ADAPTING THE LEGER 20 METRE SHUTTLE RUN TO A SUBMAXIMAL PROTOCOL TO PREDICT PEAK $\dot{V}O_2$

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by
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SUPERVISORY AND EXAMINING COMMITTEE

Patrick Ash, candidate for the degree of Master of Science, has presented a thesis titled, ***Adapting the Leger 20 Metre Shuttle Run to a Submaximal Protocol to Predict Peak VO$_2$,*** in an oral examination held on January 9, 2007. The following committee members have found the thesis acceptable in form and content, and that the candidate demonstrated satisfactory knowledge of the subject material.

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Abstract

The direct assessment of peak aerobic power ($\dot{V}O_{2peak}$) is the criterion measure of cardiorespiratory fitness. The Leger 20 metre shuttle run test (LST) is an aerobic power field test in which participants' $\dot{V}O_{2peak}$ can be predicted reliably by completing a series of consecutive 20 meter shuttle runs at incremental speeds. The LST has been found to be a reliable and valid predictor of maximal aerobic power when correlated with the measure of $\dot{V}O_{2peak}$ attained using indirect calorimetry (Leger, Mercier, Gadoury, & Lambert, 1988; Leger & Gadoury, 1989). This study investigated the feasibility of using submaximal heart rate (HR) responses to the LST to predict $\dot{V}O_{2peak}$. The purpose of this study was (1) to compare the $\dot{V}O_{2peak}$ predicted from the LST with measured $\dot{V}O_{2peak}$ in healthy subjects, and (2) to develop prediction equations for $\dot{V}O_{2peak}$ using heart rate responses to submaximal intensities from the LST. Seventeen female (mean age ± SD; 21 ± 3 yrs) and 17 male subjects (23 ± 2 yrs) completed a ramped maximal exercise treadmill test (RT), a graded maximal treadmill test (GT), and the LST with a minimum of two days rest between testing sessions. Both the RT and LST involved increases in speed every minute (i.e., stage). The GT was used to validate $\dot{V}O_{2peak}$ from the RT. VO_{2peak} was determined during the RT and GT with metabolic gas analysis. The VO_{2peak} from the LST was estimated from the prediction equations developed by Leger et al. (1988), Leger and Gadoury (1989), and Stickland, Petersen, and Bouffard (2003). Data were analyzed using multiple regression and repeated measures ANOVA. Statistical significance was determined when $p < 0.05$. The LST stages completed were 7.5 ± 1.5 for females and 10 ± 2.3 for males. Throughout exercise and at peak, no statistically significant differences in heart rate were found between the RT and LST ($p > 0.05$). Peak $\dot{V}O_2$ from the RT was

similar to the GT for both males and females ($p < 0.01$). The regression equation from Leger et al. (1988) under-predicted $\dot{V}O_{2peak}$ in males and over-predicted $\dot{V}O_{2peak}$ in females ($p < 0.05$). The Leger and Gadoury (1989) regression equation accurately predicted $\dot{V}O_{2peak}$ in females ($p > 0.05$) but under-predicted $\dot{V}O_{2peak}$ in males ($p < 0.05$). The regression equation of Stickland et al. (2003) over-predicted $\dot{V}O_{2peak}$ in both males and females ($p < 0.05$). Direct entry multiple regression analyses using body mass index (X_0), HR at rest (X_1), minute 1 of the LST (X_2), minute 2 of the LST (X_3), and minute 3 of the LST (X_4) indicated a statistically significant relationship for males ($p < 0.01$; $r^2 = 0.84$; *SEE* = 3.5) and females ($p < 0.01$; $r^2 = 0.6$; *SEE* = 2.9). The following equations were developed to predict $\dot{V}O_{2peak}$ from submaximal LST intensities:

Males = $135 + (-0.72X_0) + (-0.168X_1) + (-0.05X_2) + (0.38X_3) + (-0.66X_4)$

Females = $93 + (-0.25X_0) + (-0.11X_1) + (0.14X_2) + (-0.28X_3) + (-0.05X_4)$.

These results indicated that most LST predictive equations under- or over-estimate $\dot{V}O_{2peak}$. The findings of this study also suggest that body mass index and submaximal heart rate may be used to predict $\dot{V}O_{2peak}$.

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CHAPTER 1

INTRODUCTION

1.1 Problem Statement

The cardiorespiratory system functions to ensure optimal oxygen (O_2) delivery to working tissues while removing resulting metabolic waste products. (Levitzky, 2003; Wasserman, 2005). Oxygen availability for aerobic metabolism is dependent upon the transport of O_2 rich blood by the heart (via cardiac output) (Wasserman, 2005), the O_2 carrying capacity of blood (hemoglobin concentration), and the working muscle tissue's ability to extract O_2 from blood (Levitzky, 2003).

Cardiorespiratory fitness testing of individuals requires the correct identification and assessment of activity specific physiological factors including determining the maximal amount of O_2 utilized by the working tissues ($\dot{V}O_{2peak}$), energy cost of exercise, and the maximal velocity attained at $\dot{V}O_{peak}$ (Bassett & Howley, 2000). The maximum velocity attained at $\dot{V}O_{2peak}$ is defined as aerobic endurance since $\dot{V}O_{2peak}$ sets the upper limit of the aerobic energy system pathway (Bosquet, Leger, & Legros, 2002). The tests used to measure aerobic capacity are numerous and can be classified into two categories, namely indirect calorimetry and predictive methods. Indirect calorimetry involves analyzing expired gases to assess actual $\dot{V}O_2$ for any given point during exercise. Predictive methods typically use extrapolation formulas based on the relationship between heart rate (HR) and $\dot{V}O_2$, which permits the prediction of $\dot{V}O_{2peak}$ from submaximal HRs. The rationale for submaximal aerobic testing is to predict $\dot{V}O_{2peak}$ without the need for participants to give peak effort. This allows for a greater range of participants to engage in such a test, as maximal tests tend to be limited to an athletic and highly motivated population. Submaximal tests require participants to work up to a specified percentage of their peak heart rate (HR_{peak}).

There are several methods to predict $\dot{V}O_{2peak}$ based on peak effort (e.g., Leger 20 metre Shuttle Run or "Beep Test", 1.5 mile run/walking test, Bruce Maximal Treadmill Test) or on submaximal effort (e.g., Astrand Cycle Egrometer or Bruce 85% Treadmill Protocol). Previous research has demonstrated a strong linear correlation for the HR_{peak} and $\dot{V}O_{2peak}$ using the Leger Shuttle Run test (LST) (Ahmaidi et al., 1993; Bosquet et al., 2002; Grant, Joseph, & Campagna, 1999). Grant et al. (1999) tested healthy men and women (*n* = 30, age range 18 to 35) on 7 different predictive tests (i.e., max Bruce Treadmill Protocol, 85% Bruce Treadmill Protocol, Astrand-Ryhming cycle ergometer test, heart rate extrapolation cycle ergometer, Leger Shuttle Run, 1.5 mile run, and Canadian Aerobic Fitness Step Test) and compared the predicted $\dot{V}O_{2peak}$ to those obtained from indirect calorimetry using a maximal treadmill protocol. Grant et al. (199) found that the Leger Shuttle Run (LST) significantly correlates the measured $\dot{V}O_{2peak}$ ($r = 0.86$, $p < 0.05$). Since the LST is a valid predictor of $\dot{V}O_{2peak}$, it seems logical to investigate whether the LST could be adapted to predict $\dot{V}O_{2peak}$ from submaximal effort.

1.2 Objectives of the Study

This study investigated the feasibility of using submaximal HR responses from the LST to predict $\dot{V}O_{2peak}$. This study also assessed the correlation between the $\dot{V}O_{2peak}$ predicted from peak effort on the LST with an indirect calorimetry assessment of $\dot{V}O_{2peak}$.

1.3 Research Hypotheses

1. The measured VO_{2peak} attained during peak effort on the graded treadmill protocol

(GT) will be similar to the measured VO_{2peak} attained from peak effort during the ramped treadmill protocol (RT).

2. There will be no difference between the submaximal predicted VO_2 and measured HR attained from the LST versus the RT protocol.
3. There will be no significant differences between the VO_{2peak} calculated from peak effort on the LST versus measured VO_{2peak} observed during the RT protocol.
4. The LST can be used to accurately predict VO_{2peak} by developing a regression equation using the HRs attained during the submaximal stages.

1.4 Limitations

There are a number of underlying assumptions for predictive tests to consider when assessing $\dot{V}O_{2peak}$. Firstly, as $\dot{V}O_2$ (i.e., work intensity) increases, it is assumed that HR will increase in a linear fashion. This reliance on a linear HR to power output and power output to $\dot{V}O_2$ relationship is a potential source of error when using predictive tests (Bosquet et al., 2002). Secondly, the assumption that HR_{peak} can be predicted accurately from the formula $HR_{peak} = 220$ - age is not true for everyone. It is well known that HR_{peak} can vary for a given age (i.e. HR_{peak} = 220-age ± 10 $\text{beats} \cdot \text{min}^{-1}$) and fitness level (ACSM, 2000). Thirdly, there is an assumed constant mechanical efficiency. There is also a possibility that the graded protocol will induce a greater level of muscle fatigue resulting in shorter test duration, thus reducing $\dot{V}O_{2peak}$ in comparison to the ramped protocol.

Due to the total number of testing days (3), it is anticipated that non-compliance with scheduled appointments would be problematic. Lastly, since the GT, RT, and LST are maximal tests, participant motivation to produce a peak effort may influence the results.

1.5 Delimitations

The applications of the results are restricted to healthy males and females between the ages of 18 and 30 who are able to run and are free of any chronic disease or disability.

1.6 Definitions

Age Predicted Peak Heart Rate – A method of predicting a person's peak heart rate. Age predicted peak heart rate = 220 – age ± 10 beats$\cdot$min^{-1} (ACSM, 2000).

Arteriovenous Oxygen Difference (a-v)O_2 – The difference in O_2 content between the arteries and veins, expressed in millilitres of O_2 per 100 ml of blood or volumes percent (vol. %). This is a measure of O_2 extracted by the tissues (Levitzky, 2003).

Graded Treadmill Protocol (GT) - The GT protocol is an incremental test in which the speed and grade increases every minute until the participant can no longer continue.

Lactate Threshold (LT) – Defined as the lactacte inflection point, which represents the point at which lactate entry into the blood exceeds its removal. The blood then becomes acidic and decrements in performance occur (Brooks, Fahey, White, & Baldwin, 2000).

Peak Effort – Defined as the point in exercise in which volitional fatigue is reached or the individual chooses to no longer continue to maintain the required effort due to fatigue (ACSM, 2000).

Metabolic Equivalent (MET) – Resting metabolic rate, the metabolic rate while sitting quietly in a chair. One MET is equivalent to an $\dot{V}O_2$ of 3.5 $ml \cdot kg^{-1} min^{-1}$. When using METs, exercise intensity is expressed in multiples of the resting metabolic rate (ACSM, 2000).

Peak Heart Rate (HR_{peak}) – The heart rate that corresponds to the point which the individual chooses to no longer continue due to no longer being able to maintain the required effort due to fatigue (ACSM, 2000). The value that will represent HR_{peak} in this study will be the highest 20-second average attained during the RT, GT, and LST. The typical units of measure are $beats \cdot min^{-1}$.

Peak Oxygen Uptake ($\dot{V}O_{2peak}$) – A measure of the body's ability to efficiently deliver oxygen to the mitochondria for energy production and thus is also a measure of the functional ability of the cardiorespiratory system. The value that will represent $\dot{V}O_{2peak}$ in was the highest 20-second average attained during the RT, GT, and LST. The typical units of measure are $mL \cdot kg^{-1} \cdot min^{-1}$ (Levitzky, 2003).

Respiratory Exchange Ratio (RER) – This is the content of carbon dioxide (CO_2) and O_2 in the arterial blood. The ratio of CO_2 to O_2 provides insight into the energy systems being used for exercise (Brooks et al., 2000)

Ramp Treadmill Test (RT) - The RT protocol is an incremental test in which the speed of the treadmill increases every minute until the participant can no longer continue.

Supramax $\dot{V}O_{2peak}$ *Test* - A supramax test is performed following 5 minutes of recovery in order to verify the HR_{peak} and $\dot{V}O_{2peak}$ attained during the indirect calorimetry $\dot{V}O_{2peak}$ test. The supramax test involves the participant running at a workload equivalent to one stage above the final stage achieved during the GT or RT protocol. The supramax test will continue with an increase in treadmill workload every minute until volitional fatigue or signs/symptoms of exertional intolerance are observed (ACSM, 2000). The supramax test is used to verify the results of the GT and RT by adding a supramaximal load in order to ensure that the highest $\dot{V}O_{2peak}$ value is attained.

Ventilatory Threhold (VT) – A ventilatory indices of the balance between lactate entry and removal from the blood. Lactic acid is a byproduct of short-term (glycolosis) energy production. When lactate entry becomes greater than its removal from the blood, the blood becomes acidic (i.e., lactic acidosis), a ventilatory inflection point occurs, and decrements in performance occur as a result (Brooks et al., 2000).

CHAPTER II

LITERATURE REVIEW

2.1 Assessment Techniques for $\dot{V}O_{2peak}$

Exercise scientists use available technology and laboratory tests to examine or identify key variables necessary for optimal physiological performance. The physiological data are needed to develop a profile of the characteristics necessary for optimal health or sport performance. Exercise scientists study the expression of $\dot{V}O_{2peak}$ in terms of physiological variables. These variables provide valuable insight into the overall function of the cardiorespiratory (i.e., heart, circulatory, and lung) systems and the body's ability to perform a specific workload for a given duration or distance (Brooks et al., 2000).

In order to measure or predict the $\dot{V}O_{2peak}$, the exercise scientist uses available measurement tools or field tests. A review of some of the measurement tools commonly used to assess $\dot{V}O_{2peak}$ as a performance characteristic may be helpful in the examination of the test protocols used for this study. The reliability and validity of tests, such as indirect calorimetry or maximal predictive tests, such as the Leger 20 metre Shuttle Run, will be discussed. The validity and reliability of various submaximal tests used to predict $\dot{V}O_{2peak}$ will also be reviewed and compared to indirect calorimetry and maximal predictive $\dot{V}O_{2peak}$ test protocols.

2.1.1 Maximal Tests for the Evaluation of $\dot{V}O_{2peak}$

The measure of $\dot{V}O_{2peak}$ is of particular interest because it is considered the *gold standard* indicating cardiorespiratory fitness (ACSM, 2000). Furthermore, $\dot{V}O_{2peak}$ is often used to gauge the intensity for exercise programs. Considering these applications of

$\dot{V}O_{2peak}$, there is particular interest in identifying the role of $\dot{V}O_{2peak}$ in the determining endurance performance.

Peak O_2 uptake is the product of the arterial-venous oxygen difference ($mL \cdot O_2 \cdot L^{-1}$) and the maximal cardiac output ($L \cdot min^{-1}$). The two- to three-fold differences in $\dot{V}O_{2peak}$ ($L \cdot min^{-1}$) that are present across populations are a result of the differences in maximal cardiac output (HR × stroke volume) and changes in arteriovenous oxygen difference [$(a-v)O_2$] . Therefore, $\dot{V}O_{2peak}$ is related to the functional capacity of the heart (Levitzky, 2003).

The protocols used to measure $\dot{V}O_{2peak}$ are numerous and can be classified into two categories, namely submaximal and maximal. Submaximal tests typically require participants to work up to a specified percentage of their maximum ability (i.e. a percentage of HR_{peak}). Peak $\dot{V}O_{2peak}$ is then predicted based on the known linear relationship between HR and $\dot{V}O_{2peak}$ (ACSM, 2000). In maximal test protocols, participants typically engage in some form of graded exercise, which continues until the participants experience volitional fatigue or can no longer maintain the required workload. From this effort, $\dot{V}O_{2peak}$ is either estimated or measured directly. The prediction methods use extrapolation formulas while the direct measurement involves the assessment of ventilation, $\dot{V}O_2$ and $\dot{V}CO_2$ from expired air via indirect calorimetry.

2.1.2 Lab Based Tests to Evaluate $\dot{V}O_{2peak}$

The body's ability to maintain a level of exertion (i.e., exercise) for an extended period of time is a direct reflection of cardiorespiratory fitness. Direct measurement of $\dot{V}O_{2peak}$ is the best quantitative measure of cardiorespiratory endurance. The participant performs a graded or ramped exercise test, in which the workload is progressively increased until no further increase in $\dot{V}O_2$ is elicited. The $\dot{V}O_{2peak}$ can be measured precisely in a laboratory through analysis of the air a person inhales and exhales when exercising to a level of exhaustion (i.e., peak intensity). Direct measurements of $\dot{V}O_{2peak}$ are typically preformed via open circuit spirometry. During open circuit spirometry, the participant breathes through a low-resistance valve while expired fractions of O_2 and CO_2 are measured. The open circuit spirometry can also provide information regarding capacity for O_2 transport and utilization and the rate of energy expenditure during exercise. This is known as indirect calorimetry and measures the rate of $\dot{V}O_2$ and provides general information about the substrates being used for exercise (Montoye, Ayen, Nagle, & Howley, 1985). As exercise intensity increases, the ratio of $\dot{V}CO_2$ to $\dot{V}O_2$ increases, suggesting an increased reliance on carbohydrate metabolism and the accumulation of lactic acid.

The accumulation of blood lactate during exercise is often used as a predictor of performance. However, due to the invasive nature of blood lactate testing, ventilatory threshold (VT) is often used as an indirect indicator of lactate accumulation and lactate threshold (LT). The ventilatory threshold is assessed non-invasively by monitoring the point at which $\dot{V}_E/\dot{V}O_2$ exhibits an increase without an accompanying rise in $\dot{V}_E/\dot{V}CO_2$. As the work rate increases linearly during exercise, $\dot{V}_E$, $\dot{V}O_2$, and $\dot{V}CO_2$ increase until lactic acidosis develops in the blood. When the work rate is above VT, the removal of CO_2 is greater than O_2 because CO_2 is generated by the buffering of lactic acid by bicarbonate in addition to metabolic CO_2 production (Beaver, Wasserman, & Whipp, 1986). Ventilatory threshold has been identified by several studies (Acevedo & Goldfarb, 1989; Beaver et al., 1986; Dickhuth et al., 1999; Gaskill et al., 2001). Beaver et al. (1986) suggests when

V_E increases in proportion to $\dot{V}CO_2$ (i.e., isocapnic buffering), thus is the point at which VT occurs. Minute ventilation increases linearly with $\dot{V}O_2$ (i.e., $\dot{V}_E/\dot{V}CO_2$ appears constant or decreases slightly) up to VT. With further increases in work rate, V_E begins to increase faster than CO_2 output ($\dot{V}_E/\dot{V}CO_2$ increases). This increase in ventilation compensates for lactic acidosis by causing the arterial pressure of CO_2 to decrease, thereby stabilizing the lactic acid induced decrease in blood pH. This is the logic of the Beaver et al. (1986) study in which they developed a method of measuring VT using gas exchange. The method detects the VT using computerized regression analysis of the slopes of the $\dot{V}CO_2$ versus $\dot{V}O_2$ plot, which detects the beginning of the excess $\dot{V}CO_2$ generated from the buffering of hydrogen (H^+), termed the V-slope method. Using 10 male subjects (ages 19-39), who completed an incremental cycle ergometry test, Beaver et al. (1986) demonstrated that the rise in $\dot{V}CO_2$ is correlated with LT and the rise in bicarbonate (HCO_3^-). The mean $\dot{V}O_2$ at LT computed by the V-slope analysis did not differ from the mean value determined traditional visual methods (i.e., $\dot{V}_E$, $\dot{V}O_2$, and $\dot{V}CO_2$ breakpoint), but LT could be more reliably determined by the V-slope method. This method for determining the LT is non-invasive and therefore offers advantages over other methods that depend on invasive and expensive lactate analysis equipment.

Given that the aerobic demands of submaximal running have been investigated for years, $\dot{V}O_{2peak}$, VT, and LT have garnered considerable research attention relative to identifying the predictors of endurance running performance. However, researchers have shown running economy and fractional utilization of $\dot{V}O_{2peak}$ also contribute to endurance performance (Acevedo & Goldfarb, 1989; Acevedo, Rinehardt, & Kraemer, 1994). Acevedo and Goldfarb (1989) determined the effects of increased training intensity (ITI) on $\dot{V}O_{2peak}$, plasma lactate accumulation, VT, and performance in trained distance runners. Seven male distance runners increased their training intensity from 85% HR_{peak} three days a week to 90-95% HR_{peak} three days a week for eight weeks. Increased training intensity did not alter $\dot{V}O_2$ (65 ± 2 versus 66 ± 2 $mL \cdot kg^{-1} \cdot min^{-1}$) but improved 10 km race time by 63 seconds and increased run time to exhaustion on the treadmill by 4 minutes. Decreases in plasma lactate concentration at 85 and 90% of $\dot{V}O_{2peak}$ were also observed after ITI. No differences were found in plasma lactate at 65, 70, 75 or 80% of $\dot{V}O_{2peak}$ or in LT and VT following ITI. Correlations were obtained between 10 km race times and changes in plasma lactate at 85 and 90% of $\dot{V}O_{2peak}$ ($r = 0.69$ and 0.73, respectively). Lactate accumulation (2.5 and 4.0 mM) occurred at a greater percent of $\dot{V}O_{2peak}$ after ITI. Additionally, the changes in plasma lactate were dissociated from alterations in LT and VT after ITI. These data indicate that previously trained runners can increase training intensity to improve endurance performance by lowering lactate at the intensity at which they trained despite no changes in LT, VT, and $\dot{V}O_{2peak}$. Several researchers have identified running economy as having a high correlation with distance running performance (Calbet, Chavarren, & Dorado, 2001; Cunningham, 1990; Wiswell et al., 2000). Running economy is defined as the relationship between velocity of running and $\dot{V}O_2$ (Wiswell et al., 2000). This suggests that although $\dot{V}O_{2peak}$ may set the upper limit for endurance performance, the best predictor of performance is the speed that can be maintained at LT or VT (i.e., running economy) (Berthoin et al., 1994) (See appendix A).

2.2 Maximal Predictive Tests to Evaluate $\dot{V}O_{2peak}$

The direct measurement of $\dot{V}O_{2peak}$ is preferred whenever precise measurement is required (e.g., for the prescription of exercise for the purpose of improved cardiovascular function or for clinical diagnosis). The measurement of $\dot{V}O_{2peak}$ via indirect calorimetry is technically demanding and expensive. Therefore, the use of maximal prediction tests (e.g., Bruce Max Treadmill protocol, Leger 20 metre Shuttle Run, 1.5 mile run/walking test) or submaximal tests (e.g., Astrand Cycle Egrometer or Bruce and Balke 85% Treadmill protocols) to estimate actual $\dot{V}O_{2peak}$ is common practice. Therefore, when indirect calorimetry is not feasible or desirable, a variety of predictive tests (i.e., indirect tests) are used (ACSM, 2000).

There are numerous lab based maximal effort tests that can be used to assess $\dot{V}O_{2peak}$. The Bruce treadmill protocol involves seven 3-minute stages which can be used to predict a $\dot{V}O_{2peak}$ of up to 56 $mL \cdot kg^{-1} \cdot min^{-1}$ (ACSM, 2000). A disadvantage of the Bruce test is the relatively large increments in workload, which may result in the inability to identify the plateau of physiologic responses (ACSM, 2000; Kang, Chaloupka, Mastrangelo, Biren, & Robertson, 2001; Lukaski, Bolonchuk, & Klevay, 1989). Kang et al. (2001) studied sixteen healthy men (aged 27 ± 1 year) completing treadmill testing to volitional exhaustion using the Balke, Bruce, and Ellestad protocols. The Balke protocol resulted in a greater time to exhaustion ($p < 0.01$) and total work output ($p < 0.01$), but a lower estimate $\dot{V}O_{2peak}$ ($mL \cdot kg^{-1} \cdot min^{-1}$; $p < 0.05$). The rates of increase in $\dot{V}O_2$ and blood lactate concentration were lower on the Balke than on the Bruce and Ellestead protocols. Therefore, the observed differences in $\dot{V}O_2$ and lactate concentrations may reflect differences in the rate of energy requirement, aerobic and anaerobic metabolism, and physiological stress associated with each protocol. As a result, exercise capacity may be markedly overestimated when it is predicted from exercise time or workload (ACSM, 2000). Therefore, treadmill protocols with larger increments (such as the Bruce and the Ellestad) are suited for screening younger and/or physically active individuals, whereas protocols with smaller increments (such as the Naughton, Balke-Ware), are best for older or non-active individuals (Lukaski et al., 1989).

Regression equations have been formulated from laboratory data relating measures of work rate to metabolic equivalents. Dill (1965) measured the net $\dot{V}O_2$ of level and grade running in 10 males during maximal treadmill exercise using indirect calorimetry. During walking, approximately 0.1 $mL \cdot O_2$ is needed for transporting each kg of body mass per meter (m) of horizontal distance covered (Dill, 1965). Margaria, Cerretelli, Aghemo, and Sassi (1963) used indirect calorimetric measurements on two athletes running at speeds up to 22 km/hr and grades from –20 to +15%. A nomogram was developed for calculating the energy expenditure for running when the speed and the incline are known. The energy cost per kilometer in horizontal run ($0.2\ mL \cdot kg \cdot min^{-1}$) is about double that for walking ($0.1\ mL \cdot kg \cdot min^{-1}$) at the most economical speed ($4\ km \cdot hr^{-1}$) (Margaria et al., 1963). Nagel, Balke, Baptista, Alleyia, and Howley (1971) used indirect calorimetry during progressive treadmill walking to determine that the cost of raising body mass in opposition to gravity at sea level is 1.8 ml O_2 per kg of body mass for each meter of vertical distance ($1.8\ mL \cdot kg^{-1} \cdot min^{-1}$). The $\dot{V}O_2$ of vertical ascent in treadmill running is half that of walking or $0.9\ mL \cdot kg^{-1} \cdot min^{-1}$ (Margaria et al., 1963).

The American College of Sports Medicine (2000) suggests these metabolic equations are appropriate for general clinical and laboratory use when standard ergometric devices (i.e., treadmill and bike) are available but open circuit spirometry is not. These equations can also best used to estimate or predict energy expenditure for some nonergometric exercises (e.g., outdoor or indoor walking or running). Therefore, it is important to review the validity and reliability of these equations. Latin and Elias (1993) addressed the of validity the ACSM metabolic equations by determining if $\dot{V}O_{2peak}$ could be predicted accurately with the Astrand-Ryhming (AR) nomogram in conjunction with equations reported by the American College of Sports Medicine (ACSM, 2000). Fifty-three subjects (28 males and 25 females) performed three treadmill tests to determine $\dot{V}O_{2peak}$, HR and $\dot{V}O_2$ of submaximal walking and running. Correlations between actual (i.e., via indirect calorimetry) and predicted $\dot{V}O_{2peak}$ values were strong for both walking $r = 0.82$, and running $r = 0.86$, and with low standard error of the estimate (SEE) 0.47 and 0.53 $L\cdot min^{-1}$, respectively. These results indicated that when the ACSM estimates of the $\dot{V}O_2$ of walking and running were used with the AR nomogram, reasonably accurate predictions of $\dot{V}O_{2peak}$ were obtained. Peterson, Pieper, and Morey, (2003) explored the accuracy and bias of prediction ACSM equations in older, deconditioned men and women. One hundred seventy-one men (73 ± 5 years) and women (71 ± 5 years) were examined. Oxygen uptake was measured using a standardized protocol (i.e., Pepper protocol, 0.5 $m\cdot hr^{-1}$ increase every 3 minutes) with concurrent gas analysis. Measured $\dot{V}O_{2peak}$ were compared with predicted values. The ACSM equations (ACSM, 2000) overestimated $\dot{V}O_{2peak}$ in men and women by 26 ± 8 and 21 ± 7 $mL\cdot kg^{-1}\cdot min^{-1}$, respectively as compared to the measured values of 22 ± 5 and 17 ± 4 $mL\cdot kg^{-1}\cdot min^{-1}$, respectively. These findings dispute the ACSM (2000) claim that the prediction equations are accurate when standardized conditions and steady state protocols are followed (Peterson, Pieper, & Morey, 2003). ACSM (2000) concedes that the variance of the predicted $\dot{V}O_{2peak}$ used in the metabolic calculations are much higher than the standard error of the estimate (~7%) due to inter-subject variability. The disadvantage of these lab based maximal tests is that equipment availability, motivation, and the inherent risk associated with maximal testing has to be considered when deciding on test protocol selection.

2.3 Submaximal Laboratory Tests to Evaluate $\dot{V}O_{2peak}$

Since maximal exercise testing is not feasible for assessing cardiorespiratory fitness for the majority of health and fitness practitioners, submaximal laboratory tests are the protocols of choice (ACSM, 2000). Submaximal tests use prediction equations derived from the linear correlation between the measured $\dot{V}O_{2peak}$ and HR during submaximal workloads. These tests are validated by examining (i) the correlation between directly measured $\dot{V}O_{2peak}$ and the $\dot{V}O_2$ estimated from physiologic responses to submaximal exercise (i.e., HR at a specified power output); or (ii) the correlation between directly measured $\dot{V}O_{2peak}$ and test performance (i.e., time to prescribed percent of peak HR_{peak} using a standard graded or ramped exercise test protocol) (ACSM, 2000). The linear relationship between heart rate, $\dot{V}O_2$, and work rate is well established. Arts and Kuipers (1994) analyzed the relationship between the percentage of peak workload ($\%W_{peak}$), percentage of HR_{peak}, and percentage of peak oxygen uptake ($\%\dot{V}O_{2peak}$) in 53 male cyclists. All subjects performed an incremental maximal cycle ergometer test and a linear relationship between power output, $\dot{V}O_2$, and HR was observed. The relationships between $\%W_{peak}$ and $\%\dot{V}O_{2peak}$, as well as between $\%W_{peak}$ and $\%HR_{peak}$, were linear ($r = 0.98$ and $r = 0.97$, respectively; $p < 0.001$) (Arts & Kuipers, 1994). Bot and Hollander (2000) investigated the validity of using HR responses to estimate $\dot{V}O_2$ during varying non-steady state activities. Dynamic and static exercises engaging large and small muscle masses were studied in four different experiments. In the first experiment, 16 subjects performed an interval test on a cycle ergometer, and 12 subjects performed a field test consisting of various dynamic leg exercises and found statistically significant correlations between HR and $\dot{V}O_{2peak}$ during both the interval test ($r = 0.90 \pm 0.07$) and the field test ($r = 0.94 \pm 0.04$). In the second experiment, 14 non-wheelchair-bound subjects performed both an interval wheelchair test on a motor driven treadmill, and a wheelchair field test consisting of dynamic and static arm exercise. Statistically significant relationships were found for all subjects during both the interval test ($r = 0.91 \pm 0.06$) and the field test ($r = 0.86 \pm 0.09$). Although the correlations were less than under steady state conditions, Bot and Hollander (2000) concluded that $\dot{V}O_2$ may be estimated from individual HR-$\dot{V}O_2$ regression lines during non-steady state exercise. Therefore, $\dot{V}O_{2peak}$ may be estimated using the relationship between HR and $\dot{V}O_2$ without individuals having to give maximal effort or reach steady state during workload increments. This estimation is typically done using the ACSM metabolic equations. During submaximal exercise testing, predetermined workloads are used to establish a steady state effort (i.e., plateau of $\dot{V}O_2$ and HR at a given workload). The steady state HR at each work level is plotted graphically and extrapolated to $\dot{V}O_{2peak}$ at the age predicted HR_{peak} (HR = 220-age) (McConnell, 1996).

McConnel (1996) outlined two key assumptions associated with submaximal testing which are necessary to ensure accuracy when attempting to predict $\dot{V}O_{2peak}$. Firstly, selected workloads should be reproducible and a steady state HR must be obtained during each stage of the exercise. In order to obtain steady state, workload durations of 3 minutes or more are used. However, Bot and Hollander (2000) states that the steady state HR assumption does not have to be met to predict $\dot{V}O_{2peak}$ accurately. Secondly, the HR_{peak} for a given age is variable (i.e., HR = 220 – age [± 10 $b \cdot min^{-1}$]). Heart rate and $\dot{V}O_{2peak}$ exhibit a linear relationship over a wide range of values, and as a result, the slope of $HR/\dot{V}O_{2peak}$ regression can be extrapolated to an assumed HR_{peak} (McConnell, 1996).

Unlike indirect calorimetry or maximal predictive protocols, the motivation of the participant and the inherent risk in participating in a maximal test is of less concern due to the submaximal nature of the test. The decrease in risk and motivation make the submaximal test a more participant friendly option. The disadvantage of lab-based maximal tests is that they require expensive equipment and related expertise. In contrast, field tests allow for several participants to be tested during a single testing session and are often simple to administer.

2.3.1 Field Tests to Evaluate $\dot{V}O_{2peak}$

Currently, there are no submaximal running field tests that predict of $\dot{V}O_{2peak}$ which allow more than one participant to be tested during a single testing session. The Canadian Leger 20 metre shuttle run test (LST) (Leger, Mercier, Gadoury, & Lambert, 1988), Copper 12 minute run, and 1.5 mile run all allow for mass testing, which is both time and cost efficient, however, these tests are maximal in nature (Berthoin et al., 1994; Grant et al., 1999; O'Gorman, 2000; Paliczka, Nichols, & Boreham, 1987).

Larsen et al. (2002) evaluated a submaximal, 1.5-mile endurance test for college-aged students using walking, jogging, or running exercise. College students (52 men, 47 women), ages 18-26 years, successfully completed the 1.5-mile test twice, and a maximal graded indirect calorimetry treadmill test. Participants were instructed to achieve a "somewhat hard" exercise intensity during the 1.5-mile test. In order to predict $\dot{V}O_{2peak}$, participants were instuctioned to travel the 1.5-mile distance as quickly as possible. This test was developed initially using military personnel (Grant, Corbett, Amjad, Wilson, & Aitchison, 1995). Therefore, the normative data used to predict $\dot{V}O_{2peak}$ is limited to individuals with a similar age and level of cardiorespiratory fitness. The multiple linear regression preformed generated a prediction where $\dot{V}O_{2peak} = 65.404 + 7.707 \times$ gender (1 = male; 0 =female) - $0.159 \times$ body mass (kg) - 0.843 x elapsed exercise time (minutes; walking, jogging or running). This equation showed validity ($r = .86$, SEE = 3.37 $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) similar to the accuracy of comparable field tests (i.e., LST), and reliability (ICC = .93). The calculation for predicting $\dot{V}O_{2peak}$ is done using the ACSM metabolic prediction equation for running [i.e., $\dot{V}O_2 = (0.2 \times \text{speed } (\text{m}\cdot\text{min}^{-1})) + (0.9 \times \text{speed } (\text{m}\cdot\text{min}^{-1})) \times \%$ grade + 3.5 $\text{mL}\cdot\text{kg}^{-1}\text{min}^{-1}$]. Further, this test can accommodate a range of fitness levels (from walkers to runners). However, the subjective nature of the "somewhat hard" effort level could decrease reliability as participant's evaluation of effort level could change between tests.

The LST originally developed by Leger and Lambert (1982), has been widely used to predict $\dot{V}O_{2peak}$ in a field setting. The original LST involved 2 minute stages (later shortened to 1 minute stages) of ramped exercise to exhaustion with a typical duration of 8-12 minutes. Paliczka et al. (1987) concluded that the LST is an ideal field test because the pace is regulated by audio signals, the incremental test ensures a gradual rise in work rate and HR, the test is highly reliable ($r = 0.975$), and many participants can be tested at a during a testing session (Leger & Lambert, 1982; Paliczka et al., 1987).

The LST was originally designed to predict $\dot{V}O_{2peak}$ of adults attending fitness classes and in athletes participating in sports characterized by frequent starts and stops. The LST has also been used to assess for cardiorespiratory fitness in occupational settings (Stickland, Petersen, & Bouffard, 2003). Typically, a certain level of cardiorespiratory fitness is required to perform the physical tasks of job safely and effectively. Although direct measurement of $\dot{V}O_{2peak}$ would be ideal, employers frequently find that field tests or predictive tests are more convenient and time efficient (Stickland et al., 2003). Subsequently, the accuracy of the test being used will effect the accuracy of the decisions on suitability of employment (Stickland et al., 2003).

The design of the LST (Leger et al., 1988) allows for quick set up and analysis. The speed set by a pre-recorded taped cassette increases (from 8.5 $km \cdot hr^{-1}$) at the rate of 0.5 $km \cdot hr^{-1}$ every minute until participant can no longer maintain the pace on two consecutive shuttles. The maximal aerobic speed (MAS) from the LST was used to predict the $\dot{V}O_{2peak}$ in 53 males (31 ± 8 years) and 24 women (31 ± 7 years) using the regression equation VO_{2peak} ($mL \cdot kg^{-1} min^{-1}$) = -24.4 + 6.0X, where X equals the MAS, and compared to the results attained on a multistage incline treadmill test using indirect calorimetry (TM). The correlation between the shuttle run MAS and the TM was high (*r* = 0.87, SEE 4.68). However, Table 1 from Leger et al. (1988) presents predicted $\dot{V}O_{2peak}$ values that are inconsistent with the equation. For example, if stage 10 in the LST is completed, the MAS entered into the regression equation is 13.0 $km \cdot min^{-1}$, which predicts a $\dot{V}O_{2peak}$ of 53.6 $mL \cdot kg^{-1} \cdot min^{-1}$. However, Table 1 predicts a $\dot{V}O_{2peak}$ of 50.6 $mL \cdot kg^{-1} \cdot min^{-1}$. No explanation can be found for this discrepancy. In order to validate the LST as a predictor of $\dot{V}O_{2peak}$ in adults, Leger and Gadoury (1989) referred to an earlier publication

(Mercier, 1983) where the regression equation originally developed for children was adapted for adults. The formula $\dot{V}O_{2peak} = -27.4 + 6.0 \times MAS$, calculates $\dot{V}O_{2peak}$ values that are consistent with those in Table 1 in Leger et al. (1988). Table 2.1 provides a comparison of the predicted $\dot{V}O_{2peak}$ values attained from Leger and Gadoury (1989), and Leger et al. (1988).

Leger and Gadoury (1989) presented a third regression equation $\dot{V}O_{2peak} = -32.678 + 6.592 \times MAS$ to explain the relationship between $\dot{V}O_{2peak}$ obtained at the end of a graded treadmill test and MAS. When the same MAS as used above (13 $km \cdot min^{-1}$) is entered into the above formula, $\dot{V}O_{2peak} = 53.0$ $mL \cdot kg^{-1} \cdot min^{-1}$. This is consistent with the $\dot{V}O_{2peak}$ value attained using the $-24.4 + 6.0 \times MAS$ from Leger et al. (1988) but differs from Table 1 in Leger et al. (1988).

Stickland et al. (2003) highlighted several issues concerning the LST validation articles. First, both Leger & Gadoury (1989) and Leger et al. (1988) used the same sample to develop different regression equations. No indication was given by either paper as to which formula is more appropriate. Secondly, Stickland et al. (2003) suggested that $\dot{V}O_{2peak}$ was not actually measured. For example, in Leger et al. (1988), $\dot{V}O_{2peak}$ was estimated using the backwards extrapolation technique of the $\dot{V}O_2$ recovery curve to time zero (Leger, Seliger, & Brassard, 1980). Leger and Gadoury (1989) used a Douglas bag sample collected during the final minute of a graded treadmill test to exhaustion as their criterion measure for $\dot{V}O_{2peak}$. Stickland et al. (2003) suggests both these techniques only estimate $\dot{V}O_{2peak}$ and do not provide a direct measurement. Finally, Stickland et al. (2003) proposed that the sample size (53 males, 24 females) is inadequate to conclude with

Table 2.1. Comparison of predicted $\dot{V}O_{2peak}$ values between Leger et al. (1988) and Leger & Gadoury (1989).

Time (min)	MAS ($km \cdot hr^{-1}$)	Leger et al. (1988) -24.4+(6 × MAS)	Leger & Gadoury (1989) -27.4+(6 × MAS)	Leger & Gadoury (1989) -32.678+(6.592 × MAS)
1	8.5	26.6	23.6	23.4
2	9.0	29.6	26.6	26.7
3	9.5	32.6	29.6	29.9
4	10.0	35.6	32.6	33.2
5	10.5	38.6	35.6	36.5
6	11.0	41.6	38.6	39.8
7	11.5	44.6	41.6	43.1
8	12.0	47.6	44.6	46.4
9	12.5	50.6	47.6	49.7
10	13.0	53.6	50.6	53.0
11	13.5	56.6	53.6	56.3
12	14.0	59.6	56.6	59.6
13	14.5	62.6	59.6	62.9
14	15.0	65.6	62.6	66.2

Note. VO_2 = oxygen uptake and MAS = maximum aerobic speed. $\dot{V}O_{2peak}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)

confidence that one regression equation accurately predicts $\dot{V}O_{2peak}$ for both men and women. This conclusion is a result of the commonly known gender differences in physiological characteristics. Given the above concerns, the LST prediction equations merit review.

Correlations have been found between measured $\dot{V}O_{2peak}$ and LST performance (Paliczka et al., 1987; Ramsbottom, Brewer, & Williams, 1988; Ramsbottom, Nevill, Seager, & Hazeldine, 2001). Paliczka et al. (1987) assessed the validity of the LST as both a field test of cardiorespiratory endurance and as a predictor of competitive performance in a 10 kilometre (10 km) race. Nine male subjects (age 35 ± 6 years) underwent a laboratory test of $\dot{V}O_{2peak}$ on a treadmill ($\dot{V}O_{2peak}$ = 59 ± 10 $mL \cdot kg^{-1} min^{-1}$), completed the LST (score 105 ± 24 laps) and then competed in a 10 km race (finishing time 42 ± 7 minutes). There were significant correlations between these variables (LST versus $\dot{V}O_{2peak}$, $r = 0.93$, < 0.05; LST versus 10 km, $r = -0.93$, < 0.05; $\dot{V}O_{2peak}$ versus 10 km, $r = -0.95$, < 0.05). These results support the hypothesis that the LST is a valid field test of cardiorespiratory endurance and suggest that it can be used to predict relative running performance over 10 km. Ramsbottom et al. (1988) examined the validity of using the LST to estimate $\dot{V}O_{2peak}$. Running ability was described as the final level attained on the shuttle run test and as time to complete a 5 km run. Peak $\dot{V}O_2$ was measured directly for 74 volunteers (36 men, 38 women) who completed the treadmill test using indirect calorimetry. Peak $\dot{V}O_2$ as 58 ± 7 and 47 ± 6 $mL \cdot kg^{-1} \cdot min^{-1}$ for the men and women respectively ($p < 0.01$). The levels attained on the shuttle run test were 13 ± 2 (men) and 10 ± 2 (women; $p < 0.01$). The correlation between measured $\dot{V}O_{2peak}$ and shuttle level was $r = 0.92$. The correlation between $\dot{V}O_{2peak}$ and the 5 km run was $r = -0.94$

and the correlation between both field tests was -0.96. Thus the progressive shuttle run test provides a valid estimate of $\dot{V}O_{2peak}$ and indicates 5 km running potential in active men and women. The LST can accurately predict $\dot{V}O_{2peak}$ as well as running velocity, which in turn can be used to determine ideal running economy. The calculations of running economy can offer a method of prescribing pacing and intensity in combination with the HR associated with VT, LST, and $\dot{V}O_{2peak}$ for training program design.

In contrast, there have been other articles suggesting the regression equations provided by Leger and Gadoury (1989), and Leger et al. (1988) underestimate the $\dot{V}O_{2peak}$ (Berthoin et al., 1994; St Clair Gibson, Broomhead, Lambert, & Hawley, 1998). Using the equation $\dot{V}O_{2peak} = -27.4 + 6.0 \times MAS$, Berthoin et al. (1994) found that predicted $\dot{V}O_{2peak}$ for male and female physical education students ($N = 17$) was 9 % or 5 $mL \cdot kg^{-1} \cdot min^{-1}$ lower $\dot{V}O_{2peak}$ measured in the laboratory. For 20 male squash players and runners, St. Clair Gibson et al. (1998) found that $\dot{V}O_{2peak} = -24.4 + 6.0 \times MAS$ under-predicted $\dot{V}O_{2peak}$ by and average of or 6.8% or 5.2 $mL \cdot kg^{-1} \cdot min^{-1}$. Even though St. Clair Gibson et al., (1998) have found inaccuracies with the prediction of $\dot{V}O_{2peak}$ from either regression equation, no alternative methods were suggested.

Stickland et al. (2003) found the regression equations of Leger and Gadoury (1989) and Leger et al. (1988) systematically under-predicted $\dot{V}O_{2peak}$ for both males and females ($p < 0.05$) when compared to the results from a graded exercise protocol and the automated metabolic cart. Oxygen uptake was measured during a graded treadmill test in 60 men and 62 women (mean age 25.3 and 25.1 years, respectively). The mean terminal shuttle run stage was 9.5 for men and 7.8 for women. Stickland et al. (2003) calculated new regression equations to predict $\dot{V}O_{2peak}$ for males: $Y = 2.75X + 28.8$ ($r^2 = 0.77$, $SEE =$

4.07 mL·kg^{-1}·min^{-1}); and for females: Y = 2.85X + 25.1 (r^2 = 0.66, *SEE* = 3.64 mL·kg^{-1}·min^{-1}), where X equals the last half-stage of the LST completed.

2.4 Summary

Developing a submaximal adaptation of the LST to predict $\dot{V}O_{2peak}$ will allow for a measure of cardiovascular fitness that can be used by a greater range of the population. This submaximal test should allow for the use of velocity, HR, and the percent utilization of $\dot{V}O_{2peak}$ as prediction variables for aerobic endurance and cardiorespiratory fitness. Therefore, the LST could be used on a wider range of participants and allow for the testing of a large number of participants during a testing session. The primary objective of submaximal $\dot{V}O_{2peak}$ testing is to predict $\dot{V}O_{2peak}$ without the need for participants to produce peak effort. This allows a greater range of participants to engage in such a test as maximal tests tend to be limited to an athletic or individuals from a highly motivated healthy population.

CHAPTER III

METHODOLOGY

3.1 Design

Following approval from the Research Ethics Board at the University of Regina (Appendix B), participants were recruited from the University of Regina student population. Briefly, the letter of invitation described the purposes and procedures of the study and indicated that the recipient had been identified as a possible candidate for the research project. The letter also indicated that the principal investigator would contact them by telephone or email to further explain the study, answer any questions, and query their willingness to participate (Appendix C).

Prior to giving consent (Appendix D), the purposes and procedures were once again clarified for all participants, and all questions and concerns addressed. A copy of their signed consent form that included all relevant contact information was provided to participants.

Participants completed three maximal exercise protocols, a graded exercise protocol on a treadmill, a ramped treadmill protocol, and the LST. Participants completed the ramped treadmill protocol (RT) first. In order to allow adequate recovery time between tests, participants then completed the LST no less than two days after completing the RT. Lastly, participants complete the graded treadmill protocol (GT) no less than two days after completing the LST (Figure 3.1). The reason for the test order was to provide variety to the participants by switching the testing environment to prevent boredom and increase compliance over the three test sessions. The design of the present study was similar to that described by Stickland et al. (2003) and Leger et al.

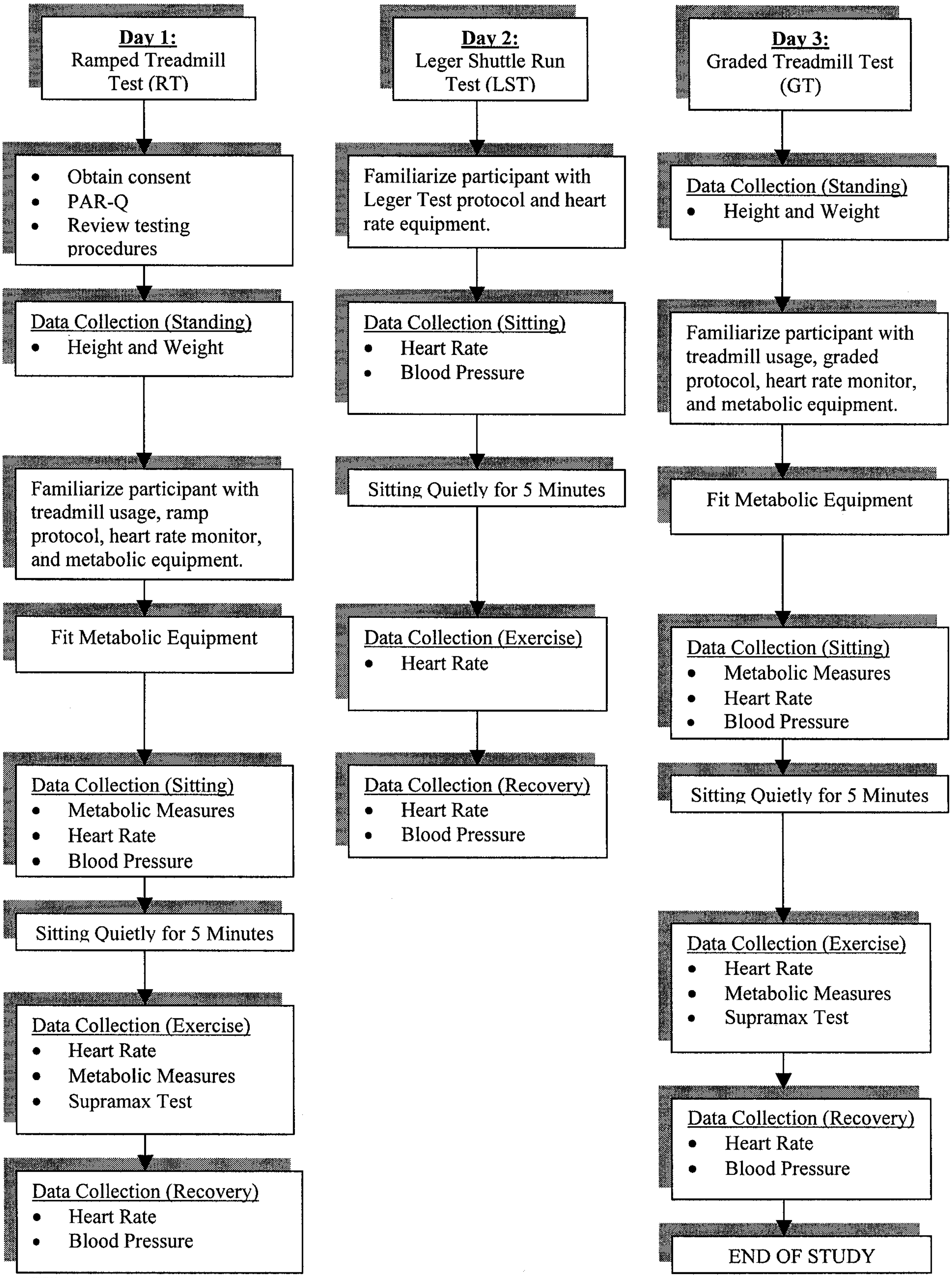

Figure 3.1 – Summary of Study Design and Testing Protocols.

(1988). All testing were completed in the Exercise Physiology Laboratory at the University of Regina.

3.1.1 Sample Size

Thirty-four participants were recruited into the study (17 male and 17 female). The sample size selection was based on a previous study where the LST's ability to predict $\dot{V}O_{2peak}$ was assessed compared to indirect calorimetry (Stickland et al., 2003). Specifically, sample size was estimated from a power calculation formula for multiple regression (Portney & Watkins, 2000) as follows:

$$N = \frac{\lambda(1-r^2)}{r^2} \tag{3.1}$$

where $\lambda = (r^2 / 1 - r^2) \times N$ (sample size from present study) and r^2 = the highest mean r^2 value (0.77) from (Stickland et al., 2003). Therefore, $\lambda = 114$ and $N = 34$ in order to achieve a desired power of 80% with α value of 0.05.

3.1.2 Participants

The participants were healthy individuals ranging in age from 18 to 30 years. Written informed consent and a completed Physical Activity Readiness Questionnaire (PAR-Q) was obtained prior to entry into the study (Appendix E). In order to participate, participants were required to respond negatively to all seven PAR-Q statements. Each participant also received an information and consent form detailing the nature of the study, the possible risks and benefits, the voluntary nature of their participation, and reassurances as to their rights to complete confidentiality. The consent form had to be completed prior to the first day of testing. Each participant also received a copy of the signed consent form while the principle investigator retained the original on file.

3.2 Exercise Testing – Protocols

Pre-Screening. Each participant was required to follow the same pre-test instruction for each test. These included avoiding eating 3-4 hours prior to the test, no smoking for a minimum of 2 hours prior to the test, no caffeine and alcohol for six hours prior to the test, and no heavy exercise on the day of the test. Prior to each test, participants were also required to be free of any acute infections.

Rest. The first day, upon entry into the lab, participants had their height and mass measured. Then participants rested quietly for 5 minutes after which time a resting $\dot{V}O_2$ was recorded for 5 minutes. Resting $\dot{V}O_2$ was only measured on days when participants completed the RT or GT protocols.

3.2.1 Treadmill Tests

Ramped Protocol. Prior to exercise testing, participants were instructed about the use of the treadmill and the various speed increments to be encountered during the test. Following the collection of the resting data, participants performed the RT. The initial workload of the RT was set at 8.5 km/hr and 0% gradient (a warm up stage equivalent to a very slow jog) (Leger & Gadoury, 1989). The RT protocol then progressed 0.5 $km \cdot hr^{-1}$ for the first five one minute stages and then increases 0.8 $km \cdot hr^{-1}$ every minute there after until volitional fatigue or signs/symptoms of exertional intolerance were observed (ACSM, 2000) (Appendix F). Participants were asked throughout the RT if they are able to continue. During exercise, HR was assessed and recorded at the end of each minute. Oxygen uptake and HR changes were monitored continuously. Heart rate was assessed and recorded immediately after exercise termination, and then again three and five minutes post-exercise to assess recovery. A supramax test was performed after 5 minutes of recovery to verify the HR_{peak} and $\dot{V}O_{2peak.}$ The supramax test required the participant to run at a speed equivalent to one stage above that which was achieved during the RT protocol. The supramax test continued with an increase in treadmill speed by 0.8 $km \cdot hr^{-1}$ every minute until volitional fatigue or signs/symptoms of exertional intolerance were observed (ACSM, 2000) (Table 3.1). The highest HR and $\dot{V}O_2$ observed during the RT or supramax test was recorded as the HR_{peak} and $\dot{V}O_{2peak}$ respectively.

Graded Protocol (GT). The GT involved participants walking on a treadmill at a constant speed (6.5 $km \cdot hr^{-1}$). Subsequent increases in workload were characterized by 2% increase in grade every 2 minutes. After the third workload (6.5 $km \cdot hr^{-1}$ at 4% grade), the second phase of the test began whereby speed increased to a comfortable running pace. Grade increased by 2% each minute until volitional fatigue or signs/symptoms of exertional intolerance were observed (ACSM, 2000; Stickland et al., 2003) (Appendix G). This protocol was identical to the one used by Stickland et al. (2003). Participants were asked throughout the exercise testing if they are able to continue. During exercise, HR was assessed and recorded at the end of each minute of exercise. Oxygen uptake and HR changes were monitored continuously. Heart rate was assessed and recorded immediately after exercise termination, and then again three and five minutes post-exercise to assess recovery. A supramax test was preformed following 5 minutes of recovery in order to verify the HR_{peak} and $\dot{V}O_{2peak.}$ The supramax test required the participant to run at speed equivalent to one stage above that which was achieved during the GT protocol. The supramax test continued with the same speed and an increase in treadmill grade by 2% every minute until volitional fatigue or signs/symptoms of exertional intolerance was observed (ACSM, 2000). The highest HR and $\dot{V}O_2$ observed

Table 3.1 Criteria for Exertional Intolerance.

Subjective Criteria	**Physiological Criteria**
Volitional fatigue	Attainment of age predicted peak HR
Shortness of breath, wheezing, leg cramps	Respiratory Exchange Ratio above 1.12
Dizziness	Plateau in $\dot{V}O_2$ despite increases in workload
Inability to keep pace without increasing the risk of injury	

Note. Subjective and physiological criteria for test termination. Volitional fatigue = participant chooses to no longer continue; age predicted peak HR = 220 – age ± 10; Respiratory Exchange Ratio = $\dot{V}CO_2 / \dot{V}O_2$ (ACSM, 2000; McArdle, Katch, Katch, 2001).

during the GT and the supramax was recorded as the HR_{peak} and $\dot{V}O_{2peak}$ respectively.

3.2.2 Leger 20 Metre Shuttle Run Testing

Prior to testing, participants were instructed about the nature of the Canadian LST test and the various speed increments to be encountered. Following the rest period, participants performed the incremental exercise test (Appendix H). The initial workload of the LST was 8.5 $km \cdot hr^{-1}$ (this warm up stage was equivalent to a very slow jog) (Leger & Gadoury, 1989). The LST then progresses 0.5 $km \cdot hr^{-1}$ every minute there after until volitional fatigue or signs/symptoms of exertional intolerance are observed (ACSM, 2000). Participants were asked to stop when they are no longer able to meet the required 20 meters between pylon markers on two consecutive occasions. When participants stopped due to volitional fatigue or were asked to stop because of an inability to maintain the required velocity, the last stage completed was used for the prediction of $\dot{V}O_{2peak}$. For example, if a participant stopped after completing stage 7.5, the final stage completed was assessed as 7 using the Leger et al. (1988), and Leger and Gadoury (1989) equations, and 7.5 using the Stickland et al. (2003) equation. During exercise, HR and stage were assessed and recorded at the end of each minute of exercise. Heart rate was also recorded immediately after exercise termination, and then again at three and five minutes post-exercise. For comparison purposes, $\dot{V}O_{2peak}$ from the LST was calculated using the regression equations developed from Leger et al. (1988) [$-24.4 + 6.0 \times$ Maximum Aerobic Speed (MAS)], Leger and Gadoury (1989) [$1989a = -32.678 + (6.592 \times MAS)$; $1989b = -27.4 + (6.0 \times MAS)$], and Stickland et al. (2003) (males: $\dot{V}O_{2peak} = 2.75X + 28.8$; females $\dot{V}O_{2peak} = 2.85X + 25.1$, where X equals the last half-stage of the shuttle run completed). Figure 3.1 provides an overview of study design. Figure 3.2 provides a graphical representation of the 3 testing protocols discussed above.

3.3 Measured Parameters

3.3.1 Heart Rate

Heart rate was recorded using the Polar Vantage XL. Data were recorded while the participant was at rest, throughout exercise and for 5 minutes of recovery. For data analyses, resting HR was recorded after participants had been sitting quietly for five minutes. Resting HR was recorded as the last 20 second average taken during the resting period. The exercise HR was calculated at each stage of exercise (i.e., mean of the final four 5 second averages (i.e., 20 second average) of each minute as well as immediately after exercise, and then again at three and five minutes post-exercise. Peak heart rate was defined as the highest 20-second average HR observed throughout the test or supramax test (i.e., whichever was the higher value).

3.3.2 Oxygen Uptake

Oxygen uptake was measured at rest and throughout the two treadmill tests. Expired gases were collected using the ParvioMedics TrueMax 2400 metabolic measurement system. The metabolic system employs a Hans Rudolph 3813 heated pneumotach flow meter for the collection of the expired gases. The specific variables monitored included minute ventilation $\dot{V}_E$, $\dot{V}O_2$, carbon dioxide production ($\dot{V}CO_2$), respiratory exchange ratio (RER). Twenty-second averages of $\dot{V}O_2$ data were used for analysis as well as for the determination of $\dot{V}O_{2peak}$. Participants rested for 5 min while connected to the metabolic measurement system to assess to breathing comfortably with the mouthpiece and to allow for adaptations in ventilatory patterns. Resting $\dot{V}O_2$ was

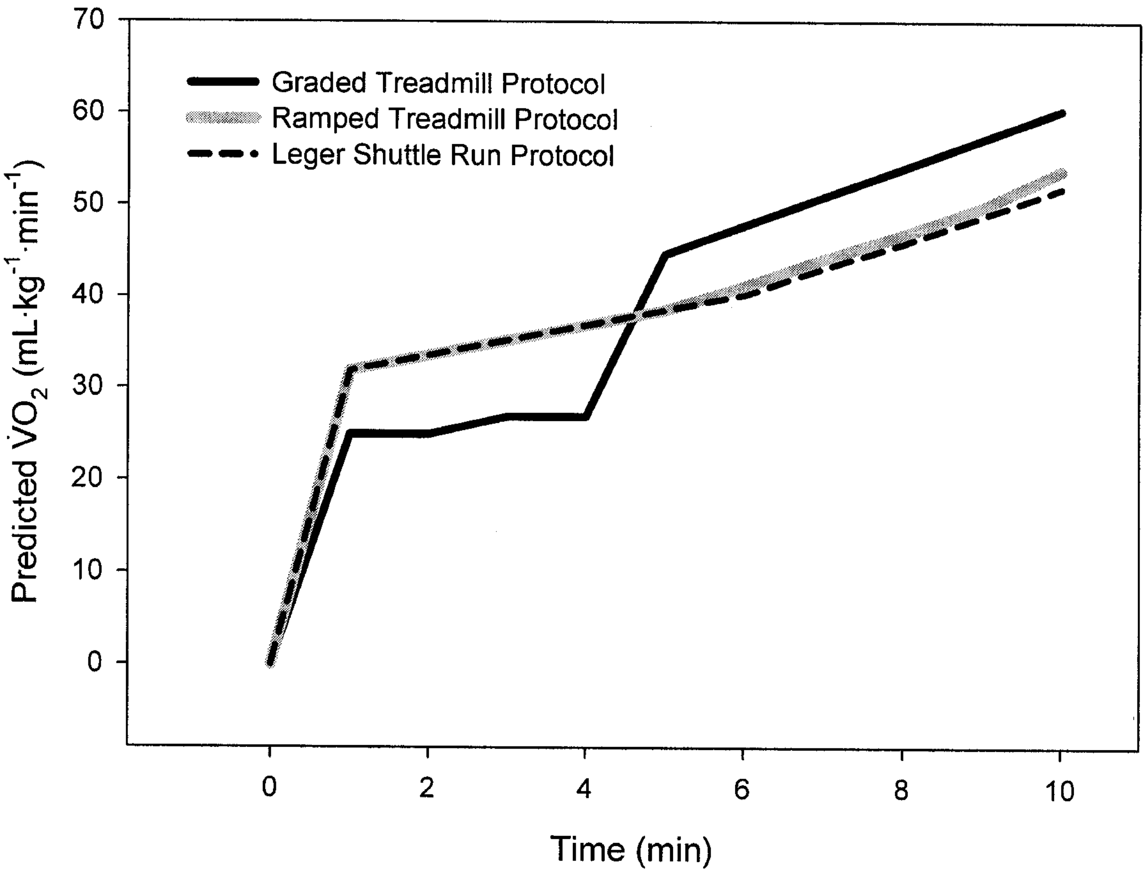

Figure 3.2 Graphical Representation of Predicted $\dot{V}O_2$ from ramped treadmill, graded treadmill, and Leger shuttle run protocols using the ACSM (2000) formula $\dot{V}O_2 = (0.2 \times \text{speed}) + (0.9 \times \text{speed} \times \text{fractional grade}) + 3.5$ where speed is in m · min^{-1}.

calculated as the average of the last 20 seconds of the resting period. Gas exchange VT was identified as the $\dot{V}O_2$ at which the $\dot{V}CO_2$ slope rose more sharply in comparison to the $\dot{V}O_2$ slope (Beaver et al., 1986). Peak $\dot{V}O_2$ was defined as the highest 20-second $\dot{V}O_2$ observed during the test or supramax test (i.e., whichever was the higher value between the max and supramax tests). In order to limit the variability in results, the metabolic cart was calibrated before each use (Stickland et al., 2003). In order to achieve a true $\dot{V}O_{2peak}$ during the RT and GT, participants continued to exercise until volitional fatigue (ACSM, 2000).

3.4 Statistical Analysis

Statistical analysis was done using the Statistical Package for Social Sciences (SPSS version 10.0). To assess difference between HR and $\dot{V}O_2$ responses during rest, the first 4 minutes of exercise, and $\dot{V}O_{2peak}$, between the LST, RT, and GT tests, repeated measures analysis of variance was used. Post-hoc comparisons were performed using the Bonferroni adjustment for multiple comparisons. Secondly, a direct entry multiple regression was employed to investigate the predictive validity of the submaximal modification of the LST using body mass index, HR at rest, HR at minute 1, HR at minute 2, and HR at minute 3 to accurately predict $\dot{V}O_{2peak}$. Lastly, the difference between predicted $\dot{V}O_{2peak}$ from the new regression equation and measured $\dot{V}O_{2peak}$ from the RT was assessed using paired t-test. The level of detection for statistical significance was set at α =.05 (Portney & Watkins, 2000).

CHAPTER IV

RESULTS

4.1 Participants

Forty individuals from the University of Regina population were initially identified and contacted. This sample was reduced to 34 due to *yes* responses on the Physical Activity Readiness Questionnaire (PAR-Q) during the health-screening portion of the study. Seventeen participants were male and 17 were female (Table 4.1).

4.2 Resting Data

As part of the health screening process, all participants' resting HR (HR_{rest}) and blood pressure (BP) were recorded prior to exercise. In order to participate in this study, each participant was required to have a HR_{rest} of $\leq$ 100 $beat \cdot min^{-1}$, and a resting BP of $\leq$ 144/94 mmHg. These limits were based on the prescreening recommendations of the Canadian Society for Exercise Physiology (CSEP, 1993). If the resting values were above these limits, the participants were instructed to sit quietly for up to five minutes, then their resting HR and BP was reassessed. If after 15 minutes of quiet rest, the HR and BP exceeded the limits, the participant was excluded from the study. One subject was excluded from the study because of an elevated resting BP. Following the HR and BP screening, seated resting $\dot{V}O_2$ was recorded for 5 minutes (Table 4.2).

4.3 Submaximal HR Responses

Paired t-tests were used to analyze the differences in HR response between protocols for men and women. For both the males and females, the HR_{rest} prior to the LST was similar to that recorded prior to the RT or GT ($p > 0.05$) (Table 4.2). In the first four minutes of the LST, the HR response for both females and males was similar to the

Table 4.1. Participant characteristics.

Sex	Subjects	Age (yrs)	Height (m)	Mass (kg)	BMI
Female	Mean	21 ± 2.9	1.7 ± 5.1	65.7 ± 7.1[†]	23 ± 2.3
	Range	18 – 30	1.59 – 1.79	54.1 - 77.9	19.3 – 27.4
Male	Mean	23 ± 3.2	1.83 ± 7.5[†]	85.2 ± 12.9	25 ± 2.5
	Range	19 - 29	1.65 – 1.93	58.8 – 108.6	21.5 – 29.0

Note. Mean is the respective mean ± standard deviation and ranges are minimum and maximum values. BMI = body mass index where BMI = mass (kg) / height $(m)^2$. [†]Statistically significant difference versus the males ($p < 0.05$).

Table 4.2. Resting cardiorespiratory variables for females and males.

Sex	Subjects	RT HR_{rest} (beats·min^{-1})[1]	LST HR_{rest}	$\dot{V}O_{2rest}$ (mL·kg^{-1}·min^{-1})[1]	SBP_{rest} (mmHg)	DBP_{rest} (mmHg)
Female	Mean	75 ± 9[†]	74 ± 9[†]	3.6 ± 0.2	112 ± 8[‡]	75 ± 8
	Range	55 – 88	54 – 90	3.3 – 4.0	90 – 124	64 – 94
Male	Mean	67 ± 10	68 ± 10	3.6 ± 0.4	123 ± 9	78 ± 8
	Range	47 – 88	49 – 90	3.0 – 4.4	104 – 142	62 – 92

Note. Mean is the respective mean ± standard deviation and ranges are minimum and maximum values. HR_{rest} = resting heart rate, LST = Leger 20 metre shuttle run, $\dot{V}O_{2rest}$ = resting oxygen uptake, SBP_{rest} = resting systolic blood pressure, DBP_{rest} = resting diastolic blood pressure. [1]The resting HR and $\dot{V}O_2$ values were obtained by averaging the resting data from the ramped and graded treadmill tests. [†]Statistically significant elevation versus the males ($p < 0.05$). [‡]Statistically significant lower response versus the males ($p < 0.01$).

the HR observed during the first four minutes of the RT (Table 4.3). When the HR response of the males and females were compared using a repeated measures ANOVA at minutes 1 to 4 of the LST (Figure 4.1), the males HR was lower ($p < 0.01$). Similarly, the HR response of the males was lower than in the females during the RT ($p < 0.01$).

4.3.1 HR Responses at VT

The exercise protocol (RT vs. GT) did not affect the HR at VT for either males or females ($p > 0.05$). However, the HR at VT during the RT and GT was higher in the males ($p < 0.01$) (Table 4.4).

4.3.2 HR Responses at Peak Exercise

For males, HR_{peak} observed during the RT, GT, and LST was not different (Table 4.5). Similarly, the HR_{peak} of the females was similar across the three test protocols ($p > 0.05$). For males and females, the HR_{peak} observed during the exercise tests were similar to the age predicted HR_{peak} (i.e. 220 – age). The HR_{peak} achieved on the RT, GT, and LST for the males and females were not different.

Paired t-test indicated the males exercised longer than the females during the RT (735 ± 174 vs 585 ± 96 sec respectively) ($p < 0.01$). When GT data from males and females were compared, the males exercised significantly longer (560 ± 126 versus 480 ± 96 sec) ($p < 0.01$). For the LST, the exercise duration of the males (600 ± 138 sec) was also significantly longer than the females (450 ± 90 sec) ($p < 0.01$).

4.4 $\dot{V}O_2$ Responses

Oxygen uptake ($\dot{V}O_2$) was analyzed using indirect calorimetry. Paired t-tests indicated no statistically significant differences in the resting $\dot{V}O_2$ responses between the males and females (Table 4.2).

Table 4.3. Submaximal heart rate responses to ramped treadmill and Leger 20-metre shuttle run tests.

Exercise Time		Minute 1		Minute 2		Minute 3		Minute 4	
Protocol		RT	LST	RT	LST	RT	LST	RT	LST
Sex		HR (beats·min^{-1})	HR (beats·min^{-1})	HR (beats·min^{-1})	HR (beats·min^{-1})	HR (beats·min^{-1})	HR (beats·min^{-1})	HR (beats·min^{-1})	HR (beats·min^{-1})
Female	Mean	150 ± 23†	152 ± 13†	161 ± 14†	166 ± 12†	168 ± 14†	172 ± 12†	175 ± 15†	179 ± 13†
	Range	126 – 172	109 – 173	131 – 183	144 – 187	137 – 185	151 – 193	143 – 190	156 – 197
Male	Mean	139 ± 23	140 ± 15	145 ± 19	145 ± 18	152 ± 18	153 ± 18	159 ± 19	161 ± 19
	Range	100 – 171	84 – 173	110 – 177	113 – 177	116 – 181	116 – 181	116 – 189	116 – 190

Note. Mean is the respective mean ± standard deviation and ranges are minimum and maximum values. RT = ramped treadmill protocol, LST = Leger 20 metre shuttle run, HR = heart rate. †Statistically significant elevation versus the males ($p < 0.01$).

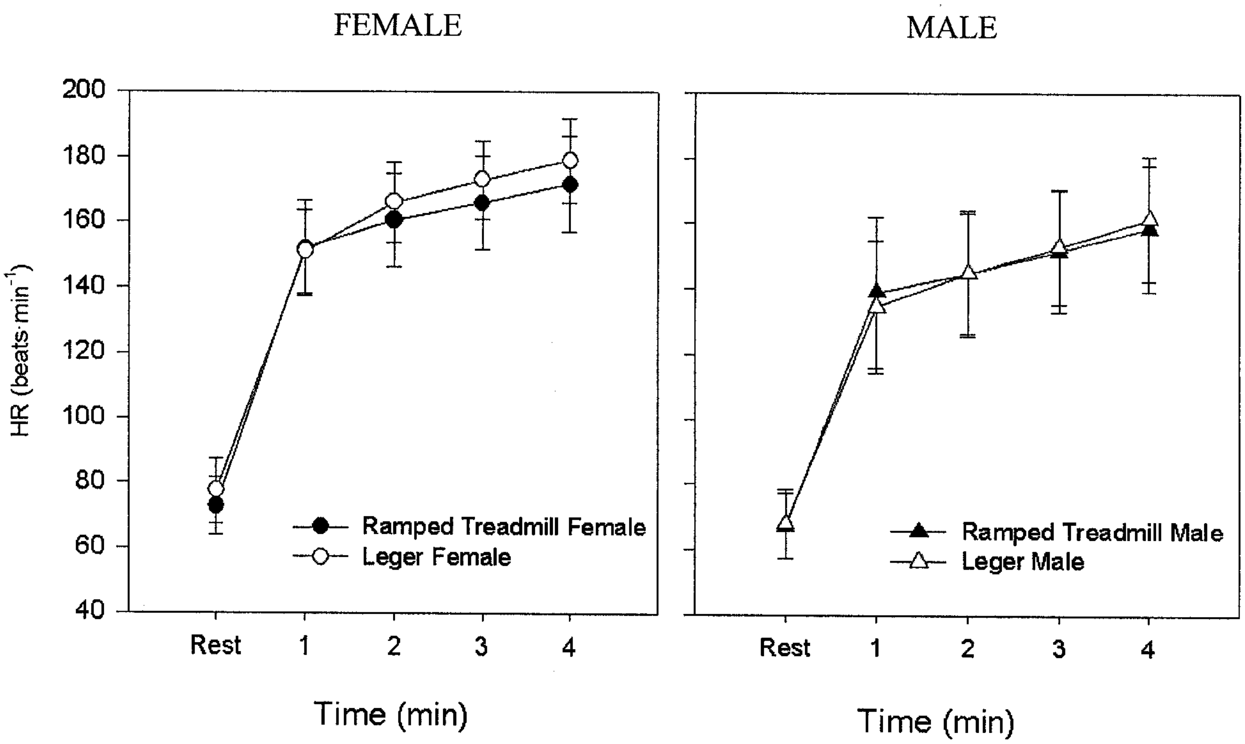

Figure 4.1. Submaximal HR responses during the Ramped Treadmill test versus the Leger 20-meter Shuttle Run test ($p > 0.05$).

Table 4.4. Heart rate at ventilatory threshold.

Protocol		GT		RT	
Sex	Subjects	HR (beats·min^{-1})	% of HR_{peak}	HR (beats·min^{-1})	% of HR_{peak}
Female	Mean	162 ± 9[†]	82 ± 3	166 ± 11[†]	84 ± 6
	Range	145 – 175		146 – 186	
Male	Mean	173 ± 10	87 ± 4	174 ± 11	88 ± 4
	Range	153 – 195		150 – 195	

Note. Mean is the respective mean ± standard deviation and ranges are minimum and maximum values. GT = graded treadmill protocol, RT = ramped treadmill protocol, HR = heart rate, % of HR = percentage of peak heart rate. [†]Statistically significant lower response versus the males ($p < 0.01$).

Table 4.5. Peak heart rate responses to graded treadmill, ramped treadmill, and Leger 20-metre shuttle run test.

Protocol		GT	RT	LST	APPHR
Sex	Subjects	HR (beats·min^{-1})	HR (beats·min^{-1})	HR (beats·min^{-1})	HR (beats·min^{-1})
Female	Mean	198 ± 7	198 ± 8	197 ± 8	199 ± 3
	Range	182 – 209	180 – 209	174 – 209	191 – 202
Male	Mean	198 ± 8	198 ± 8	198 ± 9	197 ± 3
	Range	185 – 218	187 – 218	184 – 216	191 – 201

Note. Mean is the respective mean ± standard deviation and ranges are minimum and maximum values. GT = graded treadmill protocol, RT = ramped treadmill protocol, LST = Leger 20 metre shuttle run, APPHR = age predicted maximum heart rate calculated as (220 – age), HR = heart rate.

4.4.1 $\dot{V}O_2$ Responses at VT and $\dot{V}O_{2peak}$

Paired t-tests indicated the exercise protocol (RT vs. GT) did not affect $\dot{V}O_2$ at VT for either the males or females ($p > 0.05$). However, $\dot{V}O_2$ at VT were higher in males ($p < 0.01$) (Table 4.6). Peak $\dot{V}O_2$ observed during the RT vs. GT was similar for males and females (Table 4.7). The $\dot{V}O_{2peak}$ observed during the RT and GT was significantly higher in males ($p < 0.01$). Appendix I illustrates $\dot{V}O_2$ at VT for a respective male and female participant.

4.5 Submaximal $\dot{V}O_2$ Responses between RT and LST (Leger & Gadoury, 1989a)

In the first two minutes of the LST, the $\dot{V}O_2$ estimates for the females and males under-estimated the $\dot{V}O_2$ observed during the first two minutes of the RT ($p < 0.05$). At minutes 3 and 4 of the LST, the predicted $\dot{V}O_2$ of the females was similar to the $\dot{V}O_2$ response during the RT at minutes 3 and 4. For the males, the predicted $\dot{V}O_2$ for minute 3 of the LST was similar to $\dot{V}O_2$ response observed on the RT at minute 3. However, at minute 4 of the LST, the $\dot{V}O_2$ estimate under-estimated $\dot{V}O_2$ response on the RT ($p < 0.05$). Paired t-test indicated the $\dot{V}O_2$ responses in the first four minutes of the RT were similar for both females and males.

4.5.1 $\dot{V}O_{2peak}$ Responses between RT and LST (Leger & Gadoury, 1989a)

For the male participants, the $\dot{V}O_{2peak}$ response predicted from the LST was lower than that observed from the RT ($p < 0.05$). For the females, the predicted $\dot{V}O_{2peak}$ was similar to $\dot{V}O_{2peak}$ response observed on the RT. Paired t-tests indicated the observed and predicted $\dot{V}O_{2peak}$ during the RT and LST were significantly higher in males (Table 4.7; $p < 0.05$).

Table 4.6. Oxygen uptake responses at ventilatory threshold.

Protocol		GT		RT	
Sex	Subjects	$\dot{V}O_2$ (mL·kg^{-1}·min^{-1})	% of $\dot{V}O_{2peak}$	$\dot{V}O_2$ (mL·kg^{-1}·min^{-1})	% of $\dot{V}O_{2peak}$
Female	Mean	28.8 ± 3.5[†]	66.3 ± 4.8	30.3 ± 3.2[†]	68.1 ± 4.1
	Range	22.1 – 37.3		25.3 – 36.6	
Male	Mean	35.9 ± 7.1	66.8 ± 4.8	36.1 ± 6.9	66.2 ± 4.5
	Range	26.4 – 52.3		28.2 – 52.3	

Note. Mean is the respective mean ± standard deviation and ranges are minimum and maximum values. GT = graded treadmill protocol, RT = ramped treadmill protocol, $\dot{V}O_2$ = oxygen uptake, % of $\dot{V}O_2$ = percentage of peak oxygen uptake. [†]For a given protocol, statistically significant lower response than for males ($p < 0.01$).

Table 4.7. Peak oxygen uptake responses to graded treadmill, ramped treadmill, and Leger 20-metre shuttle run test.

Protocol			LST^a	LST^b	LST^c	GT	RT
Sex	Subjects	LST stage completed	$\dot{V}O_{2peak}$ (mL·kg^{-1}·min^{-1})	$\dot{V}O_{2peak}$ (mL·kg^{-1}·min^{-1})	$\dot{V}O_{2peak}$ (mL·kg^{-1}·min^{-1})	$\dot{V}O_{2peak}$ (mL·kg^{-1}·min^{-1})	$\dot{V}O_{2peak}$ (mL·kg^{-1}·min^{-1})
Female	Mean	$7.5 \pm 1.5^{**}$	$45.8 \pm 4.3^{\dagger *}$	$46.8 \pm 4.2^{\dagger *}$	$44.5 \pm 4.6^{1\dagger}$	$43.4 \pm 3.2^{\dagger}$	$44.5 \pm 3.8^{\dagger}$
	Range	6.0 – 10.5	41.6 – 53.6	42.2 – 55.0	39.8 – 53.0	36.9 – 51.7	38.7 – 52.5
Male	Mean	10 ± 2.3	53.6 ± 7.2*	56.8 ± 6.3*	53.0 ± 7.9*	53.9 ± 7.9	54.5 ± 7.2
	Range	4.5 – 14.0	35.6 – 65.6	41.2 – 67.3	33.2 – 66.2	41.1 – 68.9	40.9 – 68.9

Note. Mean is the respective mean ± standard deviation and ranges are minimum and maximum values. GT = graded treadmill protocol, RT = ramped treadmill protocol, LST = Leger 20 metre shuttle run, HR = heart rate, and $\dot{V}O_2$ = oxygen uptake. ^{a}= using the Leger et al. (1988) equation, ^{b} = using the Stickland et al. (2003) equation, ^{c} = using the Leger & Gadoury (1989a) equation. ^{1}There were no statistically significant differences between RT and LST protocols for the same sex ($p > 0.05$). *Statistically significantly lower completion stage then that observed in the males ($p < 0.01$). †For a given exercise protocol, the $\dot{V}O_{2peak}$ as statistically significant lower responses versus the males ($p < 0.01$).

4.6 Submaximal $\dot{V}O_2$ Responses between RT and LST (Leger & Gadoury, 1989b)

In response to the first two minutes of the LST, the predicted $\dot{V}O_2$ for females and males under-estimated the $\dot{V}O_2$ observed during the RT ($p < 0.05$). At minute three, the predicted $\dot{V}O_2$ of females and males during the LST were similar to the $\dot{V}O_2$ response on the RT. At minute 4, the predicted $\dot{V}O_2$ during the LST for males under-predicted the $\dot{V}O_2$ response on the RT ($p < 0.05$), whereas the $\dot{V}O_2$ predicted for the females were similar to the $\dot{V}O_2$ response observed on the RT at minute 4 (Table 4.8).

4.6.1 $\dot{V}O_{2peak}$ Responses between RT and LST (Leger & Gadoury, 1989b)

The predicted $\dot{V}O_{2peak}$ from the LST, under-predicted the observed $\dot{V}O_{2peak}$ during the RT (Table 4.7) for both the males (50.6 ± 7.2 $mL \cdot kg^{-1} \cdot min^{-1}$) and the females (42.8 ± 4.7 $mL \cdot kg^{-1} \cdot min^{-1}$) ($p < 0.05$). The predicted $\dot{V}O_{2peak}$ and the observed $\dot{V}O_{2peak}$ from the RT were higher in the males ($p < 0.05$).

4.7 Submaximal $\dot{V}O_2$ Responses between RT and LST (Leger et al. 1988)

For the males, the predicted $\dot{V}O_2$ at minute one of the LST under-predicted the $\dot{V}O_2$ response on the RT ($p < 0.05$), whereas for the females, the estimated $\dot{V}O_2$ was similar to the $\dot{V}O_2$ response on the RT ($p > 0.05$). For minutes 2 and 3 of the LST, the $\dot{V}O_2$ estimates for females and males were similar to the $\dot{V}O_2$ observed during the minutes 2 and 3 of the RT (Table 4.9). At minute 4 of the LST, the $\dot{V}O_2$ estimate for both the females and males over-predicted the observed $\dot{V}O_2$ at minute 4 of the RT ($p < 0.05$).

4.7.1 $\dot{V}O_{2peak}$ Responses between RT and LST (Leger et al., 1988)

For males, the predicted $\dot{V}O_{2peak}$ from the LST under-estimated the $\dot{V}O_{2peak}$ response observed during the RT ($p < 0.05$), whereas for the females the LST estimate over predicted the $\dot{V}O_{2peak}$ recorded from the RT ($p < 0.05$) (Table 4.7). A paired t-test

4.8. Oxygen uptake responses to ramped treadmill and Leger 20-metre shuttle run test (Leger and Gadoury, 1989a/b).

Exercise Time		Minute 1		Minute 2		Minute 3		Minute 4	
Protocol		LST[1]	RT	LST[1]	RT	LST[1]	RT	LST[1]	RT
Sex		$\dot{V}O_2$ (mL·kg^{-1}·min^{-1})	$\dot{V}O_2$ (mL·kg^{-1}·min^{-1})	$\dot{V}O_2$ (mL·kg^{-1}·min^{-1})	$\dot{V}O_2$ (mL·kg^{-1}·min^{-1})	$\dot{V}O_2$ (mL·kg^{-1}·min^{-1})	$\dot{V}O_2$ (mL·kg^{-1}·min^{-1})	$\dot{V}O_2$ (mL·kg^{-1}·min^{-1})	$\dot{V}O_2$ (mL·kg^{-1}·min^{-1})
Female	Mean	23.4 / 23.6†	27.1 ± 2.6	26.7 / 26.6†	29.2 ± 2.3	29.9 / 29.6	31.2 ± 2.2	33.2 / 32.6	31.9 ± 2.1
	Range	-	20.3 – 31.2	-	25.1 – 34.6	-	28.0 – 35.8	-	29.1 – 36.9
Male	Mean	23.4 / 23.6†	28.3 ± 3.1	26.7 / 26.6†	30.7 ± 7.2	29.9 / 29.6	32.9 ± 3.1	33.2 / 32.6†	34.0 ± 3.8
	Range	-	23.2 – 34.7	-	25.9 – 35.9	-	28.9 – 42.3	-	30.5 – 44.7

Note. Mean is the respective mean ± standard deviation and ranges are minimum and maximum values. RT = ramped treadmill protocol, LST = Leger 20 metre shuttle run and $\dot{V}O_2$ = oxygen uptake. [1]From Leger and Gadoury (1989a) = -32.678 + 6.592 × MAS / Leger and Gadoury (1989b) = -27.4 + 6 × MAS. †Statistically significant differences between LST predictions and RT for the same sex ($p < 0.05$).

Table 4.9. Submaximal oxygen uptake responses to ramped treadmill and Leger 20-metre shuttle run test (Leger et al., 1988).

Exercise Time		Minute 1		Minute 2		Minute 3		Minute 4	
Protocol		LST[1]	RT	LST[1]	RT	LST[1]	RT	LST[1]	RT
Sex		$\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	$\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	$\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	$\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	$\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	$\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	$\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	$\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$)
Female	Mean	26.6	27.1 ± 2.6	29.6	29.2 ± 2.3	32.6	31.2 ± 2.2	35.6†	31.9 ± 2.1
	Range	-	20.3 – 31.2	-	25.1 – 34.6	-	28.0 – 35.8	-	29.1 – 36.9
Male	Mean	26.6†	28.3 ± 3.1	29.6	30.7 ± 7.2	32.6	32.9 ± 3.1	35.6†	34.0 ± 3.8
	Range	-	23.2 – 34.7	-	25.9 – 35.9	-	28.9 – 42.3	-	30.5 – 44.7

Note. Mean is the respective mean ± standard deviation and ranges are minimum and maximum values. RT = ramped treadmill protocol, LST = Leger 20 metre shuttle run, and $\dot{V}O_2$ = oxygen uptake. [1]From Leger et al. (1988) = -24.4 + (6 × MAS). †Statistically significant differences between test protocols for the same sex ($p < 0.05$).

indicated the predicted $\dot{V}O_{2peak}$ were higher in males ($p < 0.05$).

4.8 Submaximal $\dot{V}O_2$ Responses between RT and LST (Stickland et al., 2003)

For the first four minutes of the LST, the $\dot{V}O_2$ predicted using the Stickland et al. (2003) equation over-predicted the $\dot{V}O_2$ observed during the RT for both males and females ($p < 0.05$). Across minutes 1 to 4 of the LST (Table 4.10), the males predicted $\dot{V}O_2$ was higher than the females ($p < 0.01$). Similarly, males' $\dot{V}O_2$ response was higher than females during the RT ($p < 0.05$). Figure 4.2 illustrates the submaximal $\dot{V}O_2$ responses compared across all four-prediction equations used. Appendix J illustrates submaximal $\dot{V}O_2$ responses across all four LST prediction equations and RT for a respective male and female participant.

4.8.1 $\dot{V}O_{2peak}$ Responses between RT and LST (Stickland et al., 2003)

The predicted $\dot{V}O_{2peak}$ from the LST using the Stickland et al. (2003) equation over-predicted the observed $\dot{V}O_{2peak}$ during the RT for both males and females ($p < 0.05$). The predicted $\dot{V}O_{2peak}$ for the LST was higher in males ($p < 0.05$).

4.9 Multiple Regression for Prediction of $\dot{V}O_{2peak}$

The direct entry multiple regression analysis using body mass index (X_0), HR at rest (X_1), minute 1 (X_2), minute 2 (X_3), and minute 3 of the LST (X_4) indicated a statistically significant relationship for males ($p < 0.01$; $r^2 = 0.84$; $SEE = 3.5$) and females($p < 0.01$; $r^2 = 0.6$; $SEE = 2.9$). Multiple combinations of variables were used (e.g. age, height, mass, BMI, HR_{rest}, and submaximal HRs to minute 4) when formulating the regression equations and the final analysis resulted in the strongest relationship to the $\dot{V}O_{2peak}$ attained during the RT (Table 4.11). The following equations were developed to

Table 4.10. Submaximal oxygen uptake responses to ramped treadmill and Leger 20-metre shuttle run test (Stickland et al., 2003).

Exercise Time		Minute 1		Minute 2		Minute 3		Minute 4	
Protocol		LST^1	RT	LST^1	RT	LST^1	RT	LST^1	RT
Sex		$\dot{V}O_2$ $(mL \cdot kg^{-1} \cdot min^{-1})$	$\dot{V}O_2$ $(mL \cdot kg^{-1} \cdot min^{-1})$	$\dot{V}O_2$ $(mL \cdot kg^{-1} \cdot min^{-1})$	$\dot{V}O_2$ $(mL \cdot kg^{-1} \cdot min^{-1})$	$\dot{V}O_2$ $(mL \cdot kg^{-1} \cdot min^{-1})$	$\dot{V}O_2$ $(mL \cdot kg^{-1} \cdot min^{-1})$	$\dot{V}O_2$ $(mL \cdot kg^{-1} \cdot min^{-1})$	$\dot{V}O_2$ $(mL \cdot kg^{-1} \cdot min^{-1})$
Female	Mean	$28.0^{\dagger}$	27.1 ± 2.6	$30.8^{\dagger}$	29.2 ± 2.3	$33.7^{\dagger}$	31.2 ± 2.2	$36.5^{\dagger}$	31.9 ± 2.1
	Range	-	20.3 – 31.2	-	25.1 – 34.6	-	28.0 – 35.8	-	29.1 – 36.9
Male	Mean	$31.6^{\dagger}$	28.3 ± 3.1	$34.3^{\dagger}$	30.7 ± 7.2	$37.1^{\dagger}$	32.9 ± 3.1	$39.5^{\dagger}$	34.0 ± 3.8
	Range	-	23.2 – 34.7	-	25.9 – 35.9	-	28.9 – 42.3	-	30.5 – 44.7

Note. Mean is the respective mean ± standard deviation and ranges are minimum and maximum values. RT = ramped treadmill protocol, LST = Leger 20 metre shuttle run and $\dot{V}O_2$ = oxygen uptake. *From Stickland et al. (2003) Males = $2.75X + 28.8$; Females = $2.85X + 25.1$; where X = last half stage completed. †Statistically significant differences between test protocols for the same sex ($p < 0.05$).

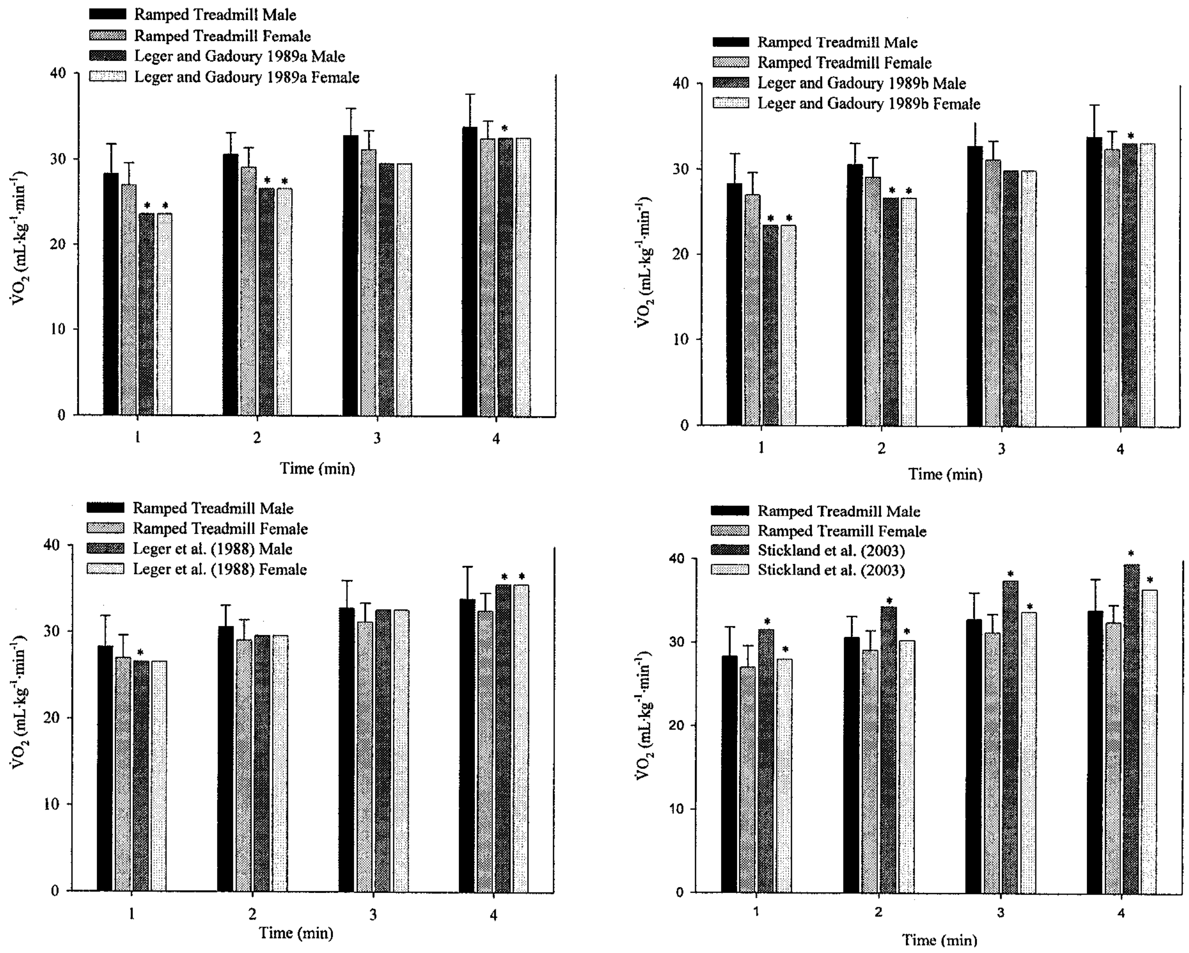

Figure 4.2. Comparisons of submaximal measured $\dot{V}O_2$ responses from the Ramped Treadmill test with predicted $\dot{V}O_2$ responses from the Leger 20-meter Shuttle Run test for the first 4 minutes of exercise. Vertical bars = mean, error bars = standard deviation. *Significant differences between test protocols for the same sex ($p > 0.05$).

Table 4.11. Direct Entry Multiple Regression Analyses.

Dependant Variable $\dot{V}O_{2peak}$ from RT	Predictor Variable #1	Predictor Variable #2	Predictor Variable #3	Predictor Variable #4	Predictor Variable #5	r^2	Sig.
Female	BMI	HR_{rest}	HR_1	HR_2	HR_3	.60	.004
Male	BMI	HR_{rest}	HR_1	HR_2	HR_3	.84	.001
Female	BMI	HR_1	HR_2	HR_3	HR_4	.44	.004
Male	BMI	HR_1	HR_2	HR_3	HR_4	.72	.001
Female	Mass	HR_{rest}	HR_1	HR_2	HR_3	.44	.004
Male	Mass	HR_{rest}	HR_1	HR_2	HR_3	.72	.001
Female	Mass	HR_1	HR_2	HR_3	HR_4	.44	.004
Male	Mass	HR_1	HR_2	HR_3	HR_4	.72	.001
Female	Age	HR_{rest}	HR_1	HR_2	HR_3	.44	.004
Male	Age	HR_{rest}	HR_1	HR_2	HR_3	.72	.001
Female	Age	HR_1	HR_2	HR_3	HR_4	.44	.004
Male	Age	HR_1	HR_2	HR_3	HR_4	.72	.001
Female	HR_{rest}	HR_1	HR_2	HR_3	HR_4	.44	.004
Male	HR_{rest}	HR_1	HR_2	HR_3	HR_4	.72	.001
Female	HR_{rest}	HR_1	HR_2	HR_3		.44	.004
Male	HR_{rest}	HR_1	HR_2	HR_3		.72	.001
Female	HR_1	HR_2	HR_3	HR_4		.44	.004
Male	HR_1	HR_2	HR_3	HR_4		.72	.001
Female	HR_1	HR_2	HR_3			.44	.004
Male	HR_1	HR_2	HR_3			.72	.001

Note. RT = ramped treadmill protocol, BMI = body mass index, HR = resting heart rate, HR_1 = heart rate at minute 1 of the LST, HR_2 = heart rate at minute 2 of the LST, HR_3 = heart rate at minute 3 of the LST, HR_4 = heart rate at minute 4 of the LST.

predict $\dot{V}O_{2peak}$ from submaximal LST intensities:

Equation 1

Males = $135 + (-0.72X_0) + (-0.168X_1) + (-0.05X_2) + (0.38X_3) + (-0.66X_4)$

Equation 2

Females = $93 + (-0.25X_0) + (-0.11X_1) + (0.14X_2) + (-0.28X_3) + (-0.05X_4)$.

Using these equations, the predicted $\dot{V}O_{2peak}$ for males (54.6 ± 8.2 $mL \cdot kg^{-1} \cdot min^{-1}$) was not significantly different to the measured $\dot{V}O_{2peak}$ during the RT (54.5 ± 7.2 $mL \cdot kg^{-1} \cdot min^{-1}$; Table 4.7). Further, predicted $\dot{V}O_{2peak}$ for females (44.3 ± 3.7 $mL \cdot kg^{-1} \cdot min^{-1}$) was not significantly different to that observed during the RT (44.5 ± 3.8 $mL \cdot kg^{-1} \cdot min^{-1}$) (Table 4.7). Correlations between measured $\dot{V}O_{2peak}$ and predicted $\dot{V}O_{2peak}$ responses for males ($r = 0.90$) and females ($r = 0.74$) were statistically significant ($p < 0.01$). The homogeneity of regression slopes was not rejected, ($p > 0.05$), indicating that both genders have a similar predicted increment in $\dot{V}O_2$ for the same increment on the LST (Stickland et al., 2003). Figure 4.3 illustrates the relationship between measured $\dot{V}O_{2peak}$ from the RT and the predicted $\dot{V}O_{2peak}$ using the equations for males and females. Appendix K illustrates the predicted $\dot{V}O_{2peak}$ for a respective male and female participant using the new regression equations.

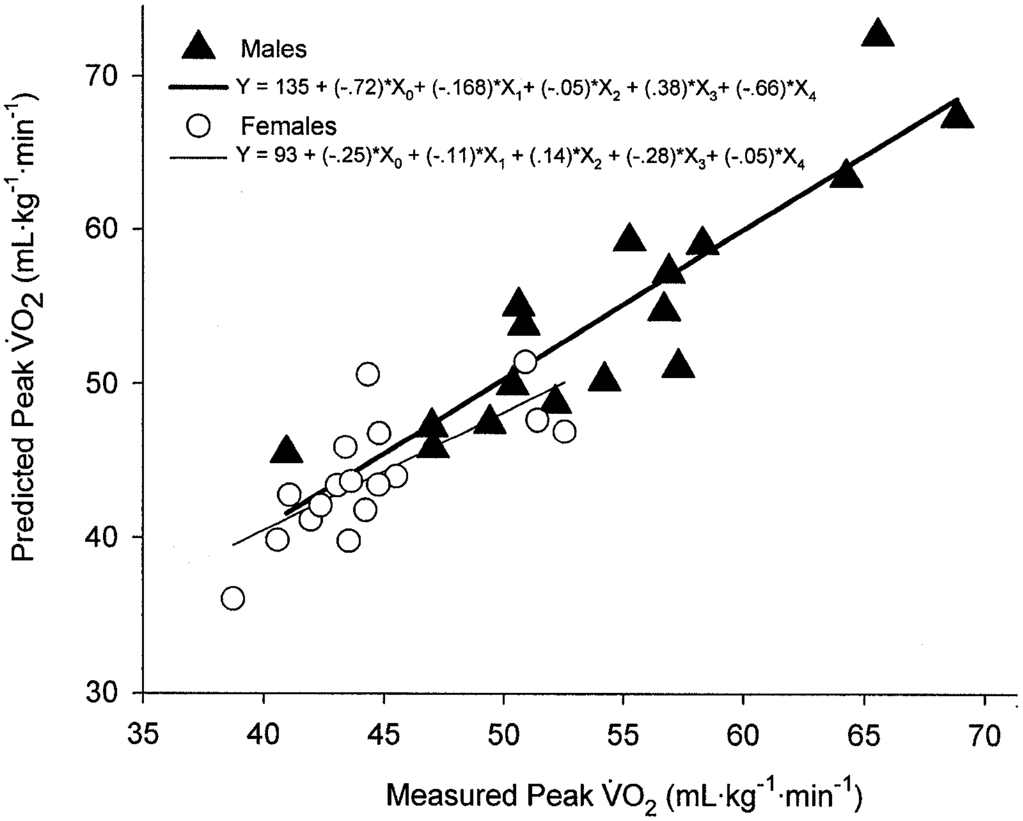

Figure 4.3. Direct entry regression analyses between body mass index (X_0), heart rate at rest (X_1), minutes 1 (X_2), 2 (X_3), and 3 (X_4) of the LST and measured $\dot{V}O_{2peak}$, significant relationship for males ($p < 0.01$; $r^2 = 0.84$; *SEE* = 3.5) and females ($p < 0.01$; $r^2 = 0.6$; *SEE* = 2.9). Data points = individual participant results.

CHAPTER V

DISCUSSION

This study examined the ability to predict $\dot{V}O_{2peak}$ from the LST. Specifically, the study compared several predictive equations that use peak effort from the LST with the measured $\dot{V}O_{2peak}$ in healthy participants. Further, new prediction equations that use BMI and the HR responses to submaximal workloads were developed.

5.1 Hypothesis Testing

The first hypothesis, that measured $\dot{V}O_{2peak}$ attained during the GT would be similar to the $\dot{V}O_{2peak}$ attained from the RT, was not rejected. These findings, and the similar workloads for the RT and LST, provided the justification for using the RT results as the criterion measure against which LST data were compared.

The second hypothesis postulated that there would be no differences between the submaximal predicted $\dot{V}O_2$ and measured HR attained from the LST versus the RT protocol. Published regression equations, Leger and Gadoury (1989 a and b), Leger et al. (1988), or Stickland et al. (2003), failed to accurately predict the $\dot{V}O_2$ responses for submaximal stages of the RT. There were no statistically significant differences in submaximal or peak HR responses across the RT and LST. This was expected due to the similar workload increments between the protocols.

When examining the third hypothesis, there were statistically significant differences in the $\dot{V}O_{2peak}$ attained on the RT in comparison to the four prediction equations provided for the LST. Only the equation from Leger and Gadoury (1989b) accurately predicted $\dot{V}O_{2peak}$ for females.

To test the final hypothesis, the similarities in HR responses across the two protocols provided the explanation as to why the submaximal HR emerged as a predictor variable in the regression equation. Although not used in the calculation of $\dot{V}O_{2peak}$, BMI in combination with the HR at rest and submaximal exercise were variables which yielded the strongest predictive equations for males and females.

5.2 HR Responses

There were no differences in HR responses at rest, during the first 4 minutes of exercise (Figure 4.1, Tables 4.2 and 4.3), or at peak effort (Table 4.5) for males or females during the RT and LST. Heart rate for the males for the first 4 minutes of exercise and at VT (Table 4.4) was lower than that observed in the females but the HR_{peak} observed for males and females was similar (Table 4.5). The higher heart rate response of the females during submaximal exercise are linked to a larger myocardium size, plasma volume, stroke volume, and hemoglobin concentration in males (Gledhill, Warburton, & Jamnik, 1999; Proctor & Joyner, 1997; Washburn & Seals, 1984; Wiebe, Gledhill, Warburton, Jamnik, & Ferguson, 1998). There were no differences between the age predicted HR_{peak} (220 – age) and the measured HR_{peak} on the RT, GT, and LST for males or females (Table 4.5). This is congruent with previous research supporting the relationship between the age predicted and measured HR_{peak} Londeree & Moeschberger, 1982; Londeree, Thomas, Ziogas, Smith, & Zhang, 1995). Also, the RT, GT, and LST involved incremental running exercise to exhaustion. All participants terminated each test because they were unable to maintain the required pace and subsequently reached their age predicted maximum HR (± 10 $\text{beats}\cdot\text{min}^{-1}$).

5.3 Measured $\dot{V}O_2$ Responses

For a given gender, the relative and percent $\dot{V}O_2$ at VT observed on the RT and

GT were similar, suggesting the loading of the treadmill protocols does not effect VT. These findings were similar to previous studies comparing ramped and graded treadmill performance between men and women (Bassett et al., 1985; Freund, Allen, & Wilmore, 1986; Kang et al., 2001; Kasch, Wallace, Huhn, Krogh, & Hurl, 1976; Maeder et al., 2006). For males or females, the $\dot{V}O_{2peak}$ observed during the GT were similar to the $\dot{V}O_{2peak}$ attained on the RT (Table 4.7). For either protocol, the relative $\dot{V}O_2$ at VT and $\dot{V}O_{2peak}$ was significantly higher for the males. This observation is consistent with previous reasearch (Habedank et al., 1998; Iwaoka, Hatta, Atomi, & Miyashita, 1988) and may be attributed to differences in contracting muscle size, stroke volume, plasma volume, and hemoglobin concentration in males (Gledhill et al., 1999; Iwaoka et al., 1988; Wiebe et al., 1998).

5.4 Predicted $\dot{V}o_2$ Responses

The predicted $\dot{V}o_2$ attained during exercise and at peak effort varied depending on the Leger regression equations used. For example, during submaximal exercise, the equations developed by Leger and Gardoury (1989) (referred to hereafter as 1989a and 1989b respectively) under-predicted $\dot{V}o_2$ at minutes 1 and 2 of exercise. For minutes 3, the predicted $\dot{V}o_2$ was similar to the measured $\dot{V}o_2$ for males and females. At minute 4, the predicted $\dot{V}o_2$ was similar to the measured $\dot{V}o_2$ for the females but lower than the measured $\dot{V}o_2$ for the males (Figure 4.2, Table 4.8). The equation from Leger et al. (1988) predicted accurately measured $\dot{V}o_2$ for the first 3 minutes of exercise for females and minutes 2 and 3 for the males (Figure 4.2, Table 4.9). Lastly, the Stickland et al. (2003) equation systematically over-predicted submaximal $\dot{V}o_2$ (Figure 4.2, Table 4.10) in both the males and females (Table 4.7).

The inaccuracies of the predicted values relative to the measured VO_2 during submaximal exercise was anticipated as all four equations were designed from data on peak effort. Further, Leger and Gardoury (1989), Leger et al. (1988), and Stickland et al. (2003), exercise protocols that were inconsistent with the workloads found in the LST. For example, Leger and Gadoury (1989), and Leger et al. (1988) used a walking protocol although there are known differences in efficiency and workload between walking and running (Hall, Figueroa, Fernhall, & Kanaley, 2004; Martin, Heise, & Morgan, 1993). Stickland et al. (2003) used a graded treadmill protocol with workloads that were much greater than the LST. These protocols were used for the purpose of eliciting the highest peak $\dot{V}O_2$ value rather than for the prediction of submaximal $\dot{V}O_2$. The similarities in submaximal HR and differences in submaximal predicted $\dot{V}O_2$ across protocols provided the rational for using submaximal HR for the prediction of $\dot{V}O_{2peak}$

With regard to $\dot{V}o_{2peak}$, the equation of Leger and Gadoury (1989a) under predicted for the males but estimated accurately measured $\dot{V}o_{2peak}$ for females (Table 4.7). The equation of Leger and Gadoury (1989b) under-predicted the $\dot{V}o_{2peak}$ for both males and females. The Leger et al. (1988) equation under-and over-predicted the measured $\dot{V}o_{2peak}$ for males and females respectively (Table 4.7). The Stickland et al. (2003) equation systematically over-predicted $\dot{V}o_{2peak}$ in both the males and females (Table 4.7).

There are several possible explanations for the variance in the predicted $\dot{V}o_{2peak}$ responses. First, the participants in the present study are younger and more homogeneous, than the sample described by Leger and Gadoury (1989) (53 males and 24 females, 19 to 47 yrs. old) and Leger et al. (1988) (53 males and 24 females were below [*n* = 38] or above [*n* = 39] the age of 35 yrs.). The present sample was also smaller, and unlike

Stickland et al. (2003) (60 men and 62 women, 18-38 yrs. old), had not regularly used the LST. Stickland et al. (2003) provided a practice session for the LST where the participants completed the first 4 minutes of the LST in order to create familiarization with the graded effort and pacing required to complete the test. The learning effect caused by repeated participation in the LST has been shown to improve the predicted $\dot{V}O_{2peak}$ from the initial trial (Leger & Lambert, 1982) and have no effect on subsequent LST performance (Leger et al., 1988). A practice session was not was due to these inconclusive results pertaining to its effectiveness in improving predicted $\dot{V}O_{2peak}$ values. Leger and Gadoury (1989) found that no age effect was noticed concerning the homogeneity of running economy. However, running economy should not be assumed throughout adulthood. In the study by Sidney and Shepard (1977), the running economy of 56 older subjects (mean age 63 yrs.) was compared to 13 healthy young subjects (mean age 25 yrs.). The younger participants achieved a higher speed for a given lactate concentration and $\dot{V}O_{2peak}$ during the same treadmill test. This is similar to other research detailing differences in running economy between young and old adult populations (Waters, Hislop, Perry, Thomas, & Campbell, 1983).

The differences between the results of the present study and Leger and Gadoury (1989a and b) and Leger et al. (1988) may be further explained by the gas analysis technique and test protocols used. Leger et al. (1988) used the backward extrapolation technique to predict $\dot{V}O_{2peak}$ from the LST. The backward extrapolation technique was first described by Leger, Seliger, and Brassard (1980) and was developed to predict $\dot{V}O_{2peak}$ from field-tests. In this procedure, $\dot{V}O_{2peak}$ is obtained by backward extrapolation of the O_2 recovery curve at time zero of recovery (BE) was compared to the $\dot{V}O_{2peak}$

measured directly at the end of a continuous multistage treadmill test for 47 participants. Peak $\dot{V}O_2$ was predicted by using a single component exponential least-squares regression on the first four 20-second recovery values collected from expired air immediately at the start of recovery. The predicted $\dot{V}O_2$ from BE was not different ($p > 0.05$) from $\dot{V}O_{2peak}$ observed on the treadmill test. When participants connected themselves to another breathing valve immediately at the end of the treadmill and track test to simulate field conditions, BE and measured $\dot{V}O_{2peak}$ were similar if a time correction was made for the delay caused by this procedure (Leger et al., 1980). Despite the reported similarities between measured and predicted $\dot{V}O_{2peak}$, BE could be considered only a prediction of $\dot{V}O_{2peak}$ because gas collection was not completed at the time of peak effort.

Leger and Gadoury (1989) used the Douglas bag method where only one $\dot{V}O_2$ value was obtained during the last minute of a treadmill test. There was no description given as to how the last minute of exercise was determined, and when and how the final sample was collected. Therefore, since the final $\dot{V}O_{2peak}$ was recorded at an unspecified point within the last minute of exercise, this can be considered only an estimate of $\dot{V}O_{2peak}$.

Stickland et al. (2003) also collected expired gas data and averaged every 20 seconds, which is more sensitive to the detection of a plateau in $\dot{V}O_2$ over the final workloads (Taylor, Buskirk, & Henschel, 1955). The present study had a homogenous sample similar to Stickland et al. (2003), and subsequently, the measured $\dot{V}O_{2peak}$ for males and females from the RT (Table 4.7) was similar to the measured $\dot{V}O_{2peak}$ for males

(54.9 ± 8.3 $mL\cdot kg^{-1}\cdot min^{-1}$) and females (47.4 ± 6.2 $mL\cdot kg^{-1}\cdot min^{-1}$) from Stickland et al. (2003).

The metabolic cart was calibrated with primary gas standards immediately before each test and verified. No drift (> 0.0002 in F_EO_2 and F_ECO_2 or > 3% *SEE* between calibrations) in the gas analyzers was noted following any test (Babineau, Leger, Long, & Bosquet, 2002; Stickland et al., 2003). Therefore, it is improbable that the measured $\dot{V}O_{2peak}$ responses could result from erroneous data from the metabolic measurement system (Babineau et al., 2002).

Leger and Gadoury (1989) used a treadmill protocol that involved mostly walking. The test protocol called for an initial load of 4.83 $km\cdot hr^{-1}$ (3 $m\cdot hr^{-1}$) and 0% grade and an increase of 5% grade every 3 minutes until the 12th minute and 2.5% increase every 2 min until the 16th min. This was followed by a load increase of 0.4 $km\cdot hr^{-1}$ (0.25 $m\cdot hr^{-1}$) every 2 min. Leger and Gadoury (1989) reported the $\dot{V}O_{2peak}$ of the group was 49.4 $mL\cdot kg^{-1}\cdot min^{-1}$, which means that the participants would have achieved this value while briskly walking for approximately 20 minutes at less than 4.0 $m\cdot hr^{-1}$ and 25% grade using the ACSM (2000) prediction equation (i.e., $\dot{V}O_2 = 0.2$ (speed) + 0.9 (speed) (% grade) + 3.5). The present study used a graded treadmill protocol identical to Stickland et al. (2003) and a ramped treadmill protocol similar to the workload experienced in the LST. The present protocols typically elicited $\dot{V}O_{2peak}$ within 8-12 minutes. This is an ideal end time because it allows for a plateau in $\dot{V}O_2$ while avoiding volitional fatigue due to other factors such as localized muscle fatigue (Thoden, 1991). This is slightly shorter that the 10-15 minutes needed to elicit $\dot{V}O_{2peak}$ (Stickland et al; 2003). However, the measured $\dot{V}O_{2peak}$ of both men and women between the present study and Stickland et al. (2003) were similar and likely related to recruiting similar aged participants with similar levels of activity who exercised to a similar end point. The men and women from the present study and Stickland et al. (2003) were of similar relative fitness levels. The $\dot{V}O_{2peak}$ values attained by the men and women of each study were comparable to the normative data for active to very active North American adults (Durnin, 1985; McArdle et al., 2001).

5.5 Regression Equation $\dot{V}O_2$ Responses

Body mass index and submaximal HR were the best predictons variables of $\dot{V}O_{2peak}$. Other variables such as age, mass, and HR did not explain as much of the variance in the predicted $\dot{V}O_{2peak}$ values ($r^2 = 0.44$ and 0.72 for females and males respectively, for each variable) (Table 4.11). This is similar to other research that shows BMI to be a valid predictor of measured $\dot{V}O_{2peak}$ in treadmill and cycling performance in both males and females. For example, Oczelik et al. (1995) had 60 participants (30 males, 30 females, aged 18-25 years) perform an incremental exercise test (15 watts/min) to the limit of tolerance on an electromagnetically-braked cycle ergometer. Oczelik et al. (1995) found a negative correlation between increased BMI to maximal work rate (Wmax) capacity per kilogram body weight in male ($r = - 0.84$, $p = 0.01$) and in female ($r = -0.89$, $p = 0.01$) participants. In addition, aerobic capacities (WAT) for each kilogram body mass also negatively correlated with increased BMI in male and females ($r = -0.870$, $p < 0.01$). Oczelik et al. (1995) suggested that due to the inverse correlation between BMI, Wmax capacity, and aerobic fitness, it may be useful to consider BMI in establishing cardiopulmonary fitness in various participants. Bonen and Shaw (1995) compared the relationship between predicted peak VO_2 and recreational exercise patterns, using secondary data analysis of a comprehensive national survey (18,293 participants aged 15-69 years). Exercise participation and predicted peak VO_2 data were available for about 50% of this sample (4933 females, 4738 males). Peak VO_2 was lower in females than in the males at any age ($p < 0.01$). Age was the best predictor of VO_2 ($r = -0.71$ for males, $r = -0.73$ for females). Adjusting the data for BMI increased this relationship in the males ($r = 0.75$) and females ($r = 0.79$) ($p < 0.05$). Peterson et al. (2003) examined 171 men (72.6 ± 4.8 yr) and women (71.0 ± 5.1 yr) screened in a clinical trial. Peak VO_2 was measured using a standardized treadmill protocol with indirect calorimetry. Measured peak VO_2 were compared with predictive equations (Foster and ACSM) via mean difference analyses, and bias was explored using Bland-Altman analyses. Regression analysis determined predictors of measured peak VO_2. In men and women, the predicted $\dot{V}O_{2peak}$, using the equation from Foster, was not different from the measured peak VO_2. The ACSM prediction overestimated peak VO_2 in men and women. Using Bland-Altman plots, the ACSM equation overestimated bias in the fit women ($r = 0.29$), whereas the Foster equation yielded no estimation bias in either gender. Finally, Peterson et al. (2003) found the predictor variables of peak VO_2 were gender, BMI, age, treadmill grade, and speed, with an $r^2 = 0.70$.

In the present study, the slopes of the regression equations developed for men and women were similar even though the measured $\dot{V}O_{2peak}$ values were different. This explains the similar Y-intercept values for males (17.5) related to females (17.0) ($p > 0.05$) indicating that both genders have a similar predicted increment in $\dot{V}O_2$ for the same increment on the LST (Figure 4.3). In addition to the differences in contracting muscle size, stroke volume, plasma volume, and hemoglobin concentration, the sex differences in measured $\dot{V}O_{2peak}$ could be also attributed to running economy. Helgerud (1994) reported that the energy cost of running (i.e., running economy) is 10% lower in men than women when running at similar speeds on a treadmill when matched for marathon performance time. This finding is similar to other research which has detailed differences in running economy between men and women (Davies, Mahar, & Cunningham, 1997; Helgerud, Ingjer, & Stromme, 1990; Shephard, 2000; Shephard, Vandewalle, Bouhlel, & Monod, 1988).

The standard errors of measurement for the regression equations proposed in this study (males = 3.5 and females = 2.9) are less than those reported by Stickland et al. (2003) (4.07 for males and 3.64 for females) and Leger's group (Leger & Gadoury; 1989; Leger et al. 1988; 4.7). Previously, $\dot{V}O_{2peak}$ was predicted using the last full 1-minute stage completed (Leger & Gadoury, 1989). Participants that stopped just before completing a full one-minute stage were given the predicted $\dot{V}O_{2peak}$ value from the previous stage completed. Stickland et al. (2003) suggest the prediction equations provided by their study allow for greater sensitivity to changes in fitness and prediction of $\dot{V}O_{2peak}$ because of the inclusion of half stages completed. The strength of the prediction in the present study (r^2 = 0.84 for males and 0.60 for females) were similar those values presented by Stickland et al. (2003) (males = 0.77 and females = 0.66) (Figure 4.3).

5.6 Limitations

The present study had a much smaller sample size than Leger & Gadoury (1988), Leger et al. (1989), and Stickland et al., (2003). However, sample size was estimated from a power calculation formula for multiple regression (Portney & Watkins, 2000) and achieved a desired power of 80% with α set at 0.05. The underlying assumption of prediction tests is that as $\dot{V}O_2$ (i.e., work intensity) increases, HR will increase in a similar linear fashion. This reliance on a linear HR to power output and power output to $\dot{V}O_2$ relationship is a potential source of error when using predictive tests of maximal aerobic power (Bosquet et al., 2002). Variability in HR increases when participants are at or above VT creating a non-linear relationship between HR and $\dot{V}O_2$. For example, Cottin et al. (2004) found that the HR variability increased in 11 trained cyclists by 38% when subjects exercised above VT. Similar findings have been observed repeatedly (Bartels et al., 2004; Casadei, Cochrane, Johnston, Conway, & Sleight, 1995; Londeree, 1997; Macor, Fagard, & Amery, 1996). Recorded mean HR at minute three of the LST for females (173 ± 12 beats·min^{-1}) was slightly higher than the mean HR and at VT (166 ± 11 beats·min^{-1}) ($p < 0.05$). This may have increased the heart rate variability recorded at minute 3 of the LST and therefore contributed to a lower r^2 value for the females. In other words, the predictor variables explained less of the variance found in the predicted $\dot{V}O_{2peak}$ for the females ($r^2 = 0.6$) as compared to the males ($r^2 = 0.84$).

In order to decrease the chance of making a type I error when analyzing the differences in submaximal and peak HR and VO_2 between men and women, a mixed model ANOVA design could have been used. In this design, sex would be the between subjects factor and HR and VO_2 at rest, all submaximal stages, and peak would be within subjects factors. This model protects against type I error by measuring the differences between males and females using one statistical procedure (Portney & Watkins, 2000). Since multiple paired t-tests where used in the present study to compare the differences between men and women, there is an increased chance of compounding the alpha level (0.05) and falsely finding significant results.

5.7 Future Considerations

Future research should study larger groups of participants in different age ranges to further allow for the specific application of results to a wide cross section of the population.

5.8 Conclusion

This study demonstrated that healthy young participants who completed stage 4 or higher during peak effort on the LST may record their BMI and HR responses to the first three stages and reasonably predict their $\dot{V}O_{2peak}$. This allows a greater range of the population to use this well designed field test, as the need for peak effort on the LST is not necessary to accurately predict $\dot{V}O_{2peak}$. These results have implications for the development of new occupational and fitness testing protocols that propose less of a health risk to those who participate in this assessment of cardiorespiratory fitness.

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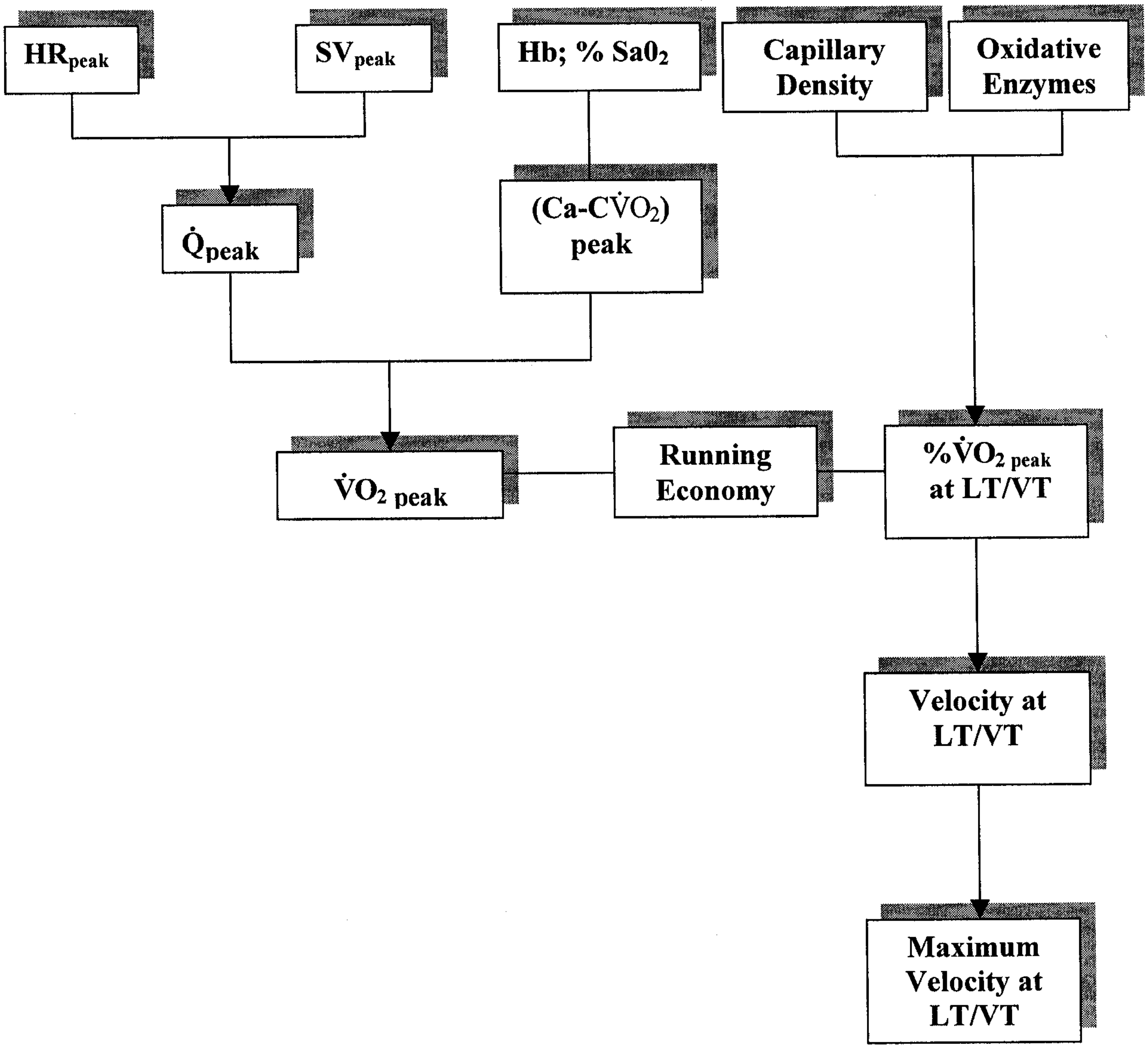
Appendix A

Summary of Major Variables Related to VO_{2peak}

Adapted from (Bassett & Howley, 2000); (G. A. Brooks, T. D. Fahey, T. P. White, & K. M. Baldwin, 2000)



HR_{peak} = Peak Heart Rate; SV_{peak} = Peak Stroke Volume; $\dot{Q}_{peak}$ = Peak Cardiac Output; Hb; % $Sa0_2$ = Hemoglobin percent saturated with oxygen; $Ca\text{-}C\dot{V}O_{2peak}$ = Peak Concentration of arterial – venous oxygen difference; $\dot{V}O_{2\ peak}$ = Peak Oxygen Uptake; LT = Lactate Threshold; VT = Ventilatory Threshold

Appendix B

University of Regina Certificate of Ethics Approval

UNIVERSITY OF
REGINA

OFFICE OF RESEARCH SERVICES

MEMORANDUM

DATE: August 5, 2003

TO: P. Ash
Kinesiology

FROM: J. Roy
Chair, Research Ethics Board

Re: **Evaluation of Leger Shuttle Run Test for the Prediction of Submaximal Exercise Performance (82S0203)**

Please be advised that the University of Regina Research Ethics Board has reviewed your proposal and found it to be:

___✓___ 1. ACCEPTABLE AS SUBMITTED. Only applicants with this designation have ethical approval to proceed with their research as described in their applications. The *Tri-Council Policy Statement on Ethical Conduct for Research Involving Humans* requires the researcher to send the Chair of the REB annual reports and notice of project conclusion for research lasting more than one year (Section 1F). **ETHICAL CLEARANCE MUST BE RENEWED BY SUBMITTING A BRIEF STATUS REPORT EVERY TWELVE MONTHS.** Clearance will be revoked unless a satisfactory status report is received.

______ 2. ACCEPTABLE SUBJECT TO CHANGES AND PRECAUTIONS (SEE ATTACHED). Changes must be submitted to the REB and subsequently approved prior to beginning research. Please address the concerns raised by the reviewer(s) by means of a <u>supplementary memo</u> to the Chair of the REB. <u>Do not submit a new application</u>. Please provide the supplementary memorandum, or contact the REB concerning the progress of the project, before **November 5, 2003,** in order to keep your file active. Once changes are deemed acceptable, approval will be granted.

______ 3. UNACCEPTABLE AS SUBMITTED. Please contact the Chair of the REB for advice on how the project proposal might be revised.

Joan M. Roy

Joan Roy

c. Dr. B. Krishnan
Dr. R. G. Haennel

JR/sn/ethics2.dot

Appendix C

Invitation to Participate

UNIVERSITY OF
REGINA
Faculty of Kinesiology and Health Studies

Project Title: Adapting the 20 Metre Shuttle Run to a Submaximal Protocol to Predict VO_{2peak}

Investigators: P. Ash & Dr. R. G. Haennel

We in the Faculty of Kinesiology and Health Studies are conducting a research study to evaluate the adaptability of a well established field athletic test (the Leger 20 metre Shuttle Run Test) for use in healthy participants. The purpose of this study is to evaluate your fitness levels using the Leger Shuttle Run Test. Specifically, we are interested in evaluating how your body adapts to changing workloads during exercise. Participation in this study requires a total of three visits to the Exercise Physiology Laboratory at the University of Regina. On the first visit you will walk/run on a treadmill with increasing speed, every minute until you choose to no longer continue. Both heart and lung function will be monitored and recorded throughout the exercise test. The second visit will involve a run on level ground between two pylons, which are 20 metres apart. The pace of walking/running will increase during each consecutive interval and you will be asked to continue until you choose to stop or can no longer keep up with the required pace. On the third visit you will walk/run on a treadmill with increasing speed and incline, every minute until you choose to no longer continue. Both heart and lung function will be monitored and recorded throughout the exercise test. It is anticipated that the total time during each visit (including the exercise test) will not exceed one hour. We wish to assure you that personal records relating to this study are confidential and that all data for analysis will be stripped of identifiers and pooled. If you are interested in participating in the outlined study or are interesting in finding out more about the research project, please print your name, email address, and phone number below, and a investigator will contact you.

______________________ ______________________
Name (please print) Phone Number

____
Email Address

3737 Wascana Parkway, Regina Saskatchewan, S4S 0A2 Phone (306)585-4066

Appendix D
Informed Consent Form

Project Title: Adapting the 20 Metre Shuttle Run to a Submaximal Protocol to Predict VO_{2peak}

Investigators: P. Ash & Dr. R. G. Haennel

Introduction

We in the Faculty of Kinesiology and Health Studies are conducting a research study to evaluate the adaptability of a well established field athletic exercise test (The Leger Shuttle Run Test) for use in healthy participants. We request your participation as you meet all the required criteria for a successful study completion.

Purpose

The purpose of this study is to evaluate your fitness levels using the Leger Shuttle Run Test. Specifically, we are interested in evaluating how your body adapts to changing workloads during exercise. Participation in this study requires a total of three visits to the Exercise Physiology Laboratory at the University of Regina. On the first visit you will walk/run on a treadmill with increasing speed, every minute until you choose to no longer continue. Both heart and lung function will be monitored and recorded throughout the exercise test. The second visit will involve a run on level ground between two pylons, which are 20 metres apart. The pace of walking/running will increase during each consecutive interval and you will be asked to continue until you choose to stop or can no longer keep up with the required pace. On the third visit you will walk/run on a treadmill with increasing speed and incline, every minute until you choose to no longer continue. Both heart and lung function will be monitored and recorded throughout the exercise test. It is anticipated that the total time during each visit (including the exercise test) will not exceed one hour.

Risks and Benefits

Your involvement in this study should not result in any pain or discomfort other than that normally associated with exercise. The American College of Sports Medicine (2000) reports the risk of morbidity (e.g., accidental injury), mortality, or complications (e.g., cardiorespiratory abnormalities) as a result of participation in an exercise test to be in the range of 0 - 0.0008%. During the study, you will be supervised by a Professional Fitness and Lifestyle Consultant who is C.P.R. and First Aid certified. It is possible that you may experience some muscle soreness or stiffness following the test. If any information collected during the course of this study indicates possible health implications, the results will be forwarded to you and your physician. You are entitled to withdraw from the study at any time. The entire procedure will be described to you before you agree to participate in the study and a separate copy of this form will be provided to you. The investigators listed above will be pleased to clarify any concerns you may have about the study. The principal investigator will offer to arrange an appointment with you to review your individual results. A copy of your testing results will be provided for your personal records, as well. A copy of the results and findings of the study can be provided to you upon request.

Confidentiality

We wish to assure you that personal records relating to this study are confidential and that all data for analysis will be stripped of identifiers and pooled. If any information collected during the course of this study indicates possible health implications, the results will be forwarded to you and your physician. If you have any other questions concerning any other aspect of this study, you may ask at any time during the test or call the phone numbers listed below should questions arise following the test. A copy of this information sheet and voluntary participation form will be provided to you.

Voluntary Participation

I acknowledge that the research procedures described above have been explained clearly to me, and that any questions that I have asked have been answered to my satisfaction. In addition, I know that I may contact the person(s) designated on this form if I have questions in the future. I understand the possible benefits of joining the research study, as well as the possible discomforts. I understand that my involvement is voluntary and that I may withdraw from the study at any time without jeopardy to my relationship with the Faculty of Kinesiology and Health Studies and the University of Regina.

Research Ethics Board at the University of Regina has approved this project. If research participants have any questions or concerns about their rights or treatment as a participant, they may contact the Chair of the University of Regina Research Ethics Board at 585-4775 or email: research.ethics@uregina.ca.

If you have any questions concerning the study, you may contact:

Patrick Ash at:	Dr. R.G. Haennel (U or R)
757-8098 (Home)	585-4844
585-4066 (Work)	

(Name, Please Print)

(Signature)

(Today's Date)

(Signature of Witness)

A copy of this information sheet and voluntary participation form has been provided.

(Signature)

Appendix E

Physical Activity Readiness Questionnaire (PAR-Q)
(CSEP, 2002)

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.

1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor? Yes __ No_____
2. Do you feel pain in your chest when you do physical activity? Yes __ No_____
3. In the past month, have you had chest pain when you were not doing physical activity?
Yes ____ No_____
4. Do you lose your balance because of dizziness or do you ever lose consciousness?
Yes ____ No_____
5. Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity? Yes ____ No_____
6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition? Yes ____ No_____
7. Do you know of any other reason why you should not do physical activity?
Yes ____ No_____

If you answered YES honestly to any PAR-Q 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.

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. 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.

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.

If you answered NO honestly to all 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. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

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)

Informed Use of the PAR-Q: 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.

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

Appendix F

Ramp Treadmill Protocol

Stage	Speed (KPH)	Time (min)
1	8.5	1.0
2	9.0	2.0
3	9.5	3.0
4	10.0	4.0
5	10.5	5.0
6	11.0	6.0
7	11.9	7.0
8	12.7	8.0
9	13.6	9.0
10	14.5	10.0
11	15.3	11.0
12	16.2	12.0
13	17.0	13.0
14	17.9	14.0
15	18.7	15.0
16	19.6	16.0
17	20.5	17.0
18	21.3	18.0
19	22.2	19.0
20	23.0	20.0

Note: Due to ramp protocol the treadmill grade remains at 0% for the duration of the test

Appendix G

Graded Treadmill Protocol

(Stickland et al., 2003)

Stage	Speed (KPH)	Grade (%)	Time (min)
1	6.5	0	1.0
2	6.5	0	2.0
3	6.5	2.0	3.0
4	CRS	2.0	4.0
5	CRS	4.0	5.0
6	CRS	4.0	6.0
7	CRS	6.0	7.0
8	CRS	8.0	8.0
9	CRS	10.0	9.0
10	CRS	12.0	10.0
11	CRS	14.0	11.0
12	CRS	16.0	12.0
13	CRS	18.0	13.0
14	CRS	20.0	14.0
15	CRS	22.0	15.0
16	CRS	24.0	16.0
17	CRS	26.0	17.0
18	CRS	28.0	18.0
19	CRS	30.0	19.0
20	CRS	32.0	20.0

Note: After the third workload (6.5 km/hr at 4% grade), the second phase of the test will begin whereby speed will increase to a comfortable running speed (CRS) for each participant. Grade will continue to increase by 2% each minute until the participants decide to no longer continue to exercise.

Appendix H

Leger 20 Meter Shuttle Run Protocol
(Leger et al., 1988)

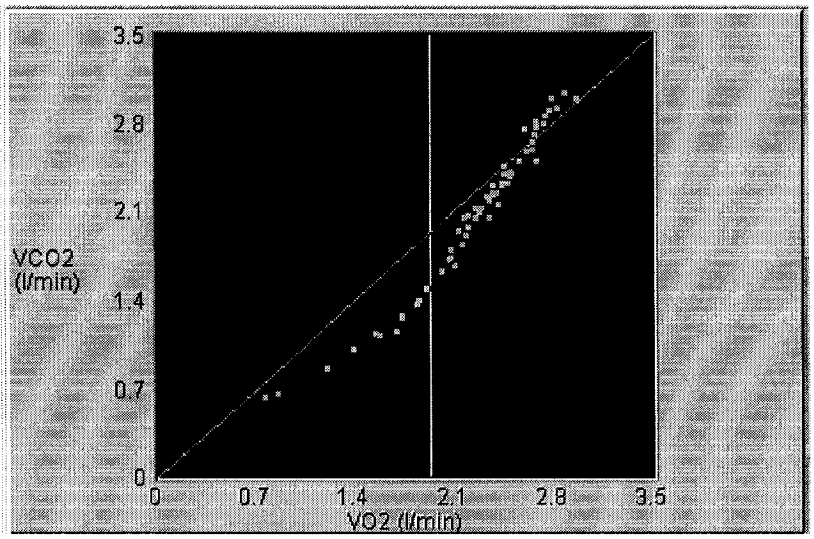
Stage	Speed (KPH)	Time (min)	METS
0	8.5	1.0	6.7
1	9.0	2.0	7.6
2	9.5	3.0	8.5
3	10.0	4.0	9.3
4	10.5	5.0	10.2
5	11.0	6.0	11.0
6	11.5	7.0	11.9
7	12.0	8.0	12.7
8	12.5	9.0	13.6
9	13.0	10.0	14.5
10	13.5	11.0	15.3
11	14.0	12.0	16.2
13	14.5	13.0	17.0
14	15.0	14.0	17.9
15	15.5	15.0	18.7
16	16.0	16.0	19.6
17	16.5	17.0	20.5
18	17.0	18.0	21.3
19	17.5	19.0	22.2
20	18.0	20.0	23.0

To calculate VO_{2peak} using the above chart: $\dot{V}o_{2peak} = -27.4 + 6.0 \times MAS$

Appendix I

Ventilatory Threshold (VT) Responses for Representative Participants

Graph #1 - Female Participant #1



Graph #2 - Male Participant # 29

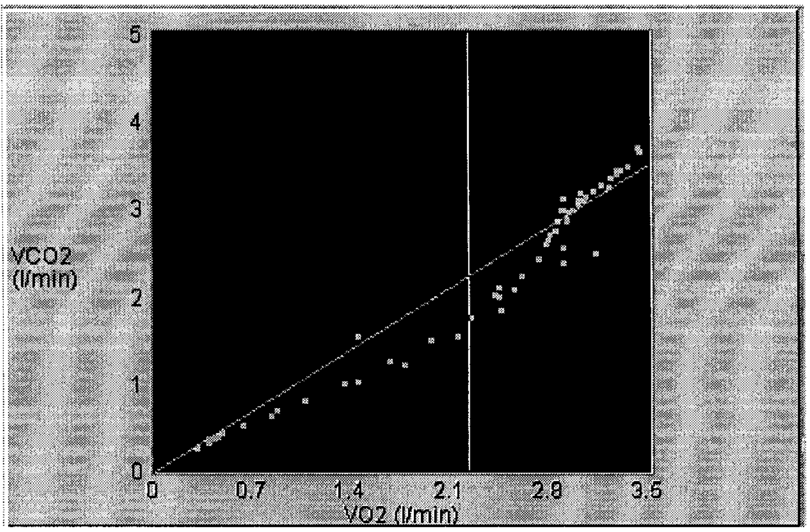


Figure I-1. CO_2 production ($\dot{V}CO_2$) vs. O_2 uptake ($\dot{V}O_2$) showing regression lines for detecting inflection point or ventilatory threshold (VT) which is indicated by the vertical line. The VT $\dot{V}O_2$ for the female participant occurred at 1.93 $L \cdot min^{-1}$ or 67% of $\dot{V}O_{2peak}$ (graph #1). The VT $\dot{V}O_2$ for the male participant occurred at 2.24 $L \cdot min^{-1}$ or 68% of $\dot{V}O_{2peak}$ (graph #2).

Appendix J

$\dot{V}O_2$ Responses during Exercise for Representative Participants

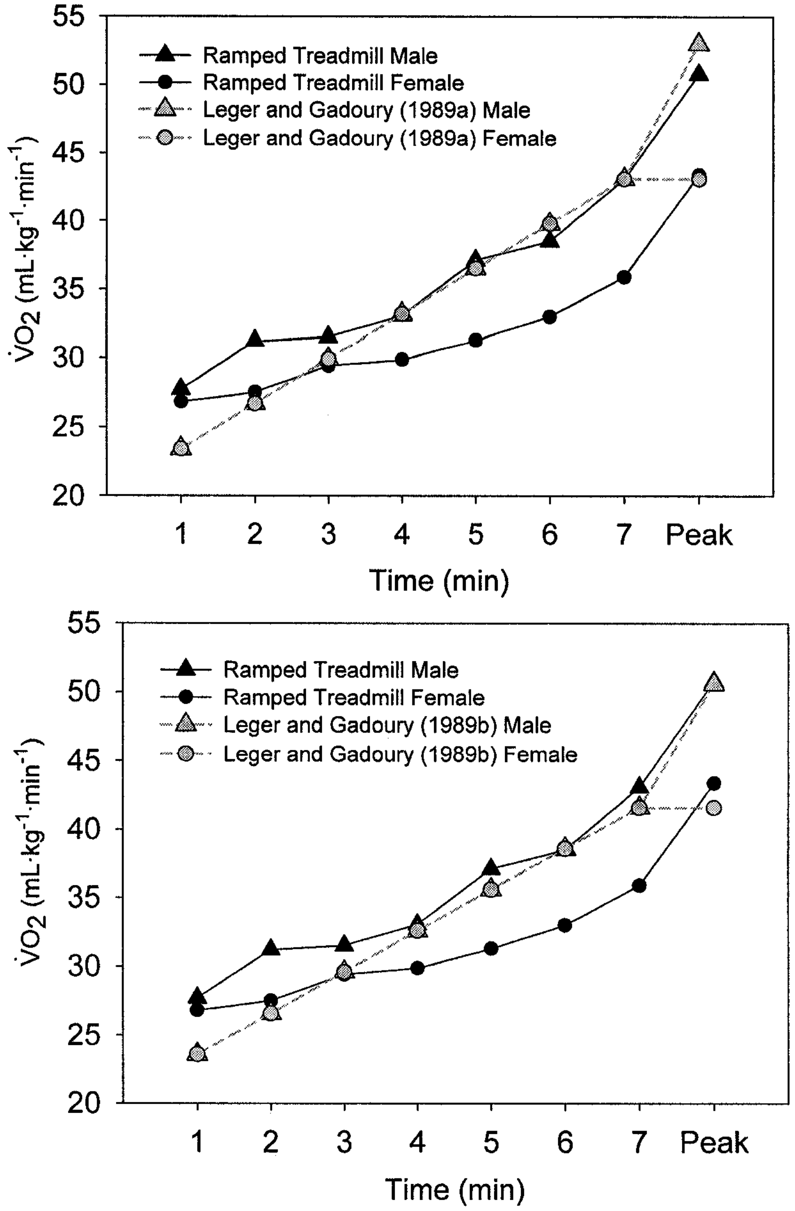


Figure J-1. Oxygen uptake ($\dot{V}O_2$) responses during LST (Leger et al., 1988) and Ramped Treadmill exercise for representative participants (female participant 5 and male participant 27). Time 1 is the first minute of exercise completed and peak is highest peak $\dot{V}O_2$ attained. Exercise terminated the female at 8 min 25 sec on the RT and 7 min 0 secs on the LST. Exercise terminated the male at 12 min 20 sec on the RT and 10 min 15 secs on the LST.

Appendix J Continued

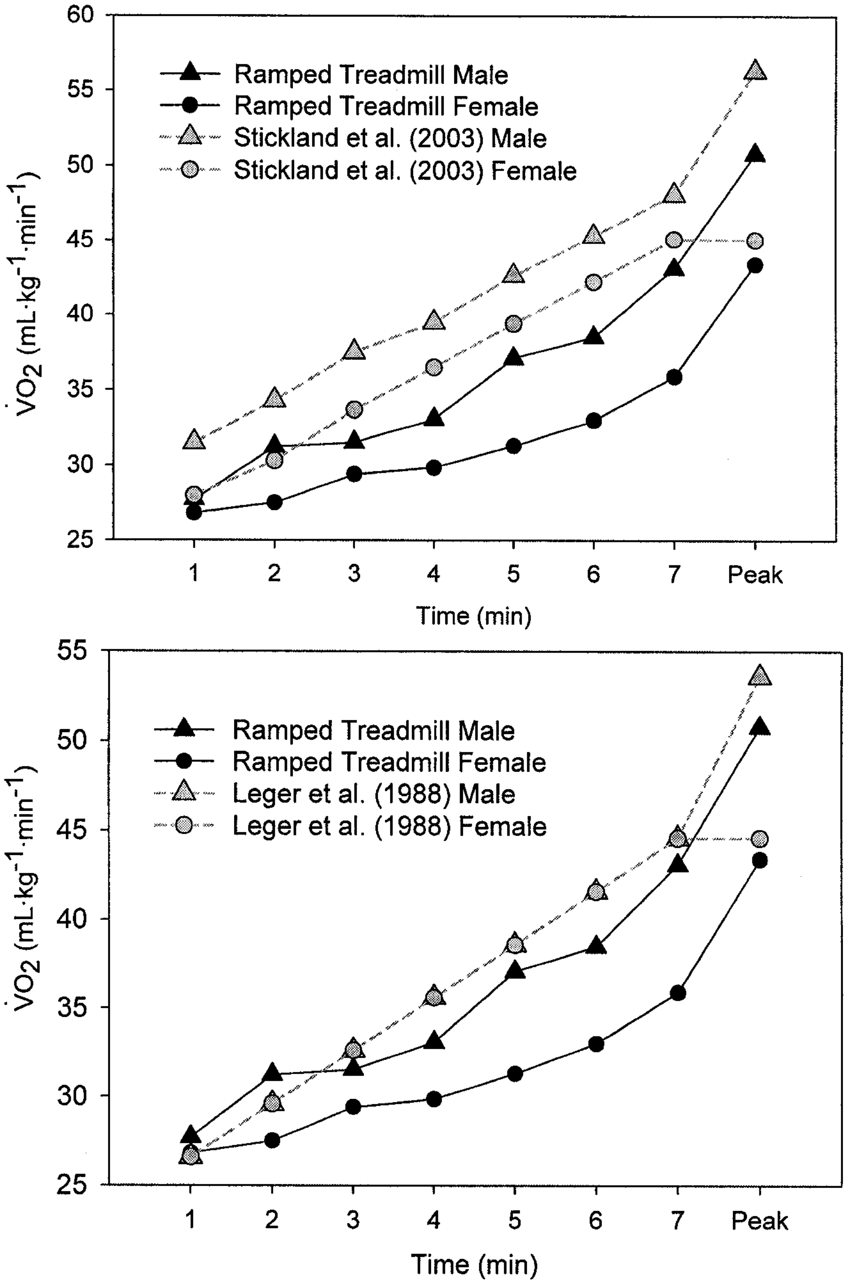


Figure J-2. Oxygen uptake ($\dot{V}O_2$) responses during LST (Stickland et al., 2003); (Leger et al., 1988) and Ramped Treadmill exercise for representative participants (female participant 5 and male participant 27). Time 1 is the first minute of exercise completed and peak is highest peak $\dot{V}$ O_2 attained. Exercise terminated the female at 8 min 25 sec on the RT and 7 min 0 secs on the LST. Exercise terminated the male at 12 min 20 sec on the RT and 10 min 15 secs on the LST.

Appendix K

$\dot{V}O_{2peak}$ Prediction Equations for Representative Participants

Male Participant #27

X_0 = **Body mass index** = 25.2

X_1 = **HRrest** = 71

X_2 = **HR at min 1 of LST** = 131

X_3 = **HR at min 2 of LST** = 136

X_4 = **HR at min 3 of LST** = 150

$\dot{V}O_{2peak}$ **predicted** = $135 + (-0.72X_0) + (-0.168X_1) + (-0.05X_2) + (0.38X_3) + (-0.66X_4)$

$\dot{V}O_{2peak}$ **predicted** = 51.3 $mL \cdot kg^{-1} \cdot min^{-1}$

$\dot{V}O_{2peak}$ **measured from RT** = 50.6 $mL \cdot kg^{-1} \cdot min^{-1}$

Female Participant #5

X_0 = **Body mass index** = 23.4

X_1 = **HRrest** = 72

X_2 = **HR at min 1 of LST** = 150

X_3 = **HR at min 2 of LST** = 163

X_4 = **HR at min 3 of LST** = 175

$\dot{V}O_{2peak}$ **predicted** = $93 + (-0.25X_0) + (-0.11X_1) + (0.14X_2) + (-0.28X_3) + (-0.05X_4)$

$\dot{V}O_{2peak}$ **predicted** = 45.8 $mL \cdot kg^{-1} \cdot min^{-1}$

$\dot{V}O_{2peak}$ **measured from RT** = 45.5 $mL \cdot kg^{-1} \cdot min^{-1}$