate if HrRr could be used to predict VO_{2max}. In addition, this study also sought to identify if the breathing apparatus used during VO_{2max} testing affects HR during and after the exercise test.

Thirty male subjects (20.6 ± 1.6 years) of various fitness levels completed three maximal exercise tests in a randomized balanced order. A treadmill test with a breathing apparatus, a treadmill test with no breathing apparatus, and a shuttle run test were completed. VO_{2max} was measured using indirect calorimetry during one of the treadmill tests, while the other two maximum tests were used to predict VO_{2max}. Immediately following the exercise tests, subjects assumed the supine position for recovery. HR was measured with a HR monitor at the end of the test and every min post-test for 5 min. From these data the 1, 2, 3, 4, and 5 min HrRr were calculated.

A 3 x 6 ANOVA was used to determine if a difference existed among the HrRr from the three tests and no interaction was found. A main effect for test type was also not seen but HrRr did decrease over time as expected. Two independent t-tests were used to compare measured VO_{2max} with each of the predicted values. No significant difference was found between measured and treadmill predicted VO_{2max}, whereas there was a significant difference between measured and shuttle-run predicted VO_{2max}. Predicted shuttle-run VO_{2max} underestimated actual VO_{2max} by 10 $ml \cdot kg^{-1} \cdot min^{-1}$. Two possible explainations for this underestimations are subject inexperience with the procedure and lack of motivation. Simple and stepwise regressions were used to determine if VO_{2max} could be predicted from HrRr. These regression analyses indicated the HrRr was not a good predictor of VO_{2max}.

Conclusions

Based on the findings of the study, the following conclusions were drawn:

1. HrRr as measured in this study can not predict VO_{2max} in college-aged males. However, additional research is needed to confirm these findings using other methodologies.
2. Breathing apparatus used during VO_{2max} testing has no effect on HR during and after exercise testing.
3. The 20-meter shuttle run test underestimated VO_{2max} in this study where subjects were tested individually and lacked familiarity with the test.
4. Only running speed was an important factor when estimating VO_{2max}.

Recommendations

Recommendations for future areas of investigation include the following:

1. Future studies should investigate the ability of HrRr to predict VO_{2max} in middle-aged individuals as examined in mortality studies.

2. The ability of using HrRr at different point in time to predict VO_{2max} should be investigated (e.g., 15 s post-exercise).
3. The ability to using HrRr to predict VO_{2max} in specific fitness groups should be investigated.
4. A reliability study should be conducted to test the predictive ability of the 20-meter shuttle run test when a subject is running alone compared to running in a group.
5. The ability to use HrRr at min 1, 2, 3, 4, and 5 post-exercise as the subjects assume standing position to predict VO_{2max} should be investigated.
6. The ability to use HrRr to predict VO_{2max} following a submaximal exercise test should be investigated.

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Appendix A

Informed Consent Document

1. Purpose of the study
   The purpose of this study was to identify if aerobic fitness (VO_{2max}) can be predicted from a simple recovery heart rate measure after maximal running exercise.

2. Benefits of the study
   The development of a new and simple method to evaluate cardiorespiratory fitness. If desired, subjects participating in the study will be given the results of their VO_{2max} testing (without fee).

3. What you will be asked to do
   You will be asked to run three maximal exercise tests with a time period between 48 hours and a week between them. Two of these exercise tests will be conducted on the treadmill where you will be asked to start running at a comfortable speed and 0 % grade, the grade will be increased by 2.5% every 2 minutes till exhaustion. The third test will be conducted in the gym where you will be asked to complete a shuttle run. During the shuttle run you will be asked to run back and forth between two points 20 meters apart. The time needed to get from one point to the other will be continually decreased until you either request to stop or fail to reach the other point in the required time. Heart measurement will be taken before, during, and after the tests. You will be asked to be seated directly after these tests to allow the heart rate measurement from the three tests to be compared. Each of these running tests will take about one hour.

4. Risks
   Exercise always involves some risk of injury or illness to the participant. Exercise testing poses as much risk as any exercise because of the maximal effort involved. It is possible that you may get sore muscles if you are not used to doing heavy exercise presently. You will be asked to fill out a medical history form and only be allowed to participate if you are seen as healthy. When working with a young, healthy population as in this study the chance of any major complication (cardiovascular risk e.g. cardiac arrest, myocardial infarction, stroke) or death exist but is extremely small.

5. If you would like more information about the study
   Please contact Mostafa Afifi by telephone (277-3182) or email (mostafa_afifi@hotmail.com)

6. Withdrawal from the study
   You are free to withdraw from your participation at any time

Appendix A (continued)

Informed Consent Document

7. <u>How the data will be maintained in confidence</u>
All data will be coded and entered into a computer for analysis. Your data will be placed in a locked office accessible to the researchers only. Data from this study will be presented as a group result and will not in any way identify any subject.

I have read the above and I understand its contents. I agree to participate in the study. I acknowlage that I am 18 years of age or older.

____

Print or Type Name

______________________________________ ______________

Signature Date

Appendix B

Subject's Date Collection Sheet

Name:
Tel #:
E-mail:
Weight:
Medication:
Smoking & Drinking Habits:

Group:
ID#:
Age:
Height:

Exercise Habits:

	Treadmill (1)				Treadmill (2)		Shuttle run	
	HR	RPE	VO_2	RER	HR	RPE	HR	RPE
Resting								
TM Speed & SR End								
Stage 1								
Stage 2								
Stage 3								
Stage 4								
Stage 5								
Stage 6								
Stage 7								
Stage 8								
Stage 9								
Stage 10								
Stage 11								
Stage 12								
Stage 13								
Stage 14								
Stage 15								

Appendix B (continued)

Subject's Date Collection Sheet

Stage 16								
T, H %, pr								
PostHr 1								
PostHr 2								
PostHr 3								
PostHr 4								
PostHr 5								

Appendix C

PAR - Q

Physical Activity Readiness Questionnaire - PAR-Q (revised 1994)

PAR - Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO		
☐	☐	1.	Has you doctor ever said that you have a heart condition <u>and</u> that you should only do physical activity recommended by a doctor?
☐	☐	2.	Do you feel pain in your chest when you do physical activity?
☐	☐	3.	In the past month, have you had chest pain when you were not doing physical activity?
☐	☐	4.	Do you lose your balance because of dizziness or do you ever lose consciousness?
☐	☐	5.	Do you have a bone or joint problem that could be made worse by a change in your physical activity?
☐	☐	6.	Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?
☐	☐	7.	Do you know of <u>any other reason</u> why you should not do physical activity?

If you answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want—as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to <u>all</u> PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active—begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal—this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively.

DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever—wait until you feel better; or
- if you are or may be pregnant—talk to your doctor before you start becoming more active.

Please note: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

<u>Informed Use of the PAR-Q</u>: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

You are encouraged to copy the PAR-Q but only if you use the entire form

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction.

NAME ______________________________

SIGNATURE ______________________________ DATE ______________________

SIGNATURE OF PARENT ______________________________ WITNESS ______________________
or GUARDIAN (for participants under the age of majority)

Supported by: Health Canada Santé Canada

Appendix D

Assigned Sequence of Subject Testing

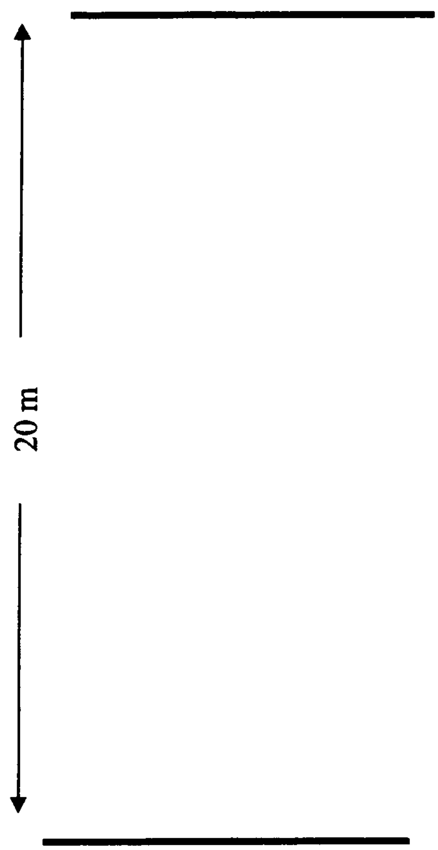
Sequence #	Sequence of tests
1	1 2 3
2	1 3 2
3	2 1 3
4	2 3 1
5	3 1 2
6	3 2 1

Note. Each subject was assigned one of the six sequences for their order of testing

Key: 1 = Treadmill test with breathing apparatus; 2 = Treadmill test without breathing apparatus; 3 = Shuttle run test.

Appendix E

20-Meter Shuttle Run Test



Note. Subjects ran back and forth placing one foot on or over the 20 meter line before hearing the beep omitted from a cassette player. Timing between beeps gradually decreased every minute. The subjects continued to run until failure to reach the 20 meter line before the beep three consecutive times or indicating that they can not run any longer.

Appendix F

HR Raw Data: Treadmill Test With Breathing Apparatus

Subject number	HrRr1	HrRr2	HrRr3	HrRr4	HrRr5	HR max
1	57	86	94	98	99	200
2	29	63	75	83	84	203
3	67	104	111	109	109	186
4	39	69	78	86	89	186
5	52	82	92	97	96	202
6	53	73	81	84	82	191
7	30	57	67	75	78	194
8	42	61	74	77	81	185
9	46	72	88	87	85	196
10	50	77	89	90	93	192
11	44	67	77	80	82	187
12	58	80	94	95	97	201
13	34	61	73	82	81	204
14	50	77	89	91	92	199
15	30	55	78	83	85	182
16	31	61	76	76	78	186
17	67	94	100	98	98	184
18	32	52	64	68	70	190
19	40	67	76	83	81	195
20	45	73	86	94	97	203
21	47	74	91	97	101	197
22	43	67	78	82	84	196
23	53	76	88	94	98	184

Appendix F (continued)

HR Raw Data: Treadmill Test With Breathing Apparatus

Subject number	HrRr1	HrRr2	HrRr3	HrRr4	HrRr5	HR max
24	65	85	80	94	95	198
25	34	57	71	74	77	189
26	42	73	87	94	98	197
27	67	79	89	88	90	189
28	50	74	85	89	91	196
29	67	84	82	88	89	184
30	61	98	99	100	102	200

Note.

HrRr1: number of beats recovered in the first minute

HrRr2: number of beats recovered in two minutes

HrRr3: number of beats recovered in three minutes

HrRr4: number of beats recovered in four minutes

HrRr5: number of beats recovered in five minutes

Hr max: number of beats at the test termination

Appendix G

HR Raw Data: Treadmill Test Without Breathing Apparatus

Subject number	HrRr1	HrRr2	HrRr3	HrRr4	HrRr5	HR max
1	58	84	90	93	93	187
2	37	57	68	70	72	187
3	74	101	104	107	105	174
4	38	70	75	81	80	180
5	47	78	88	90	93	200
6	47	62	73	80	80	190
7	33	61	76	82	89	196
8	38	63	75	84	84	192
9	44	72	86	86	88	199
10	50	78	88	93	93	194
11	45	67	72	80	84	188
12	58	81	87	97	96	202
13	36	57	67	70	79	205
14	52	79	88	92	96	202
15	33	57	80	81	86	184
16	47	74	82	88	91	200
17	80	100	100	103	98	183
18	35	59	69	67	70	189
19	39	62	74	82	82	182
20	41	69	83	90	93	200
21	50	77	91	96	100	200
22	44	66	75	77	80	192

Appendix G (continued)

HR Raw Data: Treadmill Test Without Breathing Apparatus

Subject number	HrRr1	HrRr2	HrRr3	HrRr4	HrRr5	HR max
23	53	78	88	95	102	190
24	65	82	94	97	96	194
25	32	57	69	73	78	188
26	40	66	82	87	89	188
27	56	76	82	86	85	192
28	47	68	81	88	91	199
29	56	80	87	96	94	190
30	59	81	91	95	97	201

Note.

HrRr1: number of beats recovered in the first minute

HrRr2: number of beats recovered in two minutes

HrRr3: number of beats recovered in three minutes

HrRr4: number of beats recovered in four minutes

HrRr5: number of beats recovered in five minutes

Hr max: number of beats at the test termination

Appendix H

HR Raw Data: Shuttle Run

Subject number	HrRr1	HrRr2	HrRr3	HrRr4	HrRr5	HR max
1	58	82	94	87	92	189
2	35	62	66	73	77	200
3	59	92	97	95	95	182
4	42	68	74	76	79	177
5	53	81	92	99	100	199
6	44	62	70	69	78	187
7	37	60	73	74	77	183
8	49	71	78	80	83	178
9	47	71	77	85	85	195
10	52	82	89	92	91	190
11	52	71	81	83	83	186
12	49	73	83	88	92	203
13	33	51	65	71	77	203
14	50	75	85	91	88	196
15	51	76	88	94	95	192
16	53	74	86	91	95	201
17	58	83	90	88	86	173
18	36	62	71	74	74	193
19	42	63	77	78	85	180
20	41	63	76	85	88	197
21	44	70	84	93	94	204
22	44	67	76	78	81	200
23	54	75	86	90	92	188

Appendix H (continued)

HR Raw Data: Shuttle Run

Subject number	HrRr1	HrRr2	HrRr3	HrRr4	HrRr5	HR max
24	54	76	83	89	91	187
25	31	57	69	74	76	182
26	44	70	79	87	91	192
27	35	51	60	61	63	170
28	49	75	84	86	88	199
29	57	81	93	95	101	199
30	59	84	92	94	93	195

Note.

HrRr1: number of beats recovered in the first minute

HrRr2: number of beats recovered in two minutes

HrRr3: number of beats recovered in three minutes

HrRr4: number of beats recovered in four minutes

HrRr5: number of beats recovered in five minutes

Hr max: number of beats at the test termination

Appendix I

VO_{2max} Raw Data For The Three Test Conditions

Subject number	Treadmill (breathing apparatus) (ml/kg/min)	Treadmill (no breathing apparatus) (ml/kg/min)	Shuttle run (ml/kg/min)
1	53.0	54.0	37.8
2	48.9	50.1	38.5
3	59.5	57.9	57.6
4	40.0	46.5	33.6
5	46.7	50.1	37.8
6	53.0	45.6	37.1
7	49.2	57.9	42.4
8	45.1	47.3	35.7
9	56.4	50.1	37.1
10	60.4	57.9	48.7
11	51.1	51.4	39.2
12	51.1	53.0	46.8
13	50.3	50.1	41.8
14	50.2	46.3	36.4
15	52.5	49.7	37.1
16	53.6	64.4	48.7
17	43.9	46.5	31.8
18	46.8	53.9	41.1
19	44.1	44.8	37.8
20	52.4	57.9	42.4
21	53.3	57.9	48

Appendix I (continued)

VO_{2max} Raw Data For The Three Test Conditions

Subject number	Treadmill (breathing apparatus) (ml/kg/min)	Treadmill (no breathing apparatus) (ml/kg/min)	Shuttle run (ml/kg/min)
22	48.4	48.9	41.8
23	50.6	53.7	40.5
24	46.4	50.1	41.1
25	51.1	54.0	43.9
26	60.3	66.5	54.8
27	41.8	46.5	33.6
28	43.9	48.7	40.5
29	38.1	43.1	31.8
30	63.3	65.4	43.9