DEVELOPMENT OF REFERENCE STANDARDS FOR

CARDIORESPIRATORY FITNESS FROM THE BALL STATE UNIVERSITY

ADULT PHYSICAL FITNESS PROGRAM COHORT

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ABSTRACT

THESIS: Development of Reference Standards for Cardiorespiratory Fitness from the Ball State University Adult Physical Fitness Program Cohort

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Purpose: The objective of this study was to develop adult reference standards for cardiorespiratory fitness (CRF) from directly measured maximum oxygen consumption (VO_{2max}) using the Ball State University Adult Physical Fitness Program (APFP) cohort. **Methods:** The cohort is an open cohort since 1971 of self-referred participants to the APFP established by the Clinical Exercise Physiology program. From 3,212 individual participants, 2,642 male and 1,741 female (18-79 years) test files remained after exclusion of test files if the individual was <18 or >79 years, achieved a respiratory exchange ratio <1.0 or >1.59, performed a cycle protocol, had a BMI <18.5 $kg \cdot m^{-2}$, or was the first of consecutive exercise tests within one month. Gender-specific age, physical activity (PA), body mass index (BMI), and smoking status CRF reference standards were developed from directly measured VO_{2max}. **Results:** Men had greater mean CRF (35%) than the women and consistently had greater mean CRF according to age, PA, BMI, and smoking status (p<.05). A decline in CRF of approximately 10% was

observed across each decade of age. Higher CRF was observed in the active (10%) and exercisers (37%) groups compared to the sedentary group. Groups with greater BMI had significantly lower CRF compared to groups with lower BMI. CRF was 5% greater in non-smokers compared to current smokers. **Conclusion:** CRF is greater in men, in younger decades of age, with greater level of PA, with lower BMI, and in non-smokers.

Key Words: VO_{2max}, GRADED EXERCISE TEST, NORMATIVE

CHAPTER I

INTRODUCTION

Cardiorespiratory fitness (CRF) is defined as the ability of the skeletal muscle, cardiovascular, and respiratory systems to meet the oxygen demand during maximal exercise (3, 11). CRF is the ability to perform activities of daily living as well as sustain dynamic exercise, and is measured by the maximum volume of oxygen utilized during exertion. The gold standard measurement of CRF is maximum oxygen consumption (VO_{2max}) (3). VO_{2max} is expressed as the maximum ability to transport oxygen to working muscle during exercise that results in physical exhaustion and is the product of cardiac output (product of heart rate and stroke volume) and arteriovenous oxygen difference (difference in the oxygen content of blood between the arterial and mixed venous blood) (14, 60, 75). A graded exercise test (GXT) is a noninvasive procedure used to measure VO_{2max} which can provide diagnostic and prognostic information on health status (5, 60).

In a study performed by Blair et al. (16) in 1989, a strong and inverse relationship between CRF and mortality due to cardiovascular disease, cancer, and all causes in men and women. Similarly, Myers et al. (62) observed that a 12% improvement in survival was associated with every 1-metabolic equivalent (MET) increase in treadmill performance. Low CRF is a modifiable risk factor as improvements in prognosis have been demonstrated by improvements in fitness.

VO_{2max} can be expressed in two ways: liters of oxygen per minute ($L \cdot min^{-1}$) or milliliters of oxygen per kilogram of body weight per minute ($ml \cdot kg^{-1} \cdot min^{-1}$). These are the absolute and relative terms, respectively. Expressing VO_{2max} in relative terms allows for inter-subject comparison because body mass is a factor affecting VO_{2max}. A gain in fat weight results in a decrease of VO_{2max}, while a loss of fat weight results in an increase in VO_{2max} (43). Because VO_{2max} provides insight into an individual's health and prognosis, it has become an essential physiologic variable to assess. Howley et al. states that it has become a frequent descriptive variable much like height, weight, and age (46).

In an adult population, VO_{2max} can be inversely related to an individual's age dependent upon physical activity habits. In a study performed by Åstrand (8), men and women performed maximal exercise tests initially in 1949 and at follow-up in 1970. When individual's were initially trained and remained physically active, a decline of 1% per year (10% per decade) was observed. Similarly, Dehn and Bruce (27) noted that the rate of decline in VO_{2max} with age is approximately 10% per decade, but with a greater rate of decline in VO_{2max} in the physically active (12.5% per decade) compared to physically inactive (7.5% per decade). It is important to note that although the rate of decline was greater in the active group, mean VO_{2max} was still greater than the inactive group (31.3 $ml \cdot kg^{-1} \cdot min^{-1}$ versus 28.8 $ml \cdot kg^{-1} \cdot min^{-1}$, respectively). Similar to Astrand (8) and Dehn (27), Heath et al. (43) observed a decrease in VO_{2max} of approximately 9% per decade after the age of 25 years. They determined the decrease was a result of less physical activity, gain in weight, and cardiovascular system changes common with age. They also noted that despite the inevitable decline in VO_{2max} with age, some men in their 60s and 70s can maintain their VO_{2max} above that of healthy untrained men via endurance

training. On the contrary, Fleg et al. (36) stated that regardless of physical activity habits, the longitudinal rate of decline increases in VO_{2max} in healthy adults with each successive decade. The literature is controversial on the consensus of a decline in CRF with age, when physical activity is a factor. As mentioned previously, the research provides varying rates of decline with the active population. An overall consensus that VO_{2max} in relation to age is highly variable due to physical activity habits is appropriate.

Gender is important to consider when interpreting VO_{2max} measures. In a study by Ogawa (64), it was determined that even when results were normalized for greater height and mass in men versus women, mean VO_{2max} was still higher in male subjects regardless of age and training status. Compared to the women, mean VO_{2max} in the men was still greater in the trained young (22%) and old (24%), and the untrained young (23%) and old (35%). It was also observed that regardless of age and training status, differences in VO_{2max} were seen between genders and in varying amounts. A larger maximal cardiac output in sedentary men explained nearly 40% of the sex differences in VO_{2max}. In physically conditioned men, cardiac output explained between 86% and 95% of the disparities (64). However, Bassett et al. (14) states that the normal range of VO_{2max} values seen in both age-matched sedentary and trained men and women is primarily due to the differences in maximal stroke volume. Regardless of training status or age, maximal heart rates were comparable between men and women resulting in sex differences due to stroke volume (64).

CRF information is utilized by health and fitness professionals in the development of exercise prescriptions and to track improvements in CRF. The American College of Sports Medicine (ACSM) published norms from the Cooper Clinic in Dallas, TX for the

interpretation of CRF values (3). The gender and age specific normative tables were developed from men and women volunteers. The population studied by the Cooper Clinic was well-educated, predominately white men and women in the middle and upper socioeconomic class with access to healthcare. During the Balke protocol, subjects had to achieve 85% of their age-predicted maximum heart rate (APMHR) with a normal electrocardiogram (ECG) interpretation. The Cooper Clinic cohort that remained after delimitation criterion was set was healthier than the general public (47).

The reference table released by the Cooper Clinic used the Balke treadmill protocol to determine VO_{2max} values. Highly correlated with measured VO_{2max}, the final speed and grade as published by Balke et al. (13) or treadmill time as published by Pollock et al. (68) can be used in the prediction of VO_{2max}. Although the Balke protocol is correlated with measured VO_{2max}, error is possible with the prediction of VO_{2max} in men (r=0.87; SE$\pm$2.84ml$\cdot$kg$^{-1}\cdot$min^{-1}) (38) and women (r=0.94; SE$\pm$2.2ml$\cdot$kg$^{-1}\cdot$min^{-1}) (68). The direct measurement of VO_{2max} is the standard method used to measure CRF and is recognized as such internationally (14, 79).

Purpose

The purpose of this project was to develop reference standards for CRF derived from directly measured VO_{2max} in the Ball State University (BSU) Adult Physical Fitness Program (APFP) cohort.

Specific Aim 1: To develop gender and age specific reference standards for CRF.

Specific Aim 2: To develop reference standards for CRF according to level of physical activity.

Specific Aim 3: To develop reference standards for CRF according to body mass index classification.

Specific Aim 4: To develop reference standards for CRF according to smoking status.

Study Significance

Normative tables published by the ACSM and Young Men's Christian Association have been developed to interpret CRF (3, 40). The more accurate measure of CRF from directly measured VO_{2max} could provide more specific information for the assessment of health status, development of exercise prescriptions, and the prognosis of disease.

Delimitations

Exercise test data stored in the APFP database from men and women participants were included in the study. Test files were excluded from the present study if participant's failed to achieve a respiratory exchange ratio (RER) ≥ 1.0 or exceeded 1.59, were younger than 18 years of age or greater than 79 years, performed a cycle ergometer protocol, were tested within one consecutive month, had a BMI <18.5 kg·m^{-2}, or had missing variables (gender, age, height, weight, or VO_{2max}). If re-tested within one month, the second test was used in the study. One was used to eliminate repetition of similar VO_{2max} measures.

Definitions

1. *Cardiorespiratory fitness (CRF):* is defined by the functional capacity of the skeletal muscle, cardiovascular, and respiratory systems during maximal exercise.

2. *Graded exercise test (GXT):* An exercise test with continuous increases of speed and grade to elicit physical exhaustion to evaluate the physiologic responses.

3. *Maximal oxygen consumption (VO$_{2max}$):* The maximum capacity of the cardiovascular system to transport and use oxygen during a GXT. Is the product of cardiac output and arteriovenous oxygen difference.

CHAPTER II

LITERATURE REVIEW

Cardiorespiratory fitness (CRF) is the ability to sustain dynamic exercise for an extended duration (3). Utilizing large muscle groups is important in the assessment of CRF because it reflects the capacity of the cardiovascular, skeletal muscle, and respiratory systems to supply oxygen to working muscles (3, 11, 58). CRF also reflects the ability to carry out activities of daily living that necessitate prolonged aerobic metabolism and is typically expressed as oxygen consumption (VO_2) (5). The capacity to perform aerobic exercise relies on the increase in VO_2 necessary to meet the energy requirement of a physical workload (4, 26). Maximum oxygen consumption (VO_{2max}) is a vital measure as it is considered the variable that defines the limit of the skeletal and cardiorespiratory system during exercise and implies that an individual's limit to meet physiologic demands has been achieved (5, 11).

Measurement of Cardiorespiratory Fitness

Maximal Oxygen Consumption

The model of VO_{2max} was conceived with the work of Hill et al. in 1923 (44). In 2000, Bassett and Howley (14) stated that "Hill's theories served as an ideal theoretical framework" (14). Hill and Lupton (44) hypothesized that there is an upper limit to VO_2 with inter-individual differences in VO_{2max}, VO_{2max} is limited by the oxygen carrying

capacity of the blood, and a high VO_{2max} is required for middle and long-distance running success. Hill's classical paradigm of VO_{2max} has now become the standard measure of CRF and is recognized as such internationally (14, 37, 46, 78). VO_2 is defined by the Fick equation: a function of cardiac output (product of heart rate and stroke volume) and arteriovenous oxygen difference (the difference in oxygen concentration between arterial and venous blood). When VO_2 is measured during exertion at maximal effort, VO_{2max} can be defined (4, 75). VO_{2max} is measured in liters of oxygen per minute ($L \cdot min^{-1}$) and usually expressed as milliliters of oxygen per kilogram of body weight per minute ($ml \cdot kg^{-1} \cdot min^{-1}$); these are absolute and relative values, respectively (5). In addition, relative VO_{2max} is frequently expressed in metabolic equivalent (MET), where 1 MET is equivalent to 3.5 $ml \cdot kg^{-1} \cdot min^{-1}$ (5).

Graded Exercise Tests

A graded exercise test (GXT) is a noninvasive procedure in which information is obtained to provide screening for the presence of disease, diagnostic and prognostic information, and to assess an individual's ability to perform dynamic exercise to develop individualized exercise prescriptions (2, 4, 5, 60). Rodgers et al. (74) stated that the development of a suitable exercise prescription is an indication for the use of directly measured gas analysis in published guidelines. VO_{2max} is directly measured using a GXT and is the most frequently reported and analyzed variable from a GXT (4). The diagnostic and prognostic benefit of GXTs transcends varying populations; from apparently healthy to persons at high risk and individuals with cardiovascular disease (CVD) (4).

Indirect Measurement

Measurement of VO_2 is considered indirect when the final work rate or time during a GXT is used (4). Froelicher and Lancaster (38) studied the hypothesis than an individual's VO_{2max} could be predicted by the duration of the Balke treadmill protocol. In total, 1,800 men performed the Balke treadmill protocol with samples of expired air analyzed from the United States Air Force School of Aerospace Medicine. Men were excluded for symptoms or findings of cardiovascular disease or other ailments that could limit exercise, individuals that completed a submaximal effort as judged by the investigators and those with a respiratory quotient less than one, an abnormal resting or exercise electrocardiogram, or those with a high resting blood pressure. Of the 1,025 men (20 to 53 years) remaining after exclusion criteria was set, 127 men had multiple expired air bags collected to check the air collection technique and to analyze VO_2 as the subject reached maximal exercise. For both groups, regression equations were developed and a linear regression for VO_{2max} against time revealed correlations of r=0.72 (SE±4.26 ml·kg^{-1}·min^{-1}) and r= 0.87 (SE±2.84 ml·kg^{-1}·min^{-1}) for the population and the men with additional VO_2 samples, respectively. Froelicher and Lancaster (38) concluded that tolerance limits of the protocol are so wide, that VO_{2max} can only be grossly estimated by the total treadmill time. Widely used by the Cooper Clinic, the Balke protocol can predict VO_{2max} from the treadmill speed and grade during the final minute of exercise (12, 16, 47). From the final treadmill workload, predicted VO_{2max} is highly correlated with directly measured VO_{2max} in men and women (r≥0.92) (66, 68). Myers and colleagues (61) examined ramp versus standard exercise protocols in 41 male subjects (mean age 62±7 years). The study sample included 10 subjects with chronic heart failure, 11 with asymptomatic coronary artery disease (CAD), 11 with symptom-limited CAD,

and 10 age-matched normal men. Subjects were maximally tested to directly measure VO_{2max} with the Bruce, modified Balke, and an incremental ramp protocol, with the ramp rate set to elicit a test lasting approximately 10 minutes (13, 24, 61). The Bruce protocol (22.3 ± 8 ml·kg^{-1}·min^{-1}) elicited significantly greater measures of VO_{2max} compared to the Balke (21.1 ± 8 ml·kg^{-1}·min^{-1}) and ramp (21.0 ± 8 ml·kg^{-1}·min^{-1}) protocols. The findings by Myers et al. (61) suggest the accuracy of predicted VO_2 from treadmill speed and grade was reduced in the heart disease subjects (r=0.51-0.53) compared to the healthy subjects (r=0.71). Including all of the treadmill protocols and each subject group, the mean predicted value for VO_{2max} (24.0 ± 9 ml·kg^{-1}·min^{-1}) was 11% greater than the directly measured VO_{2max} (21.4 ± 8 ml·kg^{-1}·min^{-1}). The greatest difference of 16% (4.1 ml·kg^{-1}·min^{-1}) was found between the measured and predicted VO_{2mas} with the Bruce protocol (61). With a variability of up to ±4.2 ml·kg^{-1}·min^{-1}, the need for a directly measured CRF standard is necessary as reference standards can be used to determine a person's risk of mortality.

Direct Measurement

With respect to CRF, directly measured VO_{2max} provides an accurate measure of physiologic function compared to estimated values from either final work rate or total exercise time (81, 82). Open-circuit spirometry is used to measure VO_{2max}, in which the individual breathes through a low-resistance valve while their nose is occluded. Pulmonary ventilation is measured and expired concentrations of oxygen and carbon dioxide are analyzed (3). In 1968 Shephard et al. (78) stated, "although many tests of CRF have been proposed in the past few decades, the opinion is now widespread that directly measured VO_{2max} should be accepted as the absolute criterion against which

other procedures are to be judged". Since then, numerous publications have verified that directly measured VO_{2max} is the gold standard of oxygen utilization at maximal exercise (5, 37).

Termination Criteria

It is universally accepted that the body's physiological ability to transport and utilize oxygen has an upper limit during maximal exercise (14, 83). The ability to increase VO_2 minimally or not at all in response to an increase in work rate is known as VO_2 plateau. The point at which VO_2 ceases to increase with a continuous rise in intensity is termed VO_{2max} (83). Hill and Lupton (44) hypothesized that VO_2 does not continue to increase infinitely. Through a study that involved subjects running on an outdoor course with increasing speeds, VO_2 was measured at each stage. Hill et al. found "...the rate of oxygen consumption...increases as speed increases...reaching a maximum...for speeds beyond 260 m/min. However much the speed be increased beyond that limit, no further increase in oxygen intake can occur..." (44, 46). Confirming the findings by Hill and Lupton (44), Åstrand and Saltin (10) repeated attempts to drive VO_2 higher by increasing work rate during discontinuous test protocols. However, Howley et al. (46) stated, it is not uncommon for a subject to fail to demonstrate a plateau in VO_2 during either a treadmill or cycle GXT. As established by Taylor et al. in 1955 (83), if the final two oxygen intakes were different than less than 2.1 ml·kg^{-1}·min^{-1} (0.15 L/min) then it was considered that the work rate elicited VO_{2max}. An array of studies report ranges from <50% to 90-100% of the population who have achieved a plateau in VO_{2max} (6, 9, 30, 66, 80, 83). For those individuals that do not

achieve a plateau in VO_2, other physiologic responses have been identified to evaluate achievement of VO_{2max} in a GXT.

Secondary criterion that have been established to verify maximal effort in the attainment of directly measured VO_{2max} include: respiratory exchange ratio (RER), maximal heart rate (MHR), and rating of perceived exertion (RPE) (57, 70). RER has been and continues to be the most widely used criteria for validating that VO_{2max} has been achieved (70). RER is defined as the amount of carbon dioxide (CO_2) produced by the working muscles and exhaled during exercise, divided by the amount of oxygen (O_2) inhaled in one breath. During exercise, the following reaction between a rising plasma hydrogen ion (H^+) concentration and plasma bicarbonate (HCO_3^-) occurs: $H^+ + HCO_3^-$ $\rightarrow H_2CO_3 \rightarrow H_2O + CO_2$ (14). The production of CO_2 increases ventilation which increases the ratio of expired CO_2 over inhaled O_2 (RER). At rest, RER can be <0.8, but the value of RER becomes >1.0 when intense exercise elicits a greater production of CO_2 compared to O_2 inhaled. The RER value also indicates the fuel source used at a given intensity. When fats are exclusively used for energy, the RER value can be as low as 0.7. In an individual consuming a normal diet with average amounts of fats, proteins, and carbohydrates, RER is measured at 0.825. When the value of RER is 1.0, carbohydrates are the entire source of fuel (42). Investigators have tried to establish criterion for RER but experimental evidence suggests that this has been a challenge as some individuals do not achieve greater than 1.0 and others exceed 1.4 even though a maximal effort has been performed (70, 80, 85). Although RER values >1.10-1.15 are commonly used in the research to determine that a maximal effort has been achieved, an RER >1.0 still indicates peak VO_2 has been met (4, 5). In a study by Sidney et al. (80) an RER of 1.0

would have excluded 20% of the elderly women rated as making a "good" effort as determined by the experimenters. This less conservative value has the potential to include subjects that were limited by local fatigue during the exercise, yet still gave a maximal effort. Second to RER, MHR is the most utilized secondary criterion in establishing directly measured VO_{2max} (70).

In tests that do not collect expired gases for analysis, maximal heart rate (MHR) or age-predicted maximal heart rate (APMHR, 220-age) may be used criterion to determine maximal effort (57). Criteria for MHR is difficult to define as the standard deviation from APMHR is ±11 beats per minute, making it a difficult to justify the use as criteria for achievement of VO_{2max} (46, 53). APMHR has been used to estimate MHR in men and women, but can underestimate MHR for men and women younger than 40 years and overestimate MHR for men and women older than 40 years (3). In a study by Whaley et al. (86) 2,010 men and women, aged 14 to 77 years performed maximal treadmill exercise. Five percent and 13% of men achieved approximately 20 beats·min^{-1} under or over their APMHR, while 7% and 9% of the women exceeded under or above APHMR, respectively. Older individuals commonly achieved a MHR greater than their APMHR. In addition, individuals that differ significantly from APMHR can be identified by combining information on an individual's age and smoking habits with extreme resting heart rate and body weight. More appropriately, the equations developed by Whaley et al. specific to gender, age, resting heart rate, body weight, and smoking habits would be a better criterion for VO_{2max} then APMHR.

A third criterion, although subjective, is RPE. RPE integrates signals from peripheral skeletal muscles and joints, central circulation and pulmonary function, and

the central nervous system. These signals are summed into perceived exertion. RPE is assessed using the 15-point Borg Scale with a rating system of 6-20; the 6-20 scale can be used to denote heart rates from 60 to 200 beats·min^{-1}. The Borg scale is not intended to be used too literally because heart rate values as an indicator of stress depends upon age, exercise type, anxiety, environmental, and other factors (20). Borg wrote, "number 20 on the scale refers to a kind of "absolute maximum," an intensity that most people never will have reached previously in their lives…according to the definition and instruction, 19 should be the highest intensity that most people have ever experienced" (19). The Borg scale can assist the technician in determining the degree of fatigue with a value >18 indicative that a maximal effort has been achieved (37). A study by Lamb et al. (51) assessed the reliability of Borg's RPE scale using two incremental treadmill protocols in 16 male athletes (23.6±5.1 years). In this study and RPE of 17 or volitional exhaustion was used for test termination criteria. In this athletic population, an RPE of <18 was used, which makes RPE relative to group of individuals being tested.

Factors that Affect Maximum Oxygen Consumption

Numerous studies have concluded that the capacity to increase stroke volume, heart rate and a-vO$_2$ difference in response to maximal effort exercise is affected by several factors. General physiologic responses to maximal exercise occur in individuals, but specific characteristics can affect this response. These characteristics include age, gender, fitness level, and genetics, and consideration of these factors is imperative when interpreting CRF (4, 5, 14, 25, 37, 84). Regardless of gender and age similarities, varying degrees of the inter-individuals difference can results in different measures of CRF

Gender

When interpreting VO_{2max} values to classify CRF, it is important to distinguish between the genders due to physiologic differences. In 2007 Arena et al. (5) noted in populations at any age, VO_{2max} in men was 10-20% greater than in women. This was attributed to men having both a greater hemoglobin concentration which positively affects arteriovenous oxygen (a-v O_2) difference and a larger portion of muscle mass and heart size necessitating greater stroke volume. Both the increase in stroke volume and the increase in a-v O_2 difference equate to greater VO_{2max}, as explained by the Fick equation (4, 37, 75).

Age

It is accepted that there is an age-related decline in VO_{2max}, but the rate of decline differs among studies (25). The following section will review cross-sectional and longitudinal investigations that studied the rate of decline in VO_{2max}, with some investigations including the role of conditioning status and its affect on the rate of decline. CRF characteristically declines an average of 10% per decade in sedentary men and women (35, 36, 64). This is due to a decrease in stroke volume, maximal heart rate, blood flow to skeletal muscle, and skeletal muscle function (35, 36, 45, 72). The 10% decline per decade has been consistently reported in sedentary men and women, but men who maintain physical activity levels and fat-free mass, the aging process results in a decline of approximately 5% per decade (6, 8, 36, 43).

The classic studies by Robinson (73) and Åstrand (6, 7, 9) of change in VO_{2max} with aging among men and women present a similar view. The first comprehensive cross-sectional study to determine the differences in physiological changes in response to exercise with age among active but nonathletic men was performed by Robinson et al.

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(73) in 1938. They studied the changes in physiological responses to exercise in 81 men with mean ages ranging from 6 to 75 years old. Subjects underwent exhaustive exercise on a motor driven treadmill where expired gases were analyzed, and observed the decline in VO_{2max} after the age of 25 to 75 years, to be 9.5% per decade (4.64 ml·kg^{-1}·min^{-1} per decade) in occupationally active but nonathletic men. In 1970, Åstrand et al. (8) retested 35 female and 31 male subjects between the ages of 20 to 33 years old (mean of 21.9 and 25.9 years for the female and male groups, respectively) that were initially tested in 1949. At baseline, subjects were well trained and at the follow-up approximately 20 years later, the subjects were habitually physically active. During the intervening 20 years, subjects remained active in their vocation and with leisure time physical activity. Significant decreases were seen when VO_{2max} was predicted on the basis of submaximal VO_2 and heart rate on a cycle ergometer. The Douglas bag method was used to determine VO_2 during the final minute of each work load. VO_{2max} declined by 19% in females and 23% in males over the 20 year period. This equates to an approximate decrease of 9.5% in women and 11.5% in men per decade. Reduction in maximal heart rate of 7% was seen across groups, but it was noted that no correlation occurred between the decline in VO_{2max} and the change in heart rate.   In women, Åstrand et al. (6) reported a decline of 1.5 ml·kg^{-1}·min^{-1} from age 20 to 65 years; averaging an approximate 6% decrease in VO_{2max} per decade.

Pollock et al. (41) noted that the 10% decline per decade with age is not appropriate for endurance trained athletes. In support of this statement, Hagberg et al. (41) reviewed three case reports by Pollock (69), Faria (33), and Maud (54) of older endurance athletes. The authors reported VO_{2max} values in the endurance athletes of 61,

59, and 60 ml·kg^{-1}·min^{-1} at the ages of 60, 70, and 70 years old, respectively. Hagberg (41) stated that if the athletes experienced the 10% decline in VO$_{2max}$ per decade after 25 years of age, VO$_{2max}$ values would need to be in the range of 85-92 ml·kg^{-1}·min^{-1} before the age of 25 years. In 1987, Pollock et al. (67) published a study refuting the average 10% age-related decline in VO$_{2max}$. He studied 24 master runners from the age of 50 to 82 years at baseline with an average of a 10.1 year follow-up. Two distinct groups were trained; one group maintained both training miles and speed and the second group maintained only training miles. A difference in the age-related decline was seen between these two groups, with no significant differences in weight. The group that maintained both training miles and speed experienced a decrease of 2% across the 10 year follow-up period. The group that maintained solely training miles saw a decrease in VO$_{2max}$ of 13%. With the evidence provided, it is apparent that an age-related decline of 10% in VO$_{2max}$ is not appropriate for the individuals that maintain endurance training throughout their older adulthood.

In one of the first longitudinal studies of VO$_{2max}$ published by Dill et al. (29) in 1967, 13 men were retested with a treadmill protocol in which grade and speed differed to exhaust he subjects in a run that lasted from 3 to 5 minutes. The follow-up was completed an average of 23 years after the baseline testing that took place at either Indiana University or the Harvard Fatigue Laboratory. At baseline the subjects were "Olympic contenders and a few were world champions." VO$_{2max}$ declined in all subjects, but at varying rates (from 5.7 to 28% per decade) with an average decline of 15% per decade. This average was much greater than discussed previously. The greater rate of decline is largely attributed to the fact that the men were highly trained when tested at

baseline, and most had not continued to train during the years preceding the follow-up testing.

Dehn and colleagues (27) published a study consisting of both cross-sectional and longitudinal data to investigate the role of habitual physical activity and the affect of the age-related decline on VO_{2max}. Cross-sectional data was collected from 86 healthy men with a mean age of 52.2 years (40 to 70 years) completed a multi-stage treadmill test to measure VO_{2max} (55). The highest value of VO_2 when accompanied by an RER of ≥ 1.15 or a plateau in VO_2, was accepted as an individual's VO_{2max} (27, 83). Forty of those men had previous measures of VO_{2max} an average of 28 months earlier. Subjects were stratified as either habitual exercisers (regular [>once per week] running activity) or inactive (lack of regular, weekly participation in running). The cross-sectional data represented a decline of 10% per decade in all subjects. When groups were defined as active or inactive, the decline was 12.5% and 7.5%, respectively. It is important to note that although the decline was greater in the habitually active group, the mean VO_{2max} was still greater (31.29 ± 6.92 ml·kg^{-1}·min^{-1}) compared to the inactive group (28.76 ± 3.09 ml·kg^{-1}·min^{-1}). The longitudinal data of the 40 men that had been tested previously the men that engaged in jogging had a reduced rate of decline in VO_{2max} as compared to the more sedentary and less regularly active individuals; 0.56 ml·kg^{-1}·min^{-1} (1.4%) per year versus 1.62 ml·kg^{-1}·min^{-1} (5.0%) per year, respectively over a 2.3 year follow-up period (27).

Fewer cross-sectional and longitudinal studies have been performed in women compared to men. The cross-sectional studies consistently demonstrate a lower decline in VO_{2max} with age in women (25). Twenty-three young to elderly (20 to 63 years old)

endurance trained women in which there were no significant differences among the groups for lean body mass percent fat mass. Subjects performed maximal exercise on an electrically braked cycle ergometer with VO_{2max} assessed with open circuit spirometry. The cross-sectional data demonstrated a decline in VO_{2max} at a rate of 11% per decade. Because blood volume was not changed with aging, the decline in VO_{2max} of endurance trained women was attributed to decreases in both heart rate and stroke volume (88).

A 7 year follow-up longitudinal study was completed in 8 sedentary (63 ± 2 years at follow-up) and 16 endurance trained (57 ± 2 years at follow-up) women. At baseline, the VO_{2max} in the endurance trained women was significantly greater (~70%) than the sedentary women when tested with open-circuit spirometry during incremental treadmill exercise. Over the 7 year period, the sedentary women remained inactive while the endurance trained women either reduced their exercise training volume or increased/maintained training volume. At follow-up the absolute rate of decline was significantly greater in the endurance trained versus the sedentary women, but the relative rates of decline were not significantly different; 18% versus 15% per decade in the trained and sedentary women, respectively. Neither changes in body mass nor change in maximal heart rate attributed to the different rates of decline in VO_{2max} with age seen between the two groups of women (31). Both the longitudinal and cross-sectional research support that VO_{2max} decreases with aging, but that the rate of decline can vary dependent upon level of physical activity or training status.

Training Level

Endurance training increases VO_{2max} by 10% to 30% and is primarily due to increases in stroke volume and a-v O_2 difference (76). Generally, VO_{2max} is closely

related to the exercise training status as stated by Heath el al. (43) and Ogawa et al. (64). Ogawa et al. (64) studied 110 healthy subjects that were categorized into 8 different groups on the basis of gender, age, and training status. Sedentary subject were normally active, but did not engage in regular exercise while the trained subject reported exercising strenuously for at least 30 minutes at least 3 days per week. They included 14 sedentary men (27±3 years, 45.9±6.1 ml·kg^{-1}·kg^{-1}), 15 trained men (28±3 years, 63.5±4.4 ml·kg^{-1}·kg^{-1}), 13 sedentary men (63±3 years, 27.2±5.1 ml·kg^{-1}·kg^{-1}), 14 trained men (63±4 years, 47.6±4.3 ml·kg^{-1}·kg^{-1}), 14 sedentary women (23±2 years, 37.0±4.3 ml·kg^{-1}·kg^{-1}), 13 trained women (26±3 years, 52.1±3.1 ml·kg^{-1}·kg^{-1}), 14 sedentary women (64±4 years, 22.2±3.1 ml·kg^{-1}·kg^{-1}), and 13 trained women (57±3 years, 35.3±3.3 ml·kg^{-1}·kg^{-1}). Compared to sedentary subjects of the same gender and similar age, trained subjects reported significantly greater CRF. In young trained people from 21 to 31 years of age, mean VO_{2max} was 39% greater and 41% greater for men and women, respectively compared to young sedentary individuals. In addition, trained older people had significantly greater CRF compared to sedentary men and women by 75% and 60%, respectively. This was attributed to larger maximal cardiac output and a-vO$_{2diff}$ in trained persons (64).

Conflicting the research provided by Ogawa and colleagues, early endurance training studies, individuals greater than 60 years old did not increase VO_{2max} (15, 28, 63, 65) observed noted in 1973 that older individuals responded similarly to training when using relative terms. In 1984, Seals et al. (77) studied the trainability of older men and women to increase VO_{2max}. Twenty-four healthy men and women (61 to 67 years old) participated in the study. Expired gases were collected and analyzed while subjects

completed a walking or jogging modified Balke protocol. Fourteen subjects underwent 12 months of endurance training with frequency, time and intensity gradually increasing, while the remaining ten subjects served as non-exercising controls. In the exercise group, the initial 6 months consisted of moderate-intensity (<120 beats/min) walking that was performed at least 3 times per week. For the remaining 6 months, the same group of subjects completed high-intensity exercise starting at 75% of their heart rate reserve (HRR) for 30 minutes which progressed to 45 minutes at 85% of HRR. While the control group remained unchanged, a significant mean increase in VO_{2max} of 30% was seen in the exercise group of men and women when expressed per kilogram of body weight. When expressed in absolute terms, a significant increase of 25% was observed.

The following study confirms that regardless of age, improvement in VO_{2max} is possible. Ten non-frail healthy men (n=8) and women (n=2) averaging 80.3±2.5 years of age participated in a study that aimed to determine if healthy older adults could maintain their individual ability to adapt to a rigorous endurance training program (>80% VO_2peak). The program consisted of 10-12 months of training at an average of 58 minutes at 83% of MHR during 2.5 sessions per week. The high-intensity endurance training resulted in an increase of VO_{2max} by 15±7%. The increase demonstrates that even healthy octogenarians can improvement VO_{2max} through high-intensity endurance training (32). In summary, while some research has demonstrated that older individuals are not able to increase VO_{2max}, trained individuals generally have greater CRF compared to untrained subjects at any age.

Genetics

In 1994, Bouchard and Perusse (23) stated that the genetic component of CRF is estimated to be 25 to 40%. Eighty-six nuclear families, equating to over 400 sedentary persons, participated in the HERITAGE Family Study where VO_{2max} was measured with cycle ergometry. Subjects were aged between 16 and 65 years old. It was suggested that both genetic and environmental factors contribute to the occurrence of similar responses to exercise training within a family that can be readily accounted for by chance, with maximal heritability estimates of at least 50% (22). In 1999 Bouchard et al. (21) completed an analysis using results from the HERITAGE Family Study to the hypothesis that family genetics play a role in individual differences in VO_{2max} in response to a training program. The study consisted of 481 sedentary Caucasian men and women, ranging from 16 to 65 years of age (parents and offspring). Metabolic measures were taken during maximal performance on a cycle ergometer. Subjects completed a 3 day per week, 20-week standardized cycle ergometer training program that began with 30 minutes per day at a heart rate associated with 55% of VO_{2max} determined at baseline. The training load gradually progressed to 50 minutes per day at 75% of VO_{2max} by the end of week 14. This training load was held for the final 6 weeks. The mean increase in VO_{2max} in response to the training program was approximately 16%. The study revealed 2.5 times more variation between than within families, representing that trainability is highly ancestral with a significant genetic element; an estimate of 47%.

When training is controlled for in sedentary adults, the differences between a training and non-training study are similar. An endurance exercise training study that included three independent clinical studies was conducted to use molecular classification to predict gains in VO_{2max}. Groups included young sedentary healthy Caucasian men,

young active Caucasian subjects, and the HERITAGE Family study aerobic training program. The sedentary subjects underwent 6 weeks of supervised training that consisted of cycling for 45 minutes at 70% of baseline VO_{2max} 4 times a week. The active group underwent interval and continuous training on a cycle ergometer 5 times a week for 12 weeks (84). The HERITAGE Family study protocol was described previously (21). Individual genetic differences explain why 23% of subjects failed to increase their VO_{2max} with training (84). Klissouras et al. (50) conducted a study in 1973 to determine human intrapair differences, particularly VO_{2max}, between identical and fraternal twins. Twenty-three identical and 16 fraternal twins of both genders ranged from 9 to 52 years of age. It was determined that mean intrapair differences of VO_{2max} between the sets of twins was significantly different for fraternal (10.06 ml·kg^{-1}·min^{-1}), but not identical twins (2.54 ml·kg^{-1}·min^{-1}). From this, it can be noted that regardless of age in individuals, the ability to adapt functionally in humans can be attributed to heredity. To conclude, there are natural variations in the ability increase VO_{2max} attributed to genetic factors (16, 21, 22). In summary, genetics play an important role in the ability or inability to improve CRF with endurance training.

Cardiorespiratory Fitness and Mortality

Studies exhibit that poor CRF is related to health as it is an important and independent risk factor for premature death (17, 52). Laukkanen et al. (52) examined the relationship of VO_{2max} and exercise test duration with cardiovascular disease (CVD) mortality and all-cause mortality. Direct measure of VO_{2max} on an electrically braked cycle ergometer was performed in 1,294 (42-61.3 years) men with no CVD, pulmonary disease, or cancer at baseline or over a follow-up period of 10.7 years. When categorized

into low VO_{2max} (<27.6 ml·kg^{-1}·min^{-1}) and high VO_{2max} (>37.1 ml·kg^{-1}·min^{-1}) categories, low VO_{2max} was associated with a 2.76-fold risk of overall mortality, and 3.09-fold risk of CVD-related death when adjusted for age, examination years, smoking, and alcohol consumption compared to high VO_{2max} men. CRF had a strong, graded, and inverse association with both all-cause and CVD-related mortality. With this relationship, CRF can be regarded as just as important a risk factor as smoking, hypertension, diabetes, and obesity toward risk of mortality.

Numerous studies have shown the prognostic value of maximal METs attained during a GXT. Together, they indicate that a 10% to 30% improvement in survival occurs with every MET increase during maximal exercise (59, 62, 71). CRF less than 5 METs is an indicator of poor prognosis, placing an individual at a greater risk for being diagnosed with coronary artery disease (39, 71). A maximal MET level from approximately less than 5 to greater than 10 represents the range where a vast majority of the per MET improvement in survival is understood (4). Mora and colleagues studied an asymptomatic cohort (n=6,126) to determine whether exercise capacity (METs) and heart rate recovery (HRR) could provide incremental prognostic importance for cardiovascular mortality in low or intermediate risk using the Framingham Risk Score FRS. At baseline, subjects with a mean age of 44.6±10.1 years performed the standard Bruce treadmill protocol. The test was terminated when ≥90% age-predicted maximal heart rate (APMHR) was achieved. Peak exercise capacity was determined from treadmill time and was expressed in METs. Subjects were followed up prospectively for 20 years with the end point being December 1995 or death. It was found that individuals with low (median or less) HRR (57±12 bpm for women; 57±11 bpm for men) or METs (7.5±2.1 for

women; 10.7±1.9 for men) experienced 91% of all CVD deaths. After adjustment for FRS, low HRR or low METs individually were significant for mortality but persons with both low HRR (44±9 bpm for women; 45±8 bpm for men) and low METs (5.5±1.5 for women; 8.9±1.6 for men) were at substantially higher risk. In conclusion, thresholds of 7.5 METs and 10.5 METs in women and men, respectively, are cut points in which METs of a lesser value are indicative of a high risk of mortality (59).

Blair et al. (16) studied 13,344 men (n=10,224; 41.5±9.3 years) and women (n=3,120; 40.8±9.9) from 1970 to 1981 at the Cooper Clinic in Dallas, TX. Subjects were mostly Caucasian and in the middle to upper socioeconomic strata. To be included for analysis, at baseline all subject had to achieve ≥85% of their APMHR during a GXT where CRF in METs was derived from the final workload using the modified Balke protocol. At baseline, subjects also had to be free of personal history that included: heart attack, hypertension, stroke, diabetes, and resting and exercise electrocardiogram abnormalities. With an average follow up of more than 8 years, it was determined that a strong and graded relationship between CRF and mortality due to all-causes, CVD, and cancer is present. This finding is consistent for both men and women and was not confounded by age or other risk factors. The inverse association seen across fitness groups in both men and women show that a major reduction in all cause death rates occurs between the first and second lowest quintiles of CRF. An asymptote relationship between CRF and mortality is possible in men that achieved 10 METs and women that achieved 9 METs during maximal exercise. This is possible in most adults that participate in regular exercise and appears to be protective against early mortality.

In a prospective study, Blair et al. (18) investigated 9,777 men to assess the changes in CRF and risk of mortality from December 1970 through December 1989. Using the same inclusion criteria and exercise testing methods as previously published by Blair (16), the study included healthy and unhealthy men between the ages of 20 to 82 years where the interval between two clinical examinations was 4.9±4.1years. After a 5.1±4.2 year follow-up for mortality after the second exam, 233 and 87 deaths were attributed to all-cause and CVD mortality, respectively. The highest age-adjusted all-cause death rate was observed in men who were unfit at both examinations and lowest in men who were fit at both. Men who improved from unfit to fit during the initial and subsequent exams had a 44% reduction in mortality risk relative to those who remained unfit. For each minute increase of treadmill time using the modified Balke protocol, a 7.9% decrease in risk of mortality was observed. Because each minute of exercise during the Balke protocol is approximately 0.5 METs, the 7.9% in risk with one minute of exercise would be comparable to the 10% to 30% increase with 1 MET (~2 minutes) (62, 71). To summarize, fit men who maintained or unfit men that improved their CRF level were less likely to die from both all-cause and CVD during the follow-up period compared to those men that remained unfit.

The Aerobics Center Longitudinal Study (ACLS) is a prospective epidemiological follow-up of individuals that underwent assessment at the Cooper Clinic in Dallas, TX. For this study, information from 9,925 predominantly Caucasian women was used (42.9±10.4 years). The purpose of the investigation was to determine the relation between body mass index (BMI), CRF, and all-cause mortality. BMI was calculated as the weight in kilograms per square meter and women were classified as normal (BMI,

18.5 to 24.99), overweight (BMI, 25 to 29.99), and obese (BMI, ≥30). Treadmill time was used to group the women into three CRF classifications on the basis of age cutoffs by decade: low fit (least fit 20% in each age group), moderate fit (the next 40%), and highly fit (top 40% in each age group). The relative risk of all-cause mortality was determined after adjustments for age, smoking, and baseline health status. The results demonstrated that overweight and obese BMI categories did not significantly increase risk of all-cause mortality compared to the normal category, and moderate and high CRF when compared with low CRF was associated with lower risk of mortality. Although the risk of all-cause mortality as predicted by BMI may be misleading if CRF is not taken into account, low CRF in women is an important predictor of all-cause mortality (34).

The purpose of the investigation by Blair et al. (17) in 1996 was to calculate the association of CRF to CVD-mortality and to all-cause mortality. In this observational study, a large cohort of men (n=25,341) and women (n=7,080) completed preventive medical exams which included a treadmill GXT. CVD and all-cause mortality rates were calculated for the low (least fit 20%), moderate (next 40%), and high (most fit 40%) fitness categories by risk factor levels of smoking habit, blood pressure, cholesterol levels, and health status. After the main outcomes of CVD-mortality and all-cause mortality were measured, it was determined that inverse relationships were seen for mortality across all fitness categories within the levels of other risk factors for both sexes. Those classified as fit with any combination of the previously mentioned risk factors had lower adjusted rates of mortality compared to individuals classified in the low-fit category with none of the risk factors. It can be said that low fitness is a main precursor of mortality. A protective effect of fitness held for both smokers and nonsmokers, those

with controlled and elevated levels of cholesterol and blood pressure, and those that are health and unhealthy.

Physical inactivity that is measured objectively by low CRF, has been estimated to account for 12% of all deaths in the United States (56). Physical inactivity is one of the most crucial, and preventable, health problems (52). Poor physical fitness is a risk factor that can be improved through exercise training. Because CRF can be improved through physical activity reducing the risk of mortality, low CRF is a modifiable risk factor. From the review of the literature on the relationship of CRF and risks of both CVD and all-cause mortality, it is apparent that CRF is a valuable measure obtained through maximal exercise during a GXT. By increasing CRF through a regular exercise regimen, CVD and all-cause risk of mortality can be greatly reduced.

Normative Values for Maximum Oxygen Consumption

Quantifying CRF can assist professionals by providing information to determine intensity, duration, and mode of exercise in developing individualized exercise prescriptions, and can also be used to identify, diagnose, and determine prognosis of a person's health status (2). The American College of Sport Medicine's Resource Manual for Guidelines for Exercise Testing and Prescription (2) states, "Upon completion of an exercise test, the results should be interpreted by comparing the test results with established standards or norms". Two types of standards are usually utilized for comparisons: criterion-referenced standards and normative standards. In fitness assessment, greater focus is on normative standards because data is presented using percentiles allowing for the comparison against other like individuals or against oneself is

possible. Norms are created from the VO_{2max} value from a GXT and compare individuals to other gender and aged matched individuals.

In this section, three published normative tables of cardiorespiratory fitness classifications of normative values for VO_{2max} were reviewed (1, 3, 40). It is difficult to compare these tables because the manner in which normative values of VO_{2max} were reported is not consistent. All tables are divided by gender, with the discrepancy among the tables occurring in the classification of age ranges and VO_{2max} values. Table 3.1 represents VO_{2max} values from the Preventative Medicine Center that was published by the American Heart Association (AHA). In this table, age ranges are by decade and VO_{2max} values are classified into five categories: "low", "fair", "average", "good", and "high" (1). Table 3.2 represents data from the Young Men Christian Association (YMCA). The data is classified into age groups of 18-25, 26-35, 46-55, 56-65, and 65+ years old. This varies as the first age group begins at 18 years of age, and decade distribution occurs from the middle of one decade to the next. Not only does the age classification vary, but the VO_{2max} values are arranged by every fifth percentile (40). The third table presented was published using the ACLS data. This table distributed age ranges similar to that by the AHA with an additional decade range (70-79 years old). The classification of VO_{2max} compares to that in Table 3.2 by the YMCA with the exception of the first and last category.

Not only do the three tables vary in the presentation of information, but also in the exercise test methods performed to determine VO_{2max}. Table 3.1 classified CRF with data from the Preventive Medicine Center in Palo Alto, CA, and from a survey of published sources. The table was developed according to physical fitness levels

estimated for apparently healthy men and women ranging from 20 to 69 years of age (1). Because the mode of exercise and protocol used to estimate VO_{2max} was not made clear, there are limitations in the use of this reference standard. The uncertainty of which mode of exercise was used is a limitation because exercise tests from similar modes should only be compared. Cross comparing data from different modes of exercise could yield inaccurate interpretation of CRF as cycle protocol in the untrained person generally elicits a VO_{2max} 10-20% below their treadmill measure. Secondly, the protocol used to estimate VO_{2max} could yield a limitation in the interpretation of CRF because it is unclear whether a maximal or submaximal effort was given. Although VO_{2max} may be predicted from a maximal effort, a submaximal effort could yield either an over or underestimation of how the person would perform. Because neither the exercise mode use nor level of effort given was not stated, great caution should be warranted in the interpretation of CRF.

Table 3.2 was developed using the YMCA cycle ergometer test (3). This protocol measures heart rate (HR) at a series of submaximal work rates. The measured heart rates are extrapolated to the subject's APMHR to calculate VO_{2max}. Sources of error exist in the use of this protocol. Subjects are not exercised to their maximal level leaving room for error in estimating the maximal workload the subject could achieve. This leads to the risk of incorrect predictions. Additionally, measured HRs are plotted against the work rates achieved and extrapolated to the individual's APMHR (220-age). The use of APMHR can lead to inaccuracy as the standard deviation is 11 beats·min[1] (46). If the true MHR of the individual is known accuracy in the estimation of VO_{2max} can be increased. However, because the norm tables were developed using APMHR, the

publishers advised MHR should not be used in estimation of VO_{2max}. These sources of error including the limitations that the tables were developed from submaximal exercise with a cycle protocol, caution should be taken when interpreting CRF.

Table 3.3 represents the largest and most commonly used reference table for CRF (48). Data is from the Cooper Institute in Dallas, TX which was started in approximately 1970. This reference table includes approximately 45,000 men and 15,000 women (3). VO_{2max} was predicted in these subjects through the use of predicted METs from treadmill time and final workload (speed and grade) (16). Because CRF is often interpreted using the normative table detailed by the Cooper Institute, it is important to identify the major limitation of this table, being indirectly measured VO_{2max} values.

Table 3.1 Normative VO_{2max} values presented from the Preventive Medicine Center

Level	VO_{2max} for men (ml·kg^{-1}·min^{-1})					VO_{2max} for women (ml·kg^{-1}·min^{-1})				
	Age (years)					Age (years)				
	20-29	30-39	40-49	50-59	60-69	20-29	30-39	40-49	50-59	60-69
High	>53	>49	>45	>43	>41	>49	>45	>42	>38	>35
Good	43-52	39-48	36-44	34-42	31-42	38-48	34-44	31-41	28-37	24-34
Average	34-42	31-38	27-35	25-33	23-30	31-37	28-33	24-30	21-27	18-23
Fair	25-33	23-30	20-26	18-24	16-22	24-30	20-27	17-23	15-20	13-17
Low	<25	<23	<20	<18	<13	<24	<20	<17	<15	<13

Published by the American Heart Association in Exercise Testing and Training of Apparently
Healthy Individuals (1972)

Table 3.2 Normative values of VO$_{2max}$ presented from the Young Men Christian Association

%	VO$_{2max}$ for men (ml·kg^{-1}·min^{-1})						VO$_{2max}$ for women (ml·kg^{-1}·min^{-1})					
	Age (years)						Age (years)					
	18-25	26-35	36-45	46-55	56-65	65+	18-25	26-35	36-45	46-55	56-65	65+
100	100	95	90	83	65	53	95	95	75	72	58	55
95	75	66	61	55	50	42	69	65	56	51	44	48
90	65	60	55	49	43	38	59	58	50	45	40	34
85	60	55	49	45	40	34	56	53	46	41	36	31
80	56	52	47	43	38	33	52	51	44	39	35	30
75	53	50	45	40	37	32	50	48	42	36	33	29
70	50	48	43	39	35	31	47	45	41	35	32	28
65	49	45	41	38	34	30	45	44	38	34	31	27
60	48	44	40	36	33	29	44	43	37	32	30	26
55	45	42	38	35	32	28	42	41	36	31	28	25
50	44	40	37	33	31	27	40	40	34	30	27	24
45	43	39	36	32	30	26	39	37	33	29	26	23
40	42	38	35	31	28	25	38	36	32	28	25	22
35	39	37	33	30	27	24	37	35	30	27	24	21
30	38	34	31	29	26	23	35	34	29	26	23	20
25	36	33	30	28	25	22	33	32	28	25	22	19
20	35	32	29	26	23	21	32	30	26	23	20	18
15	32	30	27	25	22	20	30	28	25	22	19	17
10	30	27	24	24	21	18	27	25	24	20	18	16
5	26	24	21	20	18	16	24	22	20	18	15	14
0	20	15	14	13	12	10	15	14	12	11	10	10

Published in the YMCA Fitness Testing and Assessment Manual 4th edition (2000)

Table 3.3 Normative values of VO$_{2max}$ presented from the Aerobic Center Longitudinal Study

%	VO$_{2max}$ for men (ml·kg^{-1}·min^{-1})						VO$_{2max}$ for women (ml·kg^{-1}·min^{-1})					
	Age (years)						Age (years)					
	20-29	30-39	40-49	50-59	60-69	70-79	20-29	30-39	40-49	50-56	60-69	70-79
99	61.2	58.3	57.0	54.3	51.1	49.7	55.0	52.5	51.1	45.3	42.4	42.4
95	56.2	54.3	52.9	49.7	46.1	42.4	50.2	46.9	45.2	39.9	36.9	36.7
90	54.0	52.5	51.1	46.8	43.2	39.5	47.5	44.7	42.4	38.1	34.6	33.5
85	52.5	50.7	48.5	44.6	41.0	38.1	45.3	42.5	40.0	36.7	33.0	32.0
80	51.1	47.5	46.8	43.3	39.5	36.0	44.0	41.0	38.9	35.2	32.3	30.2
75	49.2	47.5	45.4	41.8	38.1	34.4	43.4	40.3	38.1	34.1	31.0	29.4
70	48.2	46.8	44.2	41.0	36.7	33.0	41.1	38.8	36.7	32.9	30.2	28.4
65	46.8	45.3	43.9	39.5	35.9	32.3	40.6	38.1	35.6	32.3	29.4	27.6
60	45.7	44.4	42.4	38.3	35.0	30.9	39.5	36.7	35.1	31.4	29.1	26.6
55	45.3	43.9	41.0	38.1	33.9	30.2	38.1	36.7	33.8	30.9	28.3	26.0
50	43.9	42.4	40.4	36.7	33.1	29.4	37.4	35.2	33.3	30.2	27.5	25.1
45	43.1	41.4	39.5	36.6	32.3	28.5	36.7	34.5	32.3	29.4	26.9	24.6
40	42.2	41.0	38.4	35.2	31.4	28.0	35.5	33.8	31.6	28.7	26.6	23.8
35	41.0	39.5	37.6	33.9	30.6	27.1	34.6	32.4	30.9	28.0	25.4	22.9
30	40.3	38.5	36.7	33.2	29.4	26.0	33.8	32.3	29.7	27.3	24.9	22.2
25	39.5	37.6	35.7	32.3	28.7	25.1	32.4	30.9	29.4	26.6	24.2	21.9
20	38.1	36.7	34.6	31.1	27.4	23.7	31.6	29.9	28.0	25.5	23.7	21.2
15	36.7	35.2	33.4	29.8	25.9	22.2	30.5	28.9	26.7	24.6	22.8	20.8
10	35.2	33.8	31.8	28.4	24.1	20.8	29.4	27.4	25.6	23.7	21.7	19.3
5	32.3	31.1	29.4	25.8	22.1	19.3	26.4	25.5	24.1	21.9	20.1	17.9
1	26.6	26.6	25.1	21.3	18.6	17.9	22.6	22.7	20.8	19.3	18.1	16.4

Published in the ACSM's Guidelines for Exercise Testing and Prescription 8th edition (2010)

CHAPTER III

METHODOLOGY

Direct measurement of maximum oxygen consumption (VO_{2max}) is the gold standard and is an international reference standard of cardiorespiratory fitness (CRF) (78). Interpretation of CRF is used by health professionals to develop individualized exercise prescriptions, assess health status, and determine diagnosis and prognosis of disease. This project was conducted to develop a VO_{2max} reference standard that was based on directly measured values from the Ball State University (BSU) Adult Physical Fitness Program (APFP) cohort.

Source of Data

Demographic and clinical variables from the APFP cohort were utilized for this study. The APFP database has stored test file data since the program's inception in 1971 to the present in the FileMaker Pro 11 database program (FileMaker, Inc., Santa Clara, CA).

Study Population

The APFP cohort is an open cohort established by Clinical Exercise Physiology program at BSU. Participants were self-referred, provided written consent for exercise testing, and completed a cardiovascular risk screening and physical fitness evaluation. Stored data files are primarily from APFP participants with some individuals that utilized

the services for testing purposes only. The APFP database administrator created a de-identified data set of demographic and clinical variables from the test data files in the APFP database and compiled the information in the form of an Excel spreadsheet.

A health history questionnaire (HHQ) was completed including, but not limited to age, personal and family history, smoking, and physical activity history (PA). Demographic variables included gender and age, and clinical variables included height, weight, RER, and VO_{2max}. Test data files were excluded from the present study if subjects failed to achieve a respiratory exchange ratio (RER) ≥ 1.0 or exceeded 1.59, were younger than 18 years of age or greater than 79 years, performed a cycle ergometer protocol, were tested within one consecutive month, had a BMI <18.5 kg·m^{-2}, or had missing variables (gender, age, height, weight, or VO_{2max}). After the exclusion criteria was set, 4,353 data files from 3,212 individual participants allowed for the analysis of 2,642 men and 1,741 women test data files.

Test Measurements

The APFP has followed established policies and procedures that continually evolved to follow national standards when available since the program commenced. The American College of Sport Medicine's Guidelines for Exercise Testing and Prescription was commonly referenced for pre-assessment and exercise testing.

All participants completed a health history questionnaire which included but not limited to: age, family health history, signs or symptoms, personal health history, smoking history, and PA history. The Getchell code was used to stratify smoking and physical activity status (87). Standardized procedures were used to assess height and weight. These values were used to calculate body mass index (BMI) (kg·m^{-2}). The

previously listed clinical values were used for risk stratification of cardiovascular disease prior to the GXT.

Participants were instructed to exercise to volitional exhaustion to achieve a maximal effort. GXTs were performed using a motor driven treadmill and protocols included individualized incremental walking or running protocols, modified Balke protocol, Bruce protocol, and the BSU/Bruce protocol (13, 24, 49). The chosen protocol was determined by the subject's self-reported personal health and physical activity history.

Measurement of Oxygen Uptake

During the years of 1971 through present, equipment has changed to remain current with technologies of the time. Exercise heart rates were obtained through the use of electrocardiograms from the inception of the program to present day. Respiratory gas analyses were conducted using a semi-automated system as described by Wilmore and Costill from 1971 until the transition of equipment in 1991 (89). Respiratory gases were collected in a mixing chamber and samples were measured with an Applied Electrochemistry S3A O_2 analyzer (Sunnyvale, CA), a Beckman CO_2 analyzer (Fullerton, CA), and a Parkinson-Cowan gas meter (Manchester, England). These components were integrated by an A-D converter (Rayfield Equipment Lt., Waitsfield, VT) to a microcomputer. $VO_{2max}$was determined as the peak value measured during a 30 second sample. From September 1991 through July 2001, exhaled respiratory gases were collected and analyzed using the Sensor Medics 2900 Metabolic Measurement Cart (Sensor Medics Corporation, Yorba Linda, CA). In August 2001, VO_{2max} was measured using the SensorMedics Vmax system (Sensor Medics Corporation, Yorba Linda, CA).

This metabolic system was used through May 2005. Furthermore, VO_{2max} was highest VO_2 value that had at least two other five breath averaged data points within 2 $ml \cdot kg^{-1} \cdot min^{-1}$ for the Sensor Medics 2900 and Sensor Medics Vmax systems (i.e. 1991 to May 2005). From June 2005 to present the present, VO_{2max} was quantified through the analysis of respiratory gases by the TrueOne 2400 Metabolic Measurement System (ParvoMedics, Inc., Sandy, UT).

The current system, TrueOne 2400 Metabolic Measurement System is calibrated with a 3-L precision calibration syringe, and used a standard reference gas tank with a known concentration of oxygen and carbon dioxide. Participants wore a nose clip and breathed through a Hans Rudolph Two-way rebreathing valve (2700 Series, Hans Rudolph Inc., Kansas City, MO). The criterion for VO_{2max} was the highest VO_2 value that had at least one other 20 second averaged data point within 2 $ml \cdot kg^{-1} \cdot min^{-1}$. If another VO_2 value fell within the said range, then all three values were averaged to determine the participant's VO_{2max}.

Statistical Analysis

The data analysis was performed using IBM Statistical Package for the Social Sciences (SPSS) Statistics version 20.0 (SPSS Inc. Chicago, IL). Gender- and age-specific CRF percentile values were generated using descriptive statistics. Age categories defined in the analysis were as follows: 18-29 years, 30-39 years, 40-49 years, 50-59 years, 60-69 year, and 70-79 years.

Independent t-tests were used to examine gender differences in height, body weight, BMI, RER, and VO_{2max}. Analysis of variance (ANOVA) was performed to determine differences in VO_{2max} across categories of age, PA, BMI, and smoking status,

respectively. Following ANOVA, the Dunn-Sidak post-hoc for multiple comparisons was performed to determine where the significant differences occurred. A simple effects analysis for gender was performed to determine if significant group differences were seen for both males and females. Significance was determined using a p-value of $< .05$.

CHAPTER IV

RESEARCH MANUSCRIPT

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DEVELOPMENT OF A REFERENCE STANDARD FOR CARDIORESPIRATORY FITNESS FROM THE BALL STATE UNIVERSITY ADULT PHYSICAL FITNESS PROGRAM COHORT

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Abstract

 Purpose: The objective of this study was to develop adult reference standards for cardiorespiratory fitness (CRF) from directly measured maximum oxygen consumption (VO_{2max}) using the Ball State University Adult Physical Fitness Program (APFP) cohort. **Methods:** The cohort is an open cohort since 1971 of self-referred participants to the APFP established by the Clinical Exercise Physiology program. From 3,212 individual participants, 2,642 male and 1,741 female (18-79 years) test files remained after exclusion of test files if the individual was <18 or >79 years, achieved a respiratory exchange ratio <1.0 or >1.59, performed a cycle protocol, had a BMI <18.5 kg·m^{-2}, or was the first of consecutive exercise tests within one month. Gender-specific age, physical activity (PA), body mass index (BMI), and smoking status CRF reference standards were developed from directly measured VO_{2max}. **Results:** Men had greater mean CRF (35%) than the women and consistently had greater mean CRF according to age, PA, BMI, and smoking status (p<.05). A decline in CRF of approximately 10% was observed across each decade of age. Higher CRF was observed in the active (10%) and exercisers (37%) groups compared to the sedentary group. Groups with greater BMI had significantly lower CRF compared to groups with lower BMI. CRF was 5% greater in non-smokers compared to current smokers. **Conclusion:** CRF is greater in men, in younger decades of age, with greater level of PA, with lower BMI, and in non-smokers. **Key Words:** VO_{2max}, GRADED EXERCISE TEST, NORMATIVE

Introduction

  Cardiorespiratory fitness (CRF) is defined as the ability of the skeletal muscle, cardiovascular, and respiratory systems to meet the oxygen demand during maximal exercise (2, 4). CRF is the ability to perform activities of daily living as well as sustain dynamic exercise, and is measured by the maximum volume of oxygen utilized during exertion (3). The gold standard measurement of CRF is maximum oxygen consumption (VO_{2max}). At maximal exercise, VO_{2max} can be defined by the Fick equation: the product of cardiac output and arterial-venous oxygen difference (6). VO_{2max} is measured by means of a graded exercise test (GXT) at maximal exercise and expressed as volume of oxygen in milliliter per kilogram body weight per minute (3). A graded exercise test (GXT) is a noninvasive procedure used to measure VO_{2max} which can provide diagnostic and prognostic information on health status (3, 19).

  Low CRF is a modifiable risk factor as improvements in prognosis have been demonstrated by improvements in fitness. A strong and inverse relationship between CRF and all-cause mortality rates across quintiles of fitness level for both men and women was observed by Blair et al. (8). Similarly, Myers et al. observed that a 12% improvement in survival was associated with every 1-metabolic equivalent (MET) increase in treadmill performance (21).

  Research has been conducted to develop normative standards for CRF classification. However, these standards have been developed by means of predicted VO_{2max}, including submaximal cycle ergometry and the final workload achieved during a maximal treadmill protocol (5, 11, 14). The most commonly used reference standard for the interpretation of CRF is published by American College of Sports Medicine (ACSM)

using data from the Cooper Institute (Dallas, TX). A significant limitation is the use of predicted METs from the Balke treadmill protocol rather than the use of directly measured expired gases (5, 14). Secondary limitations from the ACLS cohort include predominantly well-educated in the middle- to upper-socioeconomic strata from the Dallas, TX area. The gender and age specific reference standard published by the ACSM did not further stratify the sample with clinical variables. The purpose of this study was to develop reference standards from directly measured VO_{2max} from the Ball State University (BSU) Adult Physical Fitness Program (APFP) cohort.

Methods

Study Population

The APFP cohort is an open cohort established by the Clinical Exercise Physiology program at BSU. Participants were predominantly Caucasians and were self-referred to the APFP. From 1971 to the present, over 5,000 participants performed maximal GXTs at the Human Performance Lab in Muncie, Indiana. Prior to maximal exercise, all subjects provided consent and completed a cardiovascular risk screening. A de-identified dataset including demographic and clinical variables was generated from the APFP database (FileMaker Pro 22, File Maker Inc., Santa Clara, CA). Demographic variables included gender and age, and clinical variables included height, weight, RER, and VO_{2max}. A health history questionnaire (HHQ) was completed including, but not limited to age, personal and family history, smoking, and physical activity history (PA). Test data files were excluded from the present study if subjects failed to achieve a respiratory exchange ratio (RER) ≥ 1.0 or exceeded 1.59, were <18 years of age or > 79 years, performed a cycle ergometer protocol, were tested within one consecutive month,

had a BMI <18.5 kg·m^{-2}, or had missing variables (gender, age, height, weight, or VO$_{2max}$). After the exclusion criteria was set, 4,353 data files from 3,212 individual participants allowed for the analysis of 2,642 men and 1,741 women test data files.

Clinical Examination

Standardized procedures were used to measure height and body weight to determine body mass index (BMI). Defined as kilogram bodyweight per meter of height squared (kg·m^{-2}), BMI classes included normal (18.5-24.9 kg·m^{-2}), overweight (25.0-29.9 kg·m^{-2}), and obese ($\geq$30.0 kg·m^{-2}). Level of PA and smoking status were determined based on participants' responses to a health history questionnaire. Levels of PA and were defined by individuals that reported no PA (sedentary, n=867), those that reported PA but did not accrue $\geq$3 days per week of regular exercise (active, n=738), and those that exercised regularly for $\geq$3 days per week (exercisers, n=1,059). Smoking habits were categorized into groups for individuals who reported never having smoked (non-smoker, n=1656), subjects that quit over a year prior (ex-smoker, n=669), and those who were smokers (current smoker, n=246) at the time of the exercise test.

GXT treadmill protocols utilized an individualized incremental walking or running protocol, a modified Balke, Bruce, and the BSU/Bruce (5, 9, 16). The selection of the protocol type was determined by the laboratory director based on information about the subject's health status and self-reported PA history. Participants were instructed to exercise to volitional fatigue and were encouraged to continue the exercise test until a true maximal effort was reached. Trained laboratory technicians administered the exercise tests and other procedures according to the recommendations by the ACSM's Guidelines for Exercise Testing and Prescription (2).

Since the inception of the program in 1971, equipment has evolved to remain current with the technologies of the time. Exercise heart rates were obtained through the use of electrocardiograms and expired ventilatory gases were analyzed using varying metabolic systems: an integrated system that included an Applied Electrochemistry S3A O_2 analyzer, a Beckman CO_2 analyzer, and a Parkinson-Cowan gas meter, SensorMedics 2900 Metabolic Measurement Cart, SensorMedics Vmax system, and the TrueOne 2400 Metabolic Measurement system from ParvoMedics Inc. that is still in use today. Participants wore a nose clip and breathed through a Hans Rudolph Two-way rebreathing valve (2700 Series, Hans Rudolph Inc., Kansas City, MO). The criterion for VO_{2max} was adjusted over the 40 years of data collection. From 1971 to 1991, VO_{2max} was determined as the peak VO_2 measured during a 30 second sample. Furthermore, at least two other five breath averaged data points within 2 ml·kg^{-1}·min^{-1} was used as the criterion for VO_{2max} from 1991 to May 2005. Since May 2005, the highest VO_2 value that had at least one other 20 second averaged data point within 2 ml·kg^{-1}·min^{-1} has been used. If another VO_2 value fell within the 2 ml·kg^{-1}·min^{-1} range, then all three values were averaged to determine the participant's VO_{2max}.

Statistical Analysis

The data analysis was performed using IBM Statistical Package for the Social Sciences (SPSS) Statistics version 20.0 (SPSS Inc. Chicago, IL). Gender- and age-specific CRF percentile values were generated using descriptive statistics. Age categories defined in the analysis were as follows: 18-29 years, 30-39 years, 40-49 years, 50-59 years, 60-69 year, and 70-79 years.

Independent t-tests were used to examine gender differences in height, body weight, BMI, RER, and VO_{2max}. Analysis of Variance (ANOVA) was performed to determine differences in VO_{2max} across categories of age, PA, BMI, and smoking status, respectively. Following ANOVA, the Dunn-Sidak post-hoc for multiple comparisons was performed to determine where the significant differences occurred. A simple effects analysis for gender was performed to determine if significant group differences were seen for both males and females. Significance was determined using a p-value of <.05.

Results

Table 4.1 provides general characteristics of men and women. Descriptive statistics revealed significant gender differences in age, height, weight, BMI, and VO_{2max} (p<.05). The men were older, taller, heavier, and had higher VO_{2max} than women with the mean VO_{2max} for men having 35% greater CRF. The BMI was also greater for men compared to women, with 65.8% of men with a BMI greater than 25.0 $kg \cdot m^{-2}$, while 54.6% percent of women fell into the overweight and obese categories. Of the 4,383 subjects, 61% of the subjects had self-reported PA and 59% has self-reported smoking status. Of those that reported PA, 32.5% were sedentary while 27.7% of subjects reported being active and the remaining 39.8% were categorized as exerciser. For smoking status, 64.4% were categorized as non-users, 26.0% as ex-smokers, and the remaining 9.6% were current smokers.

Age-related difference in CRF

Gender and age specific reference standards of CRF are presented as tabulated percentile from 5 to 95 (Table 4.2). Figure 4.1 shows and age-related decrease in CRF for the cohort, men, and women (p<.05). In the cohort, older age groups had consistently

lower CRF than younger age groups. Similarly, CRF in men and women for the older groups were lower than the younger groups with the exception of women between the age of 70 and 79 years. An overall decline of approximately 17 $ml \cdot kg^{-1} \cdot min^{-1}$ (mean difference of 41%) was observed from the youngest compared to the oldest group of subjects, with an average 3.4 $ml \cdot kg^{-1} \cdot min^{-1}$ (10%) decline in VO_{2max} across each age group. The decrease in mean VO_{2max} per decade ranged from 7.8% to 12.3%. In addition, men had consistently higher CRF than women across different age groups (p<.05).

PA-related difference in CRF

Gender and PA specific reference standards of CRF are presented in Table 4.3. Figure 4.3 shows age-related decrease in CRF for the cohort, men, and women (p<.05). In the cohort, lower CRF was consistently observed in groups with lower levels of self-reported PA. Between the sedentary group and the active group, mean VO_{2max} was greater in the group that participated in PA by 2.9 $ml \cdot kg^{-1} \cdot min^{-1}$ (10%). Compared to the sedentary group, the mean difference for the exercisers was 10.9 $ml \cdot kg^{-1} \cdot min^{-1}$ (37%). Furthermore, individuals that reported greater levels of PA had lower CRF than groups with lower levels of PA for men and women. In addition, men had consistently higher CRF than women across different age groups (p<.05).

BMI-related difference in CRF

Gender and BMI specific reference standards for CRF are presented in Table 4.4. Figure 4.4 shows BMI related differences in CRF for the cohort, men, and women (p<.05). In the cohort, the groups with greater BMI had lower CRF compared to those with lower BMI. More specifically, the mean CRF for the overweight and the obese

classes were 4.4 ml·kg^{-1}·min^{-1} (11%) and 11.6 ml·kg^{-1}·min^{-1} (30%) lower than the normal group, respectively. Similarly, individuals with greater BMI had consistently lower CRF compared to the groups with lower BMI for both the men and women. In addition, men had greater CRF than women across BMI classes ($p<.05$).

Smoking-related difference in CRF

Gender and smoking specific reference standards of CRF are presented in Table 4.5. Figure 4.5 represents the mean CRF for each smoking group for the cohort, men, and women. In the cohort, the smokers had significantly lower mean CRF by 1.6 ml·kg^{-1}·min^{-1} ($p<.05$) compared to the non-smokers, while the ex-smokers were not different from the non-smokers or current smokers. For the men, the mean CRF for the ex-smokers and current smokers was significantly lower than the non-smokers by 2.9 ml·kg^{-1}·min^{-1} (8%) and 3.8 ml·kg^{-1}·min^{-1} (10%), respectively ($p<.05$). No significant differences were found between smoking status groups for the women participants. In addition, men had greater CRF than women across all smoking status subgroups ($p<.05$).

Discussion

The current study is the first to develop reference standards for CRF from directly measured VO_{2max}. Although the study sample may not be the most appropriate representation for the diverse U.S. population, the findings can be reference data for future research as well as provide individuals a reference to track CRF according to changes in age and other clinical variables. The mean CRF for men was greater than the women for the entire cohort, and was also consistently greater across each subgroup within the different clinical variables. The mean CRF was greater in the younger decades of age compared to the age groups. Furthermore, mean CRF was

greater across groups with greater levels of physical activity. Additionally, CRF was lower in groups with greater measures of BMI and in current smokers.

Gender-related difference in CRF

Findings from this study confirmed gender differences in CRF, which are well-documented in previous research. Unlike the 10-20% difference between men and women reported by Arena et al. (3) at any age, the current study observed an overall mean difference of 35% between men and women and an average difference of 36% at any age. Although much greater in the current study, gender differences are in part due to men having higher hemoglobin concentrations, greater muscle mass, and a larger stroke volume (3). The consideration of these differences is important when interpreting CRF. The uniqueness of the BSU APFP cohort could partially explain the greater differences seen between men and women. PA data was not available for all subjects, but for the men and women that did have reported PA, 26% of men reported being physically active and 45% regularly exercising, while only 32% and 30% of women reported being physically active or exercising, respectively. Overall, the men had 22% more of the participants report at least some physical activity. The large difference in baseline PA could result in the larger CRF difference between men and women compared to the literature. Furthermore, 3,212 unique individuals are in the APFP cohort, with 1,171 files second time exercise tests or more. With the possibility of higher fit men having multiple exercise tests completed since 1971, this could further explain the 35% difference between men and women.

Age-related difference in CRF

Findings from the current study confirmed lower CRF across group means for each decade of the APFP cohort. VO_{2max} declines with aging however it is also affected by other factors. Most importantly, level of exercise can change CRF depending on his/her state of physical training (13, 24). Furthermore, gain in fat weight will result in a decrease of VO_{2max} when expressed in relative terms, regardless of an unchanged absolute VO_{2max} (12). Although these factors impact VO_{2max} in addition to the natural aging process, the current study held changes in VO_{2max} with age as its own entity. On average, VO_{2max} was 10% lower than the previous decade and when further defined by gender, the decline in VO_{2max} was 10% and 11.5% for men and women, respectively. Heath et al. (12) studied young (22 ± 2 years) and master (59 ± 6 years) athletes, as well as untrained (50 ± 6 years) and lean untrained (52 ± 10 years) middle aged men. Similar to the average 10% decrease in mean CRF per decade of age for the men, Heath el al. (12) observed an approximate 9% per decade decline in VO_{2max} in the healthy sedentary men due to a decrease in PA, gain in weight, and aging changes of the cardiovascular system. Unlike the study by Heath and colleagues, the present study did not take level of PA into consideration. Had PA been adjusted for, the rate in decline could be greater since PA has been shown to slow the rate of decline. Despite the expected decrease in heart rate and VO_{2max} with age, master athletes that adhered to regular training programs can maintain their VO_{2max} above that of young untrained healthy men (12). The current study did not account for PA habits, so the comparison of the older trained participants to the young sedentary individuals was not possible. If PA were considered in respect to the age-related decline in CRF, the VO_{2max} in older trained men could be comparable to, if not greater, than the young sedentary men in the APFP cohort.

Further interpretation of the decrease in CRF with aging is presented in Figure 4.2. As discussed previously, the gender differences are easily observed in the figure as all reference standards for CRF for men were greater than that of women. Furthermore, Figure 4.2 allows the comparison of CRF at the 50th percentile in the current study to that of the normative values for the ACLS and YMCA (2, 11). Comparing CRF at the 50th percentile for men and women in by the YMCA, an average of approximately 3% lower and 22% greater CRF was demonstrated across all age groups, respectively compared to the current study. Great caution should be warranted when making comparisons between the current study and the YMCA population. This YMCA population underwent submaximal exercise for the prediction of VO_{2max}. Submaximal heart rates at predetermined workloads were extrapolated to an age-predicted maximal heart rate for the prediction of VO_{2max} from the associated workload. Not only did the use of submaximal exercise limit the ability to compare the current findings to the YMCA findings, but also the mode of exercise performed in the prediction of VO_{2max}. The protocol used in the development of the CRF standards was a cycle ergometer (11). Previous research has determined that at maximal exercise, cycle protocols elicit 10% to 20% lower CRF compared to treadmill VO_{2max} due to quadriceps fatigue in untrained subjects (18). In addition to the cycle protocol and submaximal effort used to predict VO_{2max}, it is important to identify that the range of ages are different between the YCMA and APFP reference standard. The YMCA reference standard used ten year increments like the current study, but started from the middle of the decade (i.e. 26-35 years).

The larger variability of CRF between the women in the YMCA and APFP cohort compared to men is also apparent when compared to the 50th percentile in the ACLS data.

The ACLS cohort is observably greater than the APFP cohort for almost all ages in men, where as the women fall well below that of the ACLS normative data. Caution, although not as great as the YMCA cohort, is still warranted as both directly and predicted measures of VO_{2max} are presented. The overestimation of CRF could be due to the ability to continue the exercise after a plateau in VO_2 was achieved. If subjects were able to tolerate exercise past the point in which VO_{2max} was achieved, the modified Balke protocol (5) could overestimate VO_{2max} as total time is used in the prediction of CRF. If this were the case, participants that were physically active prior to the exercise test may be overestimated, while those that reported no PA could be underestimated because fatigue could limit the subject before VO_{2max} was achieved.

Similar to the ACLS reference standard, the current study had the largest sample of participants in the 40-49 year old age group, and the smallest in the 70-79 year old age group. The distribution of sample sizes were similar across age groups relative to the overall cohort of each reference standard, but the ACLS reference standard was developed from over 43,000 data files. In addition to the comparison of CRF across each group at the 50th percentile, large discrepancies were seen among the 20th percentile. Blair et al. (8) assigned patients to physical fitness categories specific to gender, age, and duration of the treadmill exercise test. Rather than determining fitness via the gold standard method, the individuals with a treadmill time within the first quintile were assigned to the low-fit group. The less-fit individuals were at a greater risk of all-cause mortality than the more-fit men and women, while the relative risk for the least-fit quintile of men and women were significantly greater. When comparing the least-fit individuals (bottom 20% for) according to gender and age, large variability was present

between the ACLS (Table 3.3) and the APFP (Table 4.2) cohorts. The present study observed consistently lower CRF at the 20th percentile for both men and women across all age groups. The men cohort ranged from differences of 1.1 ml·kg^{-1}·min^{-1} to 3.9 ml·kg^{-1}·min^{-1}, while the women had differences from 3.6 ml·kg^{-1}·min^{-1} to 6.5 ml·kg^{-1}·min^{-1}. With such large differences between the predicted and measured values, the importance of interpreting CRF specific to risk of mortality becomes great. Specifically when looking at the male APFP cohort, a difference of 3.9 ml·kg^{-1}·min^{-1} was observed among the fifth, sixth, and seventh decades of age. Furthermore, differences in CRF greater than 6 ml·kg^{-1}·min^{-1} were seen among the fourth, fifth, seventh, and eighth decade of age. When CRF at the 20th percentile in the ACLS reference standard was classified using the APFP reference standard, CRF was classified up to the 40th percentile for men and consistently greater than the 50th percentile for all but the youngest decade of age; even as great as the 70th percentile. Because CRF has been determined to be the strong predictor of mortality, the importance of which classification is crucial when interpreting CRF (17).

PA-related difference in CRF

In the current study, of those that reported PA, 32.5% were sedentary and 27.7% were active, while the remaining 39.8% were categorized as exercisers as they self-reported participating in a regular exercise program 3 days or more per week. According to the Center for Disease Control and Prevention (CDC) (25) in 2011, 48% of the U.S. population aged 18 and older met the 2008 Guidelines for Physical Activity (1). When further distributed by gender, approximately 45% and 30% of men and women respectively, were categorized as exercisers in the APFP cohort, while 57% met the PA

guidelines as presented by the CDC. In addition to the APFP cohort reporting lower percentages of regular PA, individual participants may be used multiple times when developing the reference standard. Because not all VO_{2max} tests had unique participants associated with them, there is the possibility that some individuals reporting any one of the PA status groups may be within that group multiple times, or possibly in multiple groups. Without this specific information, the distribution of participants is a limitation.

The PA specific reference standards (Table 4.3) demonstrate that at any percentile, greater CRF is observed in groups with greater reported PA. As it would be expected from the research published by Ogawa (22) and Heath (12) on the relationship between increased training status and VO_{2max}, VO_{2max} increased as reported PA increased. In the overall cohort of the current study, significant increases were observed between groups of increasing activity level for both men and women. From sedentary to active, VO_{2max} increased 10% and from active to the exercisers group, VO_{2max} increased by 25%. Exercise evidence demonstrates that exercise training status is positively related to VO_{2max} (12, 22, 26). Across age ranges, trained individuals consistently reported grater values of VO_{2max} compared to those that are untrained by Ogawa et al. Limited by the present study's sample size, level of PA was not further classified by age.

BMI-related difference in CRF

Significant differences were demonstrated across BMI class for the APFP as well as for each gender. The reference standard for BMI-specific to CRF clearly demonstrates progressively lower CRF with increasing BMI. Comparing percentiles of CRF, greater differences are observed between groups when looking at the most fit of each group compared to the least fit. For both men and women, larger differences are observed

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between BMI groups at the 99th percentile where as the range in CRF is much smaller. Research has demonstrated higher fitness attenuated or eliminated risk of mortality in obese men and women. In the present study, the 99th percentile for CRF in the obese class would be classified as the 70th percentile in the normal category. When the same is done for the women, the highest level of CRF falls just above the 80th percentile.

As previously defined in research, the low fitness group is defined as the first quintile of fitness distribution (8). The low fit individuals in the normal BMI group for men (35 ml^{-1}kg^{-1}·min) and women (24.5 ml^{-1}kg^{-1}·min) compared to the obese group would include CRF levels between the 70th and 80th percentiles. With such a vast majority of the men and women in the obese group classified as low fit, it could be presumed that the likelihood of having high fitness is greatly influence by BMI in the APFP population. Furthermore, Wei et al. (28) demonstrated that low CRF was a strong and independent predictor of both all-cause and cardiovascular disease mortality among all BMI classes. Furthermore, the lowest fit men and women are in the highest BMI class, while the most fit men and women are in the normal BMI class. Because of the vast majority of the obese individuals in the present study interpreted as low fit, the need for BMI specific CRF from the APFP cohort may lead to misinterpretation of a person's risk for mortality.

Smoking-related difference in CRF

Of the 4,383 men and women, 58.7% of the subjects had reported smoking habits. Of those that reported, 64.4% reported never having smoked and 26.0% reported having quite more than a year previous. The remaining 9.6% were smokers at the time of the test. As reported by the CDC (25) from the 2011 Summary Health Statistics for U.S.

adults age 18 and older, 59% were non-smokers, 22% were ex-smoker, and 19% were current smokers. Compared to the present study, it appears that the APFP cohort had more non- and ex-smokers with less current smokers than the U.S. population. In the interpretation CRF specific to smoking status, it should be cautioned that the distribution of smoking level was not equivalent to that of the general population.

In the current study CRF was significantly greater (1.6 ml·kg^{-1}·min^{-1}) in non-smokers compared to smokers in the APFP cohort. Bernaards et al. (7) found that moderate to heavy smoking was negatively related to VO_{2max} in both men and women. Unlike the study by Bernaards and colleagues, no significant differences in men were observed between smokers and non-smokers. The finding that no differences were observed between smoking groups in women could be due to a greater proportion of men reporting smoking (10% versus 7.5%). This could also be due the fact that VO_{2max} in the 1st and 99th percentiles in current smokers for women were greater than both the non- and ex-smokers. Additionally, it is possible that women that reported being smokers at the time of their exercise test did not smoke as heavily as men that reported smoking status. If the men that reported being current smokers did have a greater pack-year number, this could explain the differences in CRF specific to smoking status for men and women.

Strengths and Limitations

Reference standards exist for the interpretation of CRF, but these standards were developed from predicted rather than measured VO_{2max}. The major strength of this study was the use of directly measured respiratory gases from maximal exercise tests for the development of CRF standards. Not only were norms generated for the interpretation of CRF by decade of age, but also by clinical variables of PA, BMI, and smoking history

not yet reported by research in the form of a reference standard (15). The interpretation

of CRF has yet to be specific to level of PA, body composition, or smoking status.

Although PA was objectively measured, the beneficial effect of PA on VO_{2max} at any

given age and in the slowed rate of decline with age, the development of a CRF reference

standard specific to PA will positively impact the interpretation of CRF. In addition, the

BMI specific reference standards will allow for the appropriate interpretation of CRF

based on an individual's BMI class even though fat and fat-free mass is not

differentiated.

Limitations of the present study should be considered when interpreting the

results. Because the open cohort spanned from 1971-2013, the equipment used for gas

analysis and the testing procedures changed, but did so to remain current with improving

technologies and research methods.   This is a limitation because the criterion to

determined VO_{2max} has changed over the 40 year time period. The relatively small

sample size compared to the ACLS data set (n=59,527) presents a limitation as well as

the. Moreover, generalization of these findings may only apply to mainly white

individuals. Nonetheless, this population should not differ greatly from other cities with

rural surroundings. Another limitation to this study would be not having clearly defined

the PA and exercise habits of subjects. It would be beneficial to determine total volume

of exercise and time spent being physically active. This could be objectively measured

by PA monitors. Second to the lack of distinction between exercise and PA, subjects

self-reported allowing for one's own perception to skew the true amount of time spent

completing PA or exercise. Smoking history or PA was not available for the entire APFP

cohort making the tables developed have smaller sample sizes. In addition, all smokers

were included into one group regardless of the amount smoked per day or duration in years spent smoking. In addition to the use of measured VO_{2max}, the refinement of the variables used would allow for development of even more accurate reference standards.

Conclusion

The primary purpose of the current study was to reference standards for CRF from the direct measurement of respiratory gases from the BSU APFP cohort specific to age, PA, BMI and smoking status. Currently, only gender and age specific reference standards exist. Comparative to the widely used reference standard published by the ACSM, an observable difference was noted at the 50th percentile of CRF for the ACLS data and the present study. In the current study, CRF at the 50th percentile for men were slightly lower across all age groups while the women groups observed substantially lower CRF compared to the ACLS cohort. In addition, the difference in CRF at the 20th percentile from the ACLS cohort for low-fit men and women was interpreted much differently using the APFP reference standard. Across all age groups, men were consistently ranked within the 30th and 35th percentiles, while the women were consistently ranked above the 50th percentile across age groups. The well researched age-related decline of approximately 10% in VO_{2max} in both sedentary and active individuals was observed across all subjects and for both men and women in the APFP cohort (10, 22, 23, 27). Mean CRF was greater across groups with greater levels of PA, more specifically 10% between sedentary and active and a grater difference of 25% between active and exercisers. Furthermore, CRF was lower across increasing BMI class with a difference of 11% between the normal and overweight group and 22% between the overweight and obese group. Although the current sample size should be representative

of the overall population, the development of pooled directly measured CRF or expansion of the current data set would provide socio-economic, ethnic/cultural, and geographic diversity to the population.

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Table 4.1 Descriptive Statistics for All Observations of Men and Women According to Age Group; Adult Physical Fitness Program Data, 1971-2013†

Variable	All Subjects	18-29	30-39	40-49	50-59	60-69	70-79
				Men			
Subjects, n	2,642	216	569	780	659	345	73
Age, yr	47 (12)*	25 (3)	35 (3)	44 (3)	54 (3)	64 (3)	73 (2)
Height, in	70.2 (2.7)*	70.8 (2.9)	70.4 (2.7)	70.3 (2.6)	70.0 (2.8)	69.7 (2.7)	69.0 (2.6)
Weight, lb	191 (36)*	190 (41)	191 (36)	191 (34)	192 (35)	191 (36)	185 (33)
BMI, $kg \cdot m^{-2}$	27.3 (4.7)*	27.0 (5.3)	27.1 (4.9)	27.1 (4.6)	27.6 (4.5)	27.7 (4.9)	27.3 (4.3)
RER	1.18 (0.10)	1.20 (0.10)	1.19 (0.10)	1.18 (0.09)	1.17 (0.09)	1.16 (0.10)	1.14 (0.10)
VO_{2max}, $ml \cdot kg^{-1} \cdot min^{-1}$	37.6 (10.3)*	46.0 (10.9)	41.8 (9.4)	38.7 (9.4)	34.8 (8.9)	30.9 (8.5)	27.0 (6.9)
				Women			
Subjects, n	1741	210	361	494	431	203	42
Age, yr	46 (13*)	25 (3)	35 (3)	45 (3)	54 (3)	64 (3)	74 (2)
Height, in	64.4 (2.6*)	65.2 (2.6)	64.7 (2.6)	64.2 (2.5)	64.0 (2.4)	63.7 (2.7)	74.0 (2.5)
Weight, lb	160 (37*)	154 (38)	161 (41)	164 (39)	161 (34)	160 (33)	151 (29)
BMI, $kg \cdot m^{-2}$	27.0 (6.0*)	25.2 (5.6)	26.7 (6.5)	27.5 (6.3)	27.4 (5.6)	27.5 (5.5)	26.1 (4.4)
RER	1.18 (0.10)	1.17 (0.10)	1.19 (0.10)	1.18 (0.10)	1.18 (0.11)	1.14 (0.10)	1.14 (0.08)
VO_{2max}, $ml \cdot kg^{-1} \cdot min^{-1}$	27.8 (7.9*)	35.9 (9.4)	30.3 (7.3)	27.5 (6.6)	25.7 (5.8)	21.4 (4.8)	19.3 (3.8)

Abbreviations: BMI, body mass index; RER, respiratory exchange ratio; VO_{2max}, maximal oxygen consumption

†Data are expressed as mean (SD)

*Denotes significant differences between all men and women subjects

Table 4.2 CRF classification for men and women by age group

%	VO$_{2max}$ for men (ml·kg^{-1}·min^{-1})						VO$_{2max}$ for women (ml·kg^{-1}·min^{-1})					
	Age (years)						Age (years)					
	18-29	30-39	40-49	50-59	60-69	70-79	18-29	30-39	40-49	50-56	60-69	70-79
99	73.4	66.2	62.9	59.5	56.2	44.1*	61.1	49.9	47.4	42.9	36.3	26.5*
95	64.5	58.0	55.6	52.2	43.9	40.5	53.1	44.4	39.9	37.6	29.7	24.9
90	62.0	55.0	52.3	46.3	41.7	38.5	48.6	39.9	36.5	32.6	27.3	24.5
85	58.1	42.0	49.4	43.8	39.8	36.2	45.7	38.1	34.2	31.2	25.7	23.3
80	55.2	49.4	47.0	41.9	37.9	32.8	44.0	36.2	32.5	29.5	24.8	22.3
75	53.5	47.9	45.0	40.2	36.4	31.1	42.5	34.5	30.9	28.6	24.4	22.1
70	51.5	46.0	43.0	38.8	34.8	29.4	40.5	33.5	29.7	27.8	23.6	22.0
65	49.8	45.0	41.2	37.3	33.6	28.9	38.6	32.3	29.0	27.3	23.0	21.1
60	48.0	43.7	39.7	36.1	32.7	27.8	36.5	31.5	28.1	26.7	22.0	20.9
55	46.6	42.5	38.6	35.0	31.7	27.2	35.5	30.6	27.1	26.2	21.5	20.6
50	44.6	41.5	37.7	33.5	31.0	26.0	34.6	29.5	26.4	25.4	21.1	19.9
45	43.8	39.9	36.6	32.5	29.5	25.4	34.0	28.6	25.8	24.3	20.4	19.3
40	42.6	38.5	35.6	31.8	28.2	24.6	33.2	27.8	25.0	23.4	20.1	18.2
35	41.0	37.6	34.5	30.6	27.1	23.6	31.5	27.2	24.3	23.0	19.5	17.9
30	39.9	36.4	33.2	29.8	26.3	23.1	30.4	26.4	23.4	22.1	18.7	17.6
25	38.5	34.8	31.9	28.4	24.3	21.8	29.1	25.4	22.8	21.3	18.1	16.5
20	37.0	33.6	30.7	27.2	23.5	20.9	28.0	23.9	21.9	20.9	17.2	15.2
15	35.5	31.8	28.9	26.1	22.4	19.5	26.7	23.0	21.2	20.2	16.3	13.8
10	32.2	30.0	27.2	24.3	20.6	18.6	24.6	21.6	20.1	18.9	15.5	13.2
5	26.6	27.2	25.3	21.7	17.2	16.8	22.2	19.8	18.9	17.8	14.7	12.7
1	23.7	22.2	20.2	17.5	11.9	14.5	18.9	15.2	15.8	16.1	12.5	12.1
	n = 216	n = 569	n = 780	n = 659	n = 345	n = 73	n = 210	n = 361	n = 494	n = 431	n = 203	n = 42
	Total n = 2,642						Total n = 1,741					

*Represents the 100th percentile for septuagenarian men and women.

Table 4.3 CRF classification for men and women by level of physical activity

%	VO_{2max} for men (ml·kg^{-1}·min^{-1})			VO_{2max} for women (ml·kg^{-1}·min^{-1})		
	Physical Activity Status			Physical Activity Status		
	Sedentary	Active	Exercisers	Sedentary	Active	Exercisers
99	54.3	59.2	67.5	40.5	45.5	60.3
95	47.3	49.8	59.4	36.0	38.9	50.7
90	42.5	46.6	56.0	34.0	35.7	46.2
85	40.2	44.3	53.8	32.1	33.5	44.0
80	39.2	42.5	51.9	29.9	32.1	41.3
75	37.9	40.7	50.3	28.3	31.2	38.5
70	36.6	39.4	48.1	27.3	30.5	36.5
65	35.0	38.3	46.2	26.6	29.2	34.3
60	33.9	37.1	45.2	25.9	28.6	33.1
55	32.6	36.2	43.8	25.3	27.3	31.4
50	31.7	35.2	42.6	24.4	26.7	30.4
45	30.7	33.8	41.2	23.8	25.7	29.3
40	29.5	32.6	40.0	22.9	25.0	28.6
35	28.2	32.0	38.7	22.3	24.0	27.8
30	27.3	31.4	37.6	21.8	23.4	26.8
25	26.1	30.5	36.1	21.1	21.9	25.4
20	25.0	28.8	34.3	20.2	21.3	24.1
15	23.6	27.3	32.4	19.2	20.8	22.1
10	22.2	25.4	29.8	18.1	19.3	21.0
5	19.9	23.2	26.7	16.0	17.6	20.1
1	16.4	18.0	20.7	13.1	15.2	16.2
	n = 496	n = 434	n = 768	n = 371	n = 304	n = 291
	Total n = 1,698			Total n = 966		

Table 4.4 CRF classification for men and women by BMI class

%	VO$_{2max}$ for men (ml·kg^{-1}·min^{-1})			VO$_{2max}$ for women (ml·kg^{-1}·min^{-1})		
	BMI Class			**BMI Class**		
	Normal	**Overweight**	**Obese**	**Normal**	**Overweight**	**Obese**
99	68.2	58.1	49.3	55.1	46.2	38.4
95	61.7	52.2	42.0	46.7	37.1	28.7
90	57.5	48.3	38.6	42.9	33.8	27.1
85	55.1	45.8	37.2	39.9	31.9	26.3
80	53.2	44.1	35.8	38.1	30.6	25.6
75	41.3	42.5	34.4	36.4	29.4	24.8
70	49.0	40.9	32.9	35.1	28.8	23.8
65	47.2	39.7	32.0	34.0	28.2	23.2
60	45.7	38.6	31.2	33.1	27.8	22.8
55	44.3	37.6	30.0	31.9	27.2	22.0
50	43.0	36.5	29.5	30.9	26.6	21.6
45	41.6	35.5	28.5	29.6	25.8	21.2
40	40.4	34.3	27.5	28.6	25.0	20.8
35	38.9	33.1	26.6	27.5	24.3	20.4
30	37.9	32.0	25.9	26.5	23.5	19.9
25	36.6	31.0	25.3	25.7	22.7	19.1
20	35.0	29.6	23.7	24.5	21.8	18.4
15	33.1	28.0	22.4	23.3	21.0	17.6
10	31.1	26.6	21.0	21.8	19.6	16.5
5	27.6	23.7	18.7	20.4	18.0	15.5
1	22.1	17.9	15.2	15.7	14.1	12.8
	n = 904	n = 1,142	n = 596	n = 790	n = 515	n = 436
	Total n = 2,642			Total n = 1,741		

Table 4.5 CRF classification for men and women by smoking status

%	VO$_{2max}$ for men (ml·kg^{-1}·min^{-1})			VO$_{2max}$ for women (ml·kg^{-1}·min^{-1})		
	Smoking Status			**Smoking Status**		
	Non-smoker	**Ex-smoker**	**Current Smoker**	**Non-smoker**	**Ex-smoker**	**Current Smoker**
99	65.2	60.7	62.7	52.3	46.6	57.0*
95	57.8	53.5	53.4	44.3	39.4	38.9
90	53.5	48.1	46.7	38.6	36.0	34.7
85	50.8	45.6	44.6	32.9	34.5	31.5
80	47.6	43.1	42.1	33.6	32.6	29.7
75	45.7	41.7	40.5	31.9	31.3	28.9
70	43.6	40.3	38.5	30.4	29.8	27.6
65	41.4	38.6	37.5	28.9	28.7	26.7
60	40.0	36.7	36.5	28.0	27.6	26.4
55	38.6	35.7	35.2	27.1	26.9	25.9
50	37.5	34.7	34.2	26.1	26.1	25.3
45	36.4	33.1	33.4	25.3	25.2	23.9
40	34.9	32.4	32.1	24.3	24.4	23.1
35	33.4	31.2	30.4	23.4	23.3	22.4
30	31.8	29.9	29.2	22.2	22.2	21.5
25	30.1	28.2	27.8	21.4	21.5	21.1
20	28.5	27.2	26.1	20.8	21.0	20.3
15	26.8	25.8	24.1	19.7	20.4	19.6
10	25.4	23.6	22.6	18.3	18.2	18.6
5	22.6	20.6	19.4	16.1	16.8	17.5
1	16.4	16.5	14.7	13.5	13.3	15.5
	n = 904	n = 464	n = 168	n = 752	n = 205	n = 78
		Total n =			Total n =	

*Represents the 100th percentile for women smokers

Figure Legend

Figure 4.1:
Mean $VO_{2max} \pm$ SD for all subjects (black), men (gray), and women (white) by age group

* Significant difference (p<.05) from the previous age group
† Significant difference (p<.05) from the previous age group for men
‡ Significant difference (p<.05) from the previous age group for women

Figure 4.2:
Normative data from cohorts reporting age-specific reference values for men and women

Figure 4.3:
Demonstrates the mean $VO_{2max} \pm$ SD for all subjects (black), men (gray), and women (white) by PA status

* Significant differences in group means between all subjects (p<.05)
† Significant differences in group means between men (p<.05)
‡ Significant differences in group means between women (p<.05)

Figure 4.4:
Demonstrates the mean $VO_{2max} \pm$ SD for all subjects (black), men (gray), and women (white) by BMI classification
* Significant differences in group means between all subjects (p<.05)
† Significant differences in group means between men (p<.05)
‡ Significant differences in group means between women (p<.05)

Figure 4.5:
Mean $VO_{2max} \pm$ SD for all subjects (black), men (gray), and women (white) by smoking status
* Significant difference in group mean for all subjects compared to non-smokers (p<.05)
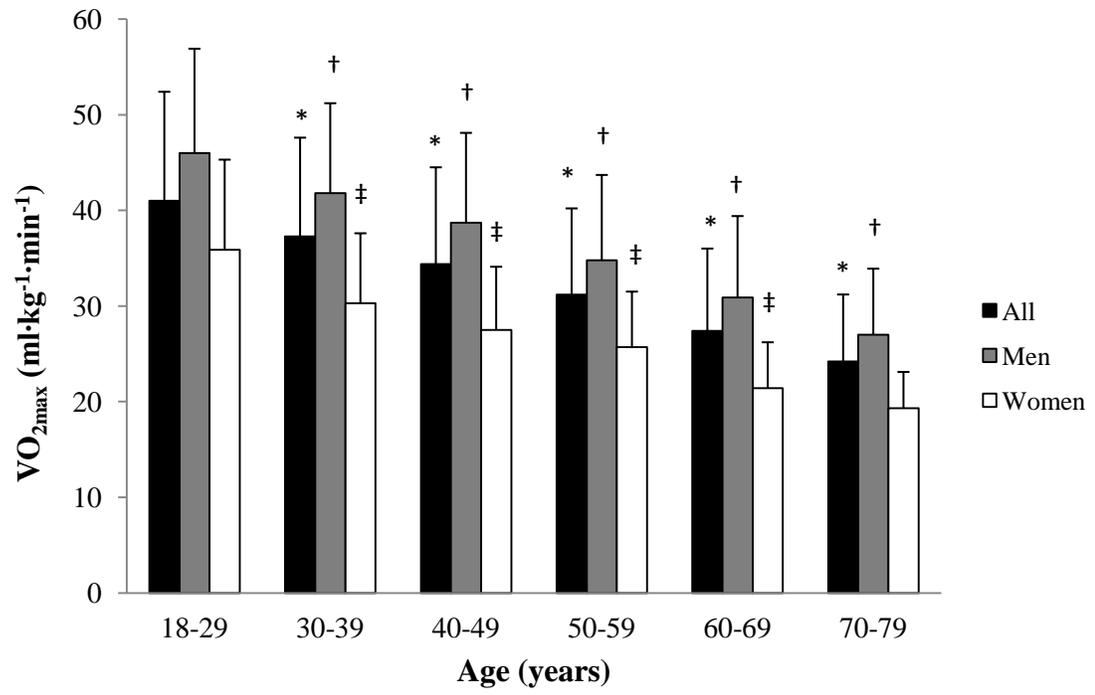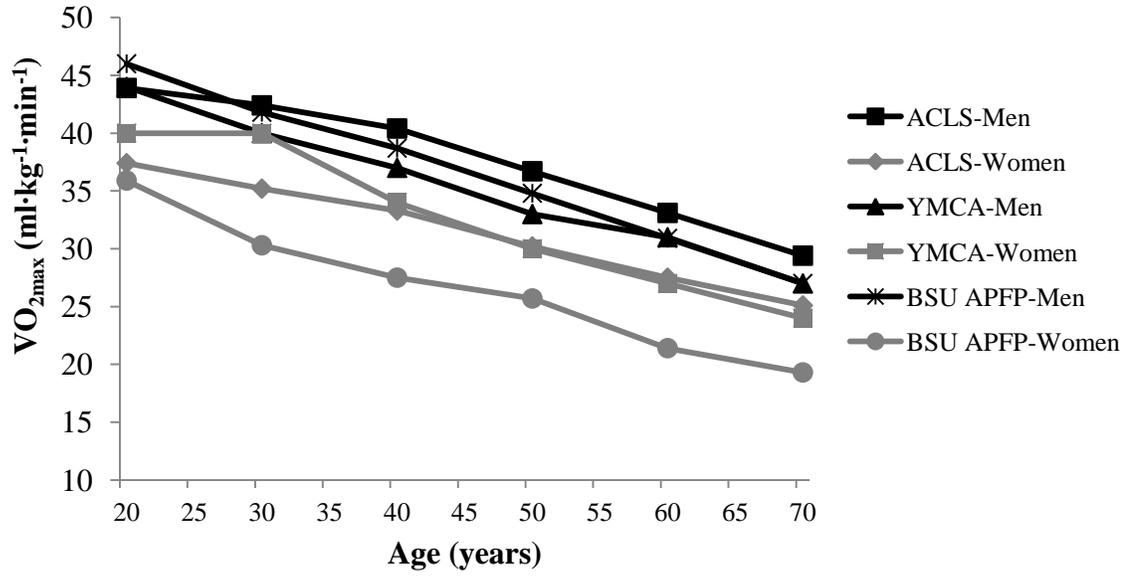† Significant difference in group mean in men compared to non-smokers (p<.05)

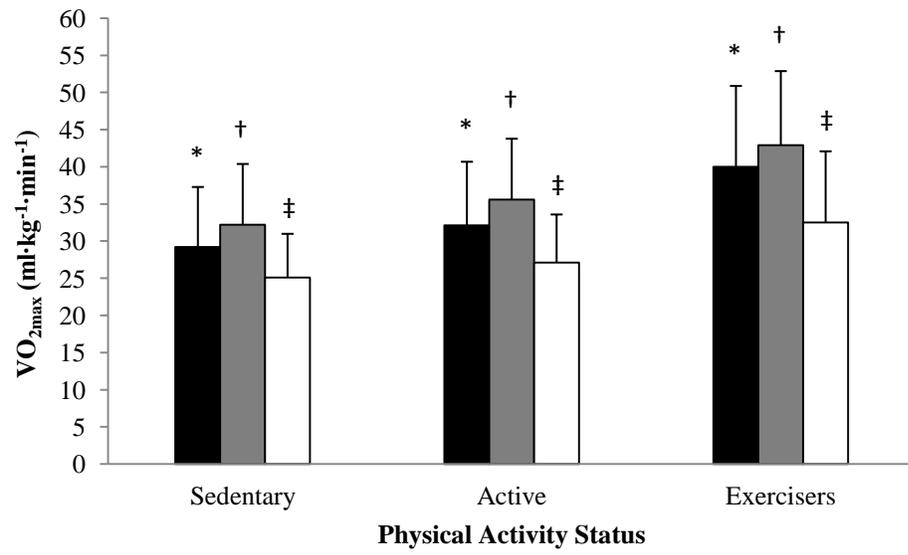**Figure 4.1**

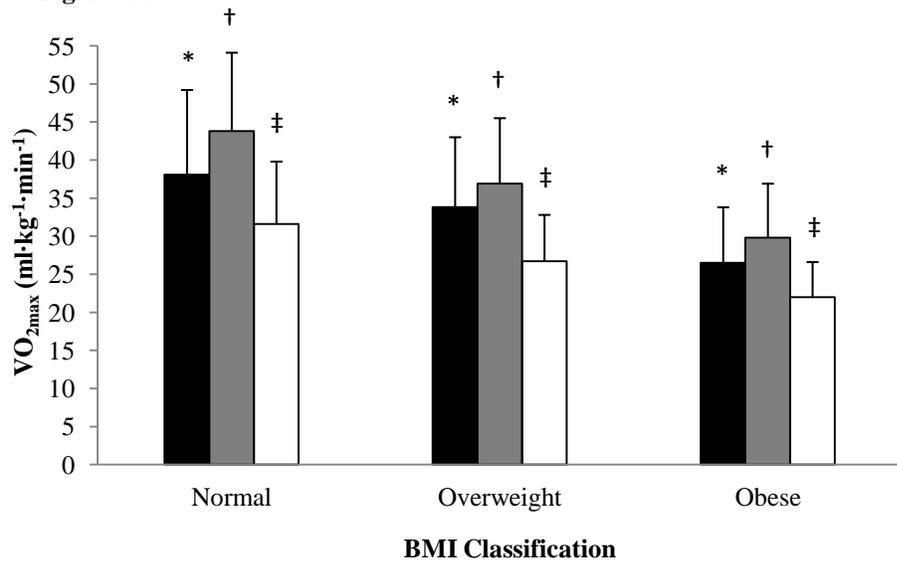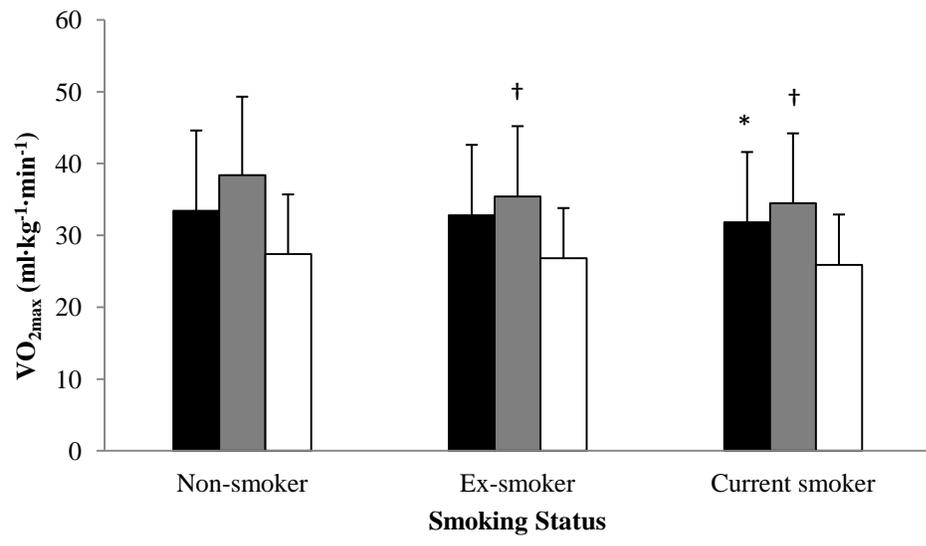**Figure 4.2**

Figure 4.3

Figure 4.4

Figure 4.5

CHAPTER V

SUMMARY AND CONCLUSIONS

The current study presents a reference standard for cardiorespiratory fitness (CRF) from directly measured maximum oxygen consumption (VO_{2max}). The previous published work determined VO_{2max} from either extrapolation of heart rate and workload or from final speed and time. The present study analyzed expiratory gases for the measurement of VO_{2max}.

Currently, only gender and age specific reference standards are available for the interpretation of CRF. Compared to the widely used reference standard published by the ACSM, an observable difference was noted at the 50th percentile of CRF for the Cooper Institute data and the present study. In the current study, CRF at the 50th percentile for men were slightly lower across all age groups while the women groups observed substantially lower CRF compared to the ACLS cohort. In addition, the difference in CRF at the 20th percentile from the ACLS cohort for low-fit men and women was interpreted much differently using the APFP reference standard. Across all age groups, men were consistently ranked within the 30th and 35th percentiles, while the women were consistently ranked above the 50th percentile across age groups. The well researched age-related decline of approximately 10% in VO_{2max} in both sedentary and active individuals was observed across all subjects and for both men and women in the APFP cohort (27,

64, 73, 79). Mean CRF was greater across groups with greater levels of PA, more specifically 10% between sedentary and active and a grater difference of 25% between active and exercisers. Furthermore, CRF was lower across increasing BMI class with a difference of 11% between the normal and overweight group and 22% between the overweight and obese group. Although the current sample size is representative of the overall population, the development of pooled directly measured CRF or expansion of the current data set would provide socio-economic, ethnic/cultural, and geographic diversity to the population.

Recommendations for Future Research

Opportunities for future research are available in the development of CRF reference standards. Future development of reference standards should include larger cohorts for the generalization to the greater population. This study was predominantly white individuals living in a midwestern city with rural surroundings. Development of a more diverse cohort to include varied race, ethnic/cultural backgrounds, socio-economic strata, demographic location, and PA or exercise history would be beneficial. In addition, more accurate measures of body composition and PA and exercise habits would provide beneficial information. Improvement in the measure of PA could be done by objectively measuring with PA monitors to determine total volume. Not only would the lack of distinction between exercise and PA be resolved, but discrepancy in subject's own perception in the amount of PA and exercise compared to what is actually done would be eliminated. Although commonly used in large research studies, BMI lacks the ability to distinguish between fat and fat-free mass. The use of a dual X-ray absorptiometry scan

would allow for this distinction and may provide a more accurate representation of VO_{2max} stratified by body composition.

When alone or in conjunction with directly measured VO_{2max}, the reference standards provide normative data for the interpretation within each subgroup by researchers and health professionals. Health professionals can use the reference standards for the development of exercise prescriptions and to track progress in increasing or maintaining CRF within each subgroup, particularly by age. Secondly, researchers can use the reference standards to compare the fitness levels of their sample to the population represented by the norms. Finally, the reference standard not only supports the already available literature regarding CRF, but provides the first avenue for accurate interpretation of CRF. Furthermore, as presented by Kaminsky et al. (48) the need for a national registry for CRF is of great importance in understanding normative levels in the US population. With the current study being the first to develop reference standards from directly measured VO_{2max}, the normative data presented could be the foundation for a much larger and necessary national CRF registry.

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