VALIDATION OF MAXIMAL HEART RATE REGRESSION EQUATIONS

by

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Purpose: The purpose of the study was to determine if measured maximal heart rate (HR_{max}) was affected by gender or aerobic training status, as well as to determine the accuracy of three common clinical maximal heart rate regression equations (MHREs) used to predict HR_{max}: $HR_{max} = 220 - age$, $HR_{max} = 226 - age$, & $HR_{max} = 208 - (0.7 \cdot age)$. **Methods:** Fifty-two aerobically active males (N=15) and females (N=15), and sedentary males (N=9) and females (N=13) within an age range of 18-25 years and with a normal BMI (18.5-24.9 $kg \cdot m^{-2}$) underwent a Bruce maximal treadmill exercise protocol. Heart rate, oxygen consumption (VO_2), and respiratory exchange ratio (RER) were measured. The effect of gender and training status on HR_{max} was analyzed through a two-way ANOVA, and the effect of gender, aerobic training status, and regression equation on accuracy of the HR_{max} prediction was assessed with a three-way ANOVA (α=0.05). The dependent variables for the three-way ANOVA included both signed residuals (observed HR_{max} – predicted HR_{max}) and unsigned residuals [absolute value of (observed HR_{max} – predicted HR_{max})]. **Results:** Males and sedentary individuals had higher measured HR_{max} ($p<.001$ and $p=.002$, respectively) than females and active individuals. The prediction equation $HR_{max} = 208 - (0.7 \cdot age)$ had the lowest marginal error under the signed residuals ($p = 0.000$). When looking at the unsigned residuals, the best overall equation, equation for females, and equation for the active under the unsigned residuals was $HR_{max} = 208 - (0.7 \cdot age)$ $(p = 0.000)$. However, the best equation for males and those that are sedentary under

the unsigned residuals was $HR_{max} = 220 - age$. **Conclusion:** Despite small differences, $HR_{max} = 208 - (0.7 \cdot age)$ was the best overall equation to use for the greatest accuracy.

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PREFACE

First, I would like to thank my advisor Dr. Jean McCrory who has continued to motivate me through the difficult times of my thesis and has inspired me to follow my passions and to never quit on my dreams even with all the obstacles life throws at you. She has shown patience throughout this process and a zeal for research that I commend and aspire towards. She has been a big part of what I have done and will do in the future.

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1.0 INTRODUCTION

1.1 BACKGROUND

Heart rate (HR) is an important factor in giving insight into the function of the cardio-respiratory system. For years, many physiologists and medical researchers have been trying to diagnose how HR is affected by different factors such as cardiovascular disease [26], mental retardation [24], and different sexes [39, 40] during exercise. Adolf Fick created what is today known as the Fick equation: *VO_2 = cardiac output x (arterial – venous O2 difference)* [97]. This equation helps us to understand the physiological processes surrounding oxygen uptake (VO_2) by the body. Cardiac output (Q) is defined as *HR x stroke volume*. Arterial – venous oxygen difference (a-vO_2) deals with the amount of oxygen extracted by the functioning organs. In the Fick equation, HR, stroke volume (SV), and a-vO_2 are rate limiting factors to the quantity of O_2 consumed.

Since the formation of the Fick equation, physiologists have been trying to further enhance the knowledge base of heart rate, stroke volume, a-vO_2, and their relationship to VO_2. When considering maximal cardiorespiratory values, maximal VO_2 (VO_{2max}) is reached when maximal heart rate (HR_{max}), maximal a-vO_2 (a-vO_{2max}), and maximal Q (Q_{max}) are reached [11, 54]. Since a plateau-effect of SV occurs at a level > 50% VO_{2max} [11, 68, 96], HR is what drives the value of Q, given that maximal SV (SV_{max}) remains constant.

Age is the primary factor related to a decrease in VO_{2max} [68, 69, 87, 98]. Moreover, HR_{max} decreases with increasing age [77, 78, 87, 98]. HR may also be affected by training status. For example, VO_{2max} increases [69, 84, 86], HR_{max} decreases [55, 61, 84, 86], or remains constant [88], and SV_{max} increases [61, 86] in response to aerobic training. Therefore, the increase in VO_{2max} due to training is caused by an increase in Q_{max}, which is caused by an increase in SV_{max}, which would otherwise decrease due to the decrement or steadiness in HR_{max} with training. Thereafter, a decrease in VO_{2max} may be caused more by a decrease in Q_{max} [63] or a-vO_{2max} [85], which is caused by a decrease in HR_{max} [94] and SV_{max} [25].

Since Robinson et al. (1938), one of the first research teams that examined the effects of age on HR_{max} [77], many other researchers have fashioned mathematical expressions to present the inverse relationship between age and HR_{max}. Currently, a multitude of HR_{max} regression equations (MHRE) exist. These maximal HR regression equations are also known as HR_{max} prediction equations:

- $HR_{max} = 206.3 - (.711 \cdot age)$ [57]
- $HR_{max} = 200 - (.72 \cdot age)$ [65]
- $HR_{max} = 209 – (.587 \cdot age)$ [75]
- $HR_{max} = 205 – (.687 \cdot age)$ [75]
- $HR_{max} = 208.754 – (.734 \cdot age)$ [76]
- $HR_{max} = 213.6 – (.65 \cdot age)$ [21]
- $HR_{max} = 199 – (.63 \cdot age)$ [35]
- $HR_{max} = 217.4 – (.845 \cdot age)$ [17]
- $HR_{max} = 209 – (.86 \cdot age)$ [23]
- $HR_{max} = 207 – (.78 \cdot age)$ [23]

Presently, there are three HR_{max} regression models that are widely employed in research:

- $HR_{max} = 220 - age$ [26] (Equation 1)
- $HR_{max} = 226 - age$ [32, 91, 93] (Equation 2)
- $HR_{max} = 208 - (0.7 \cdot age)$ [33, 76, 88] (Equation 3)

The regression equation $HR_{max} = 220 - age$ is one of the standard regression equations that has been commonly employed since it was first published in 1971, although the exact origins remain unknown. However, this equation has not held up well to scrutiny. First, the researchers did not apply a line of best fit and made the following statement: "It may be appreciated that no single line will adequately represent the data on the apparent decline of maximal heart rate with age. The formula HR max = 220 - age defines a line not far from many data points…" [26]. The same phrase was noted by Robergs et al. [76]. Secondly, the article which first stated the equation was a review of the scientific information surrounding physical activity and its effect on coronary heart disease [26]. No statistical analyses were used to determine efficacy of the equation. If the researchers had applied a line of best fit, the regression equation would have yielded $HR_{max} = 215.4 – (0.9147 \cdot age)$ [76]. Engels et al. stated "the efficacy of continuing to promote the use of the formula 220-age can be questioned" [21].

Some studies have shown that an over prediction of HR_{max} occurs for those that are young and an under prediction for those that are old when the equation $HR_{max} = 220 - age$ was used [33, 88]. In opposition, another investigator showed that non-smoking, older age, and lighter bodyweight were factors that were associated with an over estimated HR_{max}, while smoking, younger age, and bodyweight were factors that were associated with an under estimated HR_{max} when utilizing the same equation [95]. Furthermore, the equation also over

predicted for those that had mental retardation without Downs syndrome and even more so in the individuals with Downs syndrome [24].

Although the regression equation $HR_{max} = 220 - age$ has been applied to both men and women [1, 11, 36, 71], others have incorporated a different equation specifically for women, $HR_{max} = 226 – age$ [10, 32, 76, 91, 93]. However, the equation $HR_{max} = 226 - age$ remains apocryphal as no primary scientific literature has ever proposed such a model. Warburton et al. made the following statement, "…in our practice we have found that, for women, *226 – age* (in years) provides a better estimate of the maximum heart rate than *220 – age* and therefore is more appropriate for exercise prescriptions (unpublished observations)" [93]. However, subjective evidence is not as strong as objective evidence and therefore provides little merit. Robergs et al. provided a table listing some of the different MHREs and the authors of those equations [76]. The investigators within that table listed an incorrect author for the $HR_{max} = 226 – age$ formula (Brick M., M.D.) [10] and listed an incorrect source, as the equation was not located within that source [31]. Yet, the validity of that equation is still in question as there is no scientific evidence. Once a spokesperson for Polar Heart Rate Monitors, Brick stated, "Sometimes a number becomes established and origins are lost. It is a generalization that myself and the Polar engineers found useful to guide recreational athletes" [personal communication, January 21, 2008].

Some studies have shown that women do have higher max HRs than men [40], while other studies have shown no difference between sexes [21, 33, 88]. Tanaka et al. determined a regression equation through a meta analysis utilizing over 18,000 individuals that was not gender dependent, $HR_{max} = 208 – (0.7 \cdot age)$ [88]. Other investigators have found similar equations [23, 33, 76]. There were no over or under predictions for certain ages when $HR_{max} = 208 – (0.7 \cdot age)$

was compared to $HR_{max} = 220 - age$ [33, 88]. Tanaka et al. also stated that HR_{max} was not dependent upon physical activity status and others would agree [21, 68, 87, 88] while other studies would disagree [55, 86]. Presently, there is not enough evidence to support a finding that suggests that females have a higher HR_{max} than their respective male counterparts. Furthermore, there is not enough evidence to reflect the MHRE $HR_{max} = 226 - age$ designed specifically for the female.

The MHRE should be utilized in the same manner from which it was derived. For example, the equation $HR_{max} = 209 – (.86 \cdot age)$ was developed from the results of women [23]. Therefore, it would be considered unreasonable to use that specific equation for a man. Yet, how much of a difference would be elicited if the equation $HR_{max} = 208.754 – (.734 \cdot age)$ [76] was put in place of $HR_{max} = 209 – (.86 \cdot age)$, which can be used for both men and women? While examining a gender effect on HR_{max}, some studies have shown no significance between genders [21, 33, 68, 88] while other studies have shown a gender effect [40]. Moreover, an MHRE applied to a cycle ergometer protocol should not be used to estimate HR_{max}. Oftentimes, “peak” is the definitive term used during a maximal effort on an incremental cycle ergometer protocol [14, 34, 74] or in extreme circumstances when a maximal stress test will not induce true maximal values [13, 66]. The physiological explanation resides in less muscle mass recruitment during cycle ergometer protocol rather than a treadmill protocol; therefore, less oxygen is required by the working muscles. Fernhall et al. (1996) used the term when dealing with mentally retarded individuals and those with Downs syndrome. The group also mathematically designed a MHRE for that specific population [24]. Hermensen et al. summed it up nicely with the following statement: “excellent skill in the performance of one type of sporting activity does not

necessarily result in greater general ability to perform exercise with the least possible use of energy" [40].

These MHREs serve a purpose in the field of exercise science and medicine to develop exercise prescription based on percent of the available HR range [48]. Such estimates do not allow admitted cardiac and other disabled patients to perform a maximal treadmill stress test that may be clinically contraindicated. However, a controversy currently exists as to which MHRE best predicts HR_{max} given gender and training status. Yet, in some aspects measured maximal values are also important. For example, a false positive HR_{max} value, HR_{peak}, aids in establishing the functional capacity of heart transplant candidates [74]. Also, if submaximal values of HR are measured, those values greatly enhance the predicted values of VO_{2max} [19]. In opposition, age-predicted HR_{max} underpredicts VO_{2max} [92].

1.2 PURPOSE STATEMENT

The purpose of this study is twofold: a) to determine the effects of gender and training status on measured HR_{max}, and b) to determine the accuracy of three commonly used MHREs to predict true HR_{max} for females and males, trained and sedentary.

1.3 HYPOTHESES

1. It is hypothesized that gender will have no effect on measured HR_{max} nor on comparisons made between measured and predicted values between each of the three commonly used

MHREs, i.e. HR_{max} = 220 - age, HR_{max} = 226 - age, and HR_{max} = 208 – (0.7 · age), when compared to their opposite sex counterparts.

2. It is also hypothesized that there will not be a significant training effect on measured and estimated HR_{max}.

1.4 SIGNIFICANCE OF THE STUDY

Determining the efficacy of the three generally accepted clinical MHREs will allow for more accurate measures of heart rate reserve and target heart rates when used in exercise prescriptions, which will reduce the likelihood of error. In addition, the study will help determine which equation(s) are generalizable to the public with regards to age, gender, and training status.

1.5 LIMITATIONS OF THE STUDY

1. The principal investigator intends for a precise range of ages, where the range is insignificant. Therefore, the generalizability of the study is applicable to those within the specified age range.
2. Subjects may terminate the session prior to their true maximal cardiorespiratory potential thereby rendering a false positive factor that may jeopardize the accuracy of the data.
3. A Bruce treadmill protocol will be employed, so the results of this study will not be subject to other treadmill protocols nor any other exercise modality (i.e. cycle ergometer, swimming, etc…)

4. The active individuals are limited to those who run, so the generalizability is only relevant to those that run.

1.6 DEFINITION OF TERMS

1. Myocardium – The muscle of the heart.
2. Cardiorespiratory – Refers to the process of oxygen movement in the body.
3. Maximal Heart Rate (HR_{max}) – The highest possible frequency of myocardial contractions.
4. Peak Heart Rate (HR_{peak}) – The highest frequency of myocardial contractions attainable.
5. Oxygen uptake (VO_2) – The amount of oxygen that is inspired and utilized by the body.
6. Maximal oxygen uptake (VO_{2max}) – The highest amount of oxygen that is inspired and utilized by the body.
7. Arterial – venous oxygen (O_2) difference (a-vO_2) – The difference between the amount of oxygen found in the arterial blood versus the amount found in venous blood. The difference indicates how much blood was utilized by the body.
8. Cardiac output (Q) – Product of heart rate and stroke volume.
9. Stroke volume (SV) – The volume of blood ejected from the left ventricle of the heart produced by the force of myocardial contraction. Calculated from the difference of EDV and ESV (see below).
10. Diastole – Relaxation of the heart
11. Systole – Contraction of the heart

12. End diastolic volume (EDV) – The total volume of blood in the left ventricle prior to contraction.
13. End systolic volume (ESV) – The total volume of blood remaining in the left ventricle after contraction.
14. Ejection fraction – Percentage of blood expelled from the left ventricle.
15. Respiratory exchange ratio (RER) – Ratio of volume of $^{\text{carbon dioxide expired}}/_{\text{oxygen consumed}}$. An RER value of 0.7 indicates aerobic metabolism (utilization of mainly fat), or oxidation, and a value of 1.0 indicates anaerobic metabolism (utilization of mainly glucose), or glycolysis.
16. Regression equation – An equation derived from the line of best fit through the linear equation $y = mx + b$.
17. Frank-Starling mechanism – Elastic property of the left ventricle when an abundant amount of blood flows into the left ventricle thereby stretching the walls and allowing a recoiling effect.

2.0 LITERATURE REVIEW

2.1 GENERAL ANATOMY OF THE HEART

Because this study involves the effects of gender and training status on HR, a review of the anatomy of the heart is essential. The heart consists of four chambers: right atrium, right ventricle, left atrium, and left ventricle. The atrial chambers are responsible for moving blood into the ventricles. The ventricles then disperse blood to different organs of the body, depending on the ventricle the blood exits. Cardiac muscle, also termed myocardium, surrounds each of the chambers and contracts to push the blood through the chambers. The arteries on the outside of the heart (i.e. coronary artery, circumflex artery, anterior interventricular artery, etc…) are responsible for providing oxygen to the working muscle of the heart. The cardiac veins (i.e. coronary sinus, great cardiac vein, etc…) are responsible for removing waste products from the heart. The interventricular septum is the wall separating the right ventricle from the left ventricle. Valves separate the atrium from the corresponding ventricle, and are necessary to prevent the backflow of blood. The tricuspid and mitral (i.e. bicuspid) valves are anchored by the chordae tendineae, which are often referred to the heart strings. The papillary muscles within the ventricles are connected to the chordate tendineae, which are attached to the tricuspid and mitral valves. The papillary muscles aid in opening and closing the flaps and also help to anchor the chordae tendineae. The aortic and pulmonary semilunar valves prevent the backflow of

blood between the pulmonary artery and aorta and their corresponding ventricles. The pulmonary artery is responsible for carrying deoxygenated blood to the lungs where it then becomes oxygenated. The aorta is responsible for carrying oxygenated blood to the rest of the body needing nutrients, via skeletal muscle, bones, brain, skin, and other working organs [58, 71].

2.2 BLOOD FLOW OF THE HEART

Deoxygenated blood enters the right atrium through the superior and inferior vena cavae and the coronary sinus. Initially, the heart concomitantly contracts the atria. Upon contraction, the deoxygenated blood from the right atrium will flow through the tricuspid valve and enter the right ventricle. The subsequent contraction of the heart concurrently contracts the ventricles. Upon contraction of the ventricles, the blood will move through the pulmonary semilunar valve into the pulmonary artery. From the pulmonary artery, the deoxygenated blood will move to the lungs where the waste products (carbon dioxide, CO_2) will be replaced with oxygen (O_2). Once the blood has become oxygenated, the oxygenated blood will move through the initial part of the heart contraction will require oxygenated blood to travel through the mitral (bicuspid) valve into the left ventricle. The subsequent contraction will move the oxygenated blood through the aortic semilunar valve into the aorta, where the oxygenated blood will then travel to the rest of the body. The oxygenated blood will travel to the working organs of the body, drop off oxygen and other nutrients, pick up waste products, and flow back to the right atrium via the inferior and superior vena cavae and the coronary sinus to repeat the process [58, 71].

2.3 NEURAL INPUT OF THE HEART

The sinoatrial node (SA node), located within the right atrium, is known as the “pacemaker” of the heart. The SA node sends an electrical signal which causes the heart to contract. Once the SA node fires, the signal travels down to the atrioventricular node (AV node). Once the signal reaches the AV node, the signal is delayed. The signal will then move down the atrioventricular bundle (bundle of His), will separate from the bundle of His into right and left bundle branches, and finally to the purkinje fibers, which branch off from the bundle branches into the ventricles [58, 71].

The innervation of the heart is directly routed from sympathetic and parasympathetic neurons. The sympathetic activity of the heart is responsible for increasing heart rate whereas the parasympathetic activity of the heart does just the opposite, slows the heart rate. The sympathetic cardiac nerve is of the sympathetic branch and innervates both the SA and AV nodes. Likewise, the vagus nerve of the parasympathetic branch innervates the SA and AV nodes [58]. However, the contractions of the heart are not solely based on neural stimulation. The sympathetic nervous system also activates the adrenal gland, which is responsible for releasing hormones known as catecholamines. The two catecholamines that increase force of contraction [11] and heart rate are epinephrine (adrenaline) and norepinephrine (noradrenaline) [97].

2.4 PHYSICS OF THE HEART

Between contractions, the heart is in a state of relaxation known as diastole. During this period of time, the four chambers of the heart fill with blood. During the state of contraction, which is termed systole, the heart empties the blood from the ventricles and blood in the atria empties into the corresponding ventricles. Stroke volume (SV) is the volume of blood, usually measured through the left ventricle that exits the heart within a single contraction. Just prior to contraction, before the blood is dispelled from the left ventricle, the total volume of blood in the left ventricle is expressed as end diastolic volume (EDV). After contraction of the heart and preceding the filling phase, the volume of blood that remains in the left ventricle is the end systolic volume (ESV). Hence, the SV can be calculated by calculating the difference between EDV and ESV: $SV = EDV - ESV$. The ejection fraction (EF) is calculated as the percentage of blood from the total volume that exits the left ventricle: $EF = \frac{EDV - ESV}{EDV} x\ 100$ [11, 71, 97].

2.5 FUNCTION OF THE HEART

Numerous factors affect HR including age, gender, activity level, LV wall thickness, neural input, blood pressure, and rate of Ca^{2+} uptake within the sarcoplasmic reticulum. Given that there are many influences on HR, it is a reasonable assumption that the same MHRE would not work for all individuals.

The inverse relationship between age and HR_{max} is associated with many different factors. As some studies have noted, the rate of decline in HR_{max} with age will be smaller if

individuals are aerobically fit [17]. There is a direct relationship between age and increased stiffness of the heart [4]. Increased stiffness of the heart results from a reduction in the elasticity and contractility of the heart, which may be caused by an increase of fat, elastic tissue, and collagen within the myocardium [82]. The stiffness of the heart can be measured through indirect variables such as EDV, ESV, and EF [4, 8]. However, increased stiffness of the heart can be reduced through physical training [4]. An inverse relationship has been demonstrated between age and SV [9, 97]. This finding makes sense as it has been previously mentioned that the viscoelastic properties decrease in the heart, thereby affecting contractility of the myocardium [3].

Kunsoo et al. suggested increased parasympathetic activity in physically active individuals contributed to a lower HR at rest. Yet, they did not directly measure neuronal stimulation [53]. Other studies are in agreement that increased parasympathetic activity is related to a bradycardiac response [20, 27, 35]. The cause of an increased parasympathetic response may be related to an increased SV at rest [27, 53]. Ekblom et al. attributed a decrease in sympathetic activity with an increase in parasympathetic activity through a reduced β-adrenergic receptor activity, suggesting an adrenal mediating effect [20]. However, Moore et al. showed that rats who performed aerobic exercise for 15 weeks did not alter the number of β-adrenergic receptor sites nor did exercise affect the affinity to which the hormones bind [7, 64]. The decrement in sympathetic activity is in agreement with other studies, but these studies found no parasympathetic increase in the athletes [49, 67]. In fact, Katona et al. noticed that intrinsic HR, free from neuronal stimulation due to drugs that have a blocking-effect on the neurons, was decreased in athletes when compared to sedentary individuals [49]. Disregarding controversial data for the foundation of the understanding of the bradycardiac response while at rest, one fact

remains clear: sympathetic activity is diminished in those that are physically active. A lower HR_{max} may be attributed to a carry-over effect while exercising due to the adaptability of the nervous system of the physically trained individual.

Baroreceptors aid in the monitoring of blood pressure. These are found in the carotid sinus, aortic arch and in other arteries. When the blood pressure is high, a baroreflex response occurs. The high blood pressure will stimulate the parasympathetic response to reduce the sympathetic activity and thereby decrease blood pressure. When blood pressure is too low, then the opposite occurs, i.e., sympathetic activity is increased, resulting in increased blood pressure [11]. Graettinger et al. examined hypertensive versus normotensive subjects. They noted that the hypertensive subjects had a greater relative wall thickness (RWT) of the heart, specifically in the left ventricle (LV). It was also shown that a greater RWT was related to a greater HR_{max} [35], which is most likely caused by the high blood pressure and the fact that sedentary individuals have a higher HR_{max} than those who exercise [86].

A direct relationship between age and systolic blood pressure (SBP) and diastolic blood pressure (DBP) has been reported [42, 45, 79]. Ogawa et al. noticed a significantly higher SBP and DBP in elderly women when compared to younger women, but found no significance for men [68]. The increase in blood pressure is caused mainly by an increase in peripheral resistance [42, 94], which is related to an increase in adrenergic activity [42]. The increase in adrenergic activity is an acute response due to aerobic exercise that occurs at a level $\geq$ 50 – 60% VO_{2max} [11]. In addition, an increase in age is related to a decrease of baroreflex sensitivity [42].

Alternatively, LV wall thickness is greater in athletes. Greater LV thickness is associated with a lower HR_{max} [35] because of an increase in contractility and therefore SV [68, 80, 86]. A greater SV is also associated with increased plasma volume through exercise [16, 61], which

may be caused by the Frank-Starling mechanism (see definition of terms). However, this lower HR_{max} is not caused by the increase in plasma volume that is often associated with an increase in physical activity [61]. The viscoelastic properties of the myocardium are suggested to be maintained with exercise. In fact, multiple studies have reported higher SV in elderly exercisers than sedentary elders [3, 68, 86]. Baroreflex sensitivity has been shown to decrease with increased physical activity [44, 67, 83]. Negrao et al. noted that a decrease in baroreflex sensitivity in association with a bradycardiac response due to training exemplifies that there is a pronounced decrease of the parasympathetic response; training did not increase parasympathetic activity causing bradycardia while at rest [67]. Other studies reported that baroreflex sensitivity has similar effects between sedentary and aerobically active individuals [53, 83]. Although some studies have found no difference in resting SBP and DBP between those who are sedentary and those who have been athletically trained [27, 53, 68], Pollock et al. reported a lower SBP in sedentary individuals when compared to the active [70]. Ogawa et al. reported differences in SBP and DBP between genders [68]. With the finding that a HR response occurred with reduced baroreflex sensitivity while at rest, Smith et al. made the following comment in relation to a carry-over effect: "…it appeared the ability to buffer hypertensive insult was relatively preserved in HF (high fit) individuals, an adaptive response that may be beneficial during moderate and intense exercise." Smith et al. also advocated that a reduced baroreflex sensitivity was caused by the adaptation of stretch in the arteries through the constancy of hypertension, and/or a reduction in the number of baroreceptors [83].

The rate at which blood fills into the heart chambers also affects HR. This is particularly apparent with aging. The ratio of peak early diastolic mitral inflow velocity (E) to peak late diastolic filling velocity (A) (E/A) is lower in the elderly than the young [4, 72]. Therefore,

these findings indicate a slower movement of blood through the heart in the elderly, which is a result of lower HR_{peak}; as there is a direct relationship between peak filling rate and HR [56]. However, six months of aerobic training elicited an increase in peak early filling rates in both groups, which may be attributed to an increase in SV [56].

Another factor that may have an effect on reduced HR, particularly as it relates to aging, is increased duration of papillary muscle contraction due to a lower rate of calcium (Ca^{2+}) uptake within the sarcoplasmic reticulum [89, 90]. Rats that exercise showed an improvement in papillary muscle contraction of the heart [90]. Ianuzzo et al. demonstrated a 55% increase of Ca^{2+} uptake in porcine hearts artificially paced at 180 and 220 beats $\cdot$ min^{-1} [43].

2.6 MAXIMAL HEART RATE REGRESSION EQUATIONS

In 1971, Fox et al. produced a review article that rendered the equation $HR_{max} = 220 - age$ [26]. However, quotes from articles imply that Fox et al. may not be responsible for this equation. In 1967, Kemp et al. made the following statement: "Thus a man of age 40 has a predicted peak pulse rate of 180 and how much work he does to reach this pulse is a matter of strength and conditioning" [50]. One of the ways to get such a value is to subtract 40 from 220, which would yield 180, just as the author noted. Therefore, it may be that Fox was not the original founder of the equation.

One of the problems with such regression equations as $HR_{max} = 220 - age$ and $HR_{max} = 226 - age$ is that they assume a perfect correlation (R = 1.0). In the set up of a linear regression equation, $y = mx + b$, where m is the slope and b is the y-intercept and age is plotted on the x-axis and heart rate is plotted on the y-axis [28]. The problem that then arises is $HR_{max} = 220 -$

age assumes a linear function because no regression analysis was used. In fact, as mentioned previously, Robergs and colleagues discovered the correct regression equation from the line of best fit from which $HR_{max} = 220 - age$ was derived, which was found to be $HR_{max} = 215.4 - (0.9147 \cdot age)$ [76]. Furthermore, no MHRE has been derived from any scientific research that contains a perfect correlation within the equation. The equation also assumes that with each year, as an individual increases in age, then HR_{max} automatically decreases by one beat. Yet Blair et al. discovered each 10-year age group had a HR_{max} decrease by 5 beats $\cdot$ min^{-1}. They also noted a much lower rate of decline in HR_{max} in the trained than in the individuals that did not maintain aerobic fitness [6].

Another discrepancy with the $HR_{max} = 220 - age$ equation is that it is not specific to any group of individuals. Therefore, the equation could apply to many different populations. For example, earlier in this chapter the effect of training or conditioning on HR was detailed, but this effect is not included in this equation. Some authors have noted that HR_{max} is lower in highly trained individuals when compared to sedentary people [4, 6, 55, 68, 84]. The equation does not accurately predict the HR_{max} for individuals that are very old or very young [33, 88], overweight, smokers [95], or mentally retarded [24]. This is understandable as we know that smoking causes cardiorespiratory problems that may trigger a pulmonary limitation to reaching HR_{max} [73]. Likewise, the elderly may also have some neuromuscular limitations to movement that preclude reaching HR_{max}. Subjects with mental retardation are usually handicapped in more ways than one, especially physically. However, lower HR_{max} in mentally retarded individuals may be related to an increase in parasympathetic tone [24].

Likewise, obese subjects may have limitations [6]. Miller et al. developed six different HR_{max} prediction equations. Two equations were for obese individuals and two equations were

for sedentary. In addition, they purported that the $HR_{max} = 220 - age$ equation over predicted HR for the obese subjects [62].

It is likely that the equation $HR_{max} = 226 - age$ elicits the same problems with correlation, specificity, and accuracy of the prediction; however, no studies have been done to verify these issues with this specific equation. Ogawa et al. reported no differences between HR_{max} between males and females [68] and Tanaka et al. stated that gender is independent of HR_{max} [88]. Brooks and colleagues and Wilmore et al. both agreed that with the endurance-matched subjects of opposite sex, at any given submaximal intensity, females have a higher submaximal HR, but HR_{max} does not differ between the sexes [11, 97]. However, if these results are accurate, then the supposed truism of using $HR_{max} = 226 - age$ for women and $HR_{max} = 220 - age$ for men would render false. Eskurz et al. hypothesized that as women grew older, they were more likely to decrease their training volume to a further degree than men [22]. Wilmore and coworkers attribute the higher HR to less aerobic activity on the woman's part [97]. However, Brooks et al. claim that the woman's body trying to compensate for a lesser SV than men [11].

Another problem with $HR_{max} = 220 - age$ is that the origin of the equation does not specify sex. In three different studies, three similar equations were yielded that did not take gender into account: $HR_{max} = 206.3 - (.711 \cdot age)$ [57], $HR_{max} = 208.754 - (.734 \cdot age)$ [76], and $HR_{max} = 208 - (0.7 \cdot age)$ [88]. Londeree et al. attained HR_{max} values from approximately 388 different sources published over the course of 25 years [57]. Robergs et al. derived their equation simply by gathering 30 different MHREs and calculating and plotting the predicted HR_{max} values on a graph for ages 20-100 years of age and then calculating the linear regression equation from the line of best fit from the plotted values [76]. Finally, Tanaka et al. performed a meta analysis on many different articles with many different subjects included [88]. There may

have been some overlapping, which may leave some feelings of skepticism, but the common link of these equations is that both men and women were included in the development of the equation. Therefore, these equations are genderless.

The specificity of treadmill protocol is another factor that must be considered. Froelicher et al. discovered two different MHREs for two different treadmill stress test protocols: for the Balke protocol $HR_{max} = 198 - (.34 \cdot age)$ and for the Bruce protocol $HR_{max} = 211 - (.72 \cdot age)$ [30].

In another example of specificity, particularly training specificity, Johnson et al. did not account for a exercise modality effect when they studied oarsmen running on a treadmill instead of performing an exercise that was specific to their sport [46]. Therefore, it is possible that MHREs derived from swimmers or cyclists running on a treadmill would not produce an accurate MHRE.

2.7 EFFECT OF PROTOCOL ON MAXIMAL STRESS TEST

The treadmill protocol for a maximal stress test is another important factor to consider. Researchers have shown no change in HR_{max} with differing treadmill protocols [29, 70]. However, VO_{2max} has been shown to differ with different treadmill protocols [29, 30, 70]. VO_{2max} often reaches its true maximum value between 8-17 minutes and will diminish if it does not meet those time specifications [13]. As previously mentioned, HR_{max} is reached when VO_{2max} is reached [54]. If HR_{max} remained the same, but VO_{2max} differed with differing protocols, then HR_{max} was not reached when VO_{2max} was reached. One possible explanation is that HR_{max} may not have differed during longer durations on the treadmill because SV decreased

due to an increase in core body temperature from increased amount of time on treadmill, which caused vasodilation [59]. Other studies have noted no change in VO_{2max} with differing treadmill protocols [47, 66]. There may also be a genetic link. In one study, Klissouras et al. showed that monozygotic twins had a diversified HR_{max}, but their VO_{2max} was similar and in some cases remained the same regardless of training status [52]. In another study, Klissouras showed that HR_{max} and VO_{2max} were more similar in monozygotic twins than in dizygotic twins that were raised in the same environment [51].

2.8 RATIONALE FOR STUDY

Even though the MHRE $HR_{max} = 220 - age$ or $226 - age$ are still widely used, their validity with different sexes and people of various training backgrounds is questionable. The equation $HR_{max} = 220 - age$ was derived from studies prior to 1971 [26]. Some of the techniques and methods used in determining HR_{max} in the past cannot be trusted as scientists have increased understanding of cardiorespiratory response and newer, more accurate techniques have evolved. For example, in 1938, Robinson made the statement about a measured HR_{max}, "In general, the heart rates reached in exhausting work may be considered the maximal values attainable when a large volume of blood is being pumped" [77]. What constitutes a large volume? Were the researchers willing to ignore possible genetic capabilities of the heart to pump an even larger volume had they continued the test? Furthermore, Robinson also made the following statement in his methods section: "Evidence of the extent of exertion by the subjects depends upon their testimony that they worked as hard and as long as they could, and upon the fact that with the exception of a few young boys and old men, the rate of work required more energy than could be

supplied aerobically" [77]. How reliable was their testimony? Because metablic measures of oxygen uptake were not made, it is not certain that they reached HR_{max}. Assessing other studies as to the maximal stress test protocols used, gender of subjects, and other methods is nearly impossible due to the lack of proper referencing by Fox et al. from which the derivation of $HR_{max} = 220 - age$ was made [26]. Therefore, the purpose of the study is to determine the accuracy of each MHRE and to determine a gender and training effect on measured HR_{max}.

3.0 METHODOLOGY

3.1 SUBJECTS

3.1.1 Descriptive Characteristics

A total of 52 participants (15 aerobically active males, 9 sedentary males, 15 aerobically active females, and 13 sedentary females) between the ages of 18 and 25 years participated in the study. Sedentary was defined as participating in exercise <20 min · week^{-1} for $\leq$3 days · week^{-1} and <8000 steps · day^{-1} over the course of one week [15], for a minimum period of 6 months. Aerobically active included participants that were engaged in running $\geq$ 30 min · day^{-1} for 5 day·week^{-1} of moderate intensity, or $\geq$ 20 min · day^{-1} for 3 day · week^{-1} of vigorous intensity [38], for a minimum period of 6 months. The definitions of moderate and vigorous intensity are defined below:

> Moderate-intensity aerobic activity, which is generally equivalent to a brisk walk and noticeably accelerates the heart rate, can be accumulated toward the 10 min minimum from bouts lasting 10 or more minutes. Vigorous-intensity activity is exemplified by jogging, and causes rapid breathing and a substantial increase in heart rate. This recommended amount of aerobic activity is in addition to routine

activities of daily living of light intensity or lasting less than 10 min in duration [38].

Participants were recruited via informational flyers posted around the University of Pittsburgh campus and were also distributed intramural teams and clubs that actively run to train or run as a part of the sport.

3.1.2 Phone Screening Process

All participants went through a rigorous phone-screening process prior to testing. Each subject had to answer questions on the Phone-Screening Participant Information form created by the principal investigator (Appendix A). The form provided information as to the purpose of the study, information regarding the process of the testing period, expectations of the subject, and questions to determine inclusion or exclusion. All subjects provided information to the best of their knowledge. The subjects then answered questions based on part four of the International Physical Activity Questionnaire: Long Last 7 Days Telephone Format (IPAQ, 2002) (Appendix B). The fourth part of the IPAQ was the only part that pertained to the study. For each question, the subject was encouraged to take as much time as necessary to answer the question. Finally, the subject had to answer all questions on the Physical Activity Readiness Questionnaire (PAR-Q & YOU) (See section 3.2.2 for definition). The PAR-Q is an extensively studied questionnaire that provides insight of any cardio respiratory conditions an individual may have that would prevent them from performing any strenuous exercise.

3.1.3 Inclusion and Exclusion Criteria

Inclusion criteria for the sedentary participants included the following: body mass index (BMI) value of 18.5-24.9 ($kg \cdot m^{-2}$), age of 18-25 years, and a demonstration of a sedentary lifestyle through the International Physical Activity Questionnaire (IPAQ). Inclusion criteria for the active participants included a demonstration of an active running lifestyle through a physical activity survey, a BMI value of 18.5-24.9 ($kg \cdot m^{-2}$), and age of 18-25 years. An active running lifestyle consisted of meeting the "aerobically active" requirements listed above through running (see 3.1.1). In addition, all subjects abstained from alcohol consumption, caffeine, and vigorous exercise for 24 hours and from food intake 3 hours prior to testing. Exclusion criteria for any participants consisted of the following: answering "yes" to any of the questions on the PAR-Q, diabetes, cancer, and/or any other disease that may have prevented them from exercising to maximal intensity, an eating disorder, abnormal menstrual cycle, during menses, during pregnancy, and could not have been taking any medications that affected cardiac, neurological, musculoskeletal, or cognitive function. The primary physiological criterion for the inclusion of subject data in the study is evidence of an horizontal asymptote of HR_{max} when plotted against VO_2 [99]. The highest HR value, including post test, will be used as the datum. Although not necessary, the researchers would like to see one of the following physiological criteria met to ensure HR_{max}: oxygen consumption (VO_2) $\leq$ 2.1 $ml \cdot kg^{-1} \cdot min^{-1}$ between time stages and/or respiratory exchange ratio (RER) value $\geq$ 1.1.

3.1.4 Reducing Risk

In order to reduce the risk of injury to the participant, a minimum of two researchers were always present during any of the maximal treadmill stress tests. An emergency plan was also set up for the researchers to follow in the event of an injury taking place. Furthermore, the following contraindications from the American College of Sports Medicine were utilized to eliminate the likelihood of injury: dizziness, syncope, ataxia, poor blood perfusion, wheezing, leg cramps, dyspnea, increase in chest pain, subject's desire to stop, and equipment malfunction. Subjects were familiarized to the treadmill during the 5-min warm-up period and also were given proper instruction to prevent injury.

3.2 PROCEDURES

3.2.1 Experimental Variables

Two comparisons were made in this study. First, the effect of gender and aerobic training status on measured HR_{max} was explored. The independent variables were gender and aerobic training status and the dependent variable was measured HR_{max}. In the second comparison, the effects of training within gender and prediction equation on the accuracy of the HR prediction when compared to measured HR_{max} were assessed. The independent variables were gender, aerobic training status, and prediction equation. The dependent variable was the delta between the measured HR_{max} and the predicted HR_{max}. Predicted HR_{max} was calculated from the three

commonly employed MHREs, i.e. HR_{max} = 220 - age, HR_{max} = 226 - age, and HR_{max} = 208 – (0.7 · age).

3.2.2 Equipment

1. Polar Heart Rate Monitor – A monitor with an expandable strap that runs across the xiphoid process to read the heart rate by picking up the electrical signals.
2. Open-circuit spirometer - Device open to ambient conditions for the subject to inspire that measures the composition of gas (i.e. fraction (%) of expired O_2 and CO_2) through a gas analyzer. The flow meter measures ventilation from the expired air flow of the subject being tested. The spirometer also contains a mixing gas chamber, which mixes the expired gases together to attain an average sampling of gas. The results of all the measurements taken by the spirometer are displayed on a computer interface.
3. Two-way non-rebreathing respiratory valve – A t-shaped valve that allows the movement of air to flow in one direction. Moreover, the valve contains a spit trap.
4. Treadmill – Specialized treadmill designed specifically for performing maximal stress tests that can increase to a grade of 25%.
5. Nose clip – A clamp specifically designed to fit comfortably over the nose so as to direct air movement only through the oral passage.
6. Scale – A standard scale found in most medical offices to measure body mass (kg) and height (cm).
7. Barometer – A specialized barometer that measures relative humidity (%), barometric pressure (mmHg), and temperature (^{o}C).

8. Physical Activity Readiness Questionnaire (PAR-Q & YOU) – A questionnaire determining whether a participant is healthy enough to engage in physical activity without a physician's notice.

3.2.3 Exercise Protocol

Prior to the subject performing the maximal stress test, the open-circuit spirometer was calibrated. The open-circuit spirometer was calibrated by utilizing a 3.0 L calibration syringe. This was accomplished by attaching a filter, spit trap, hose, and then a 3.0 L calibration syringe to the mixing chamber. Five flushes of progressively slow to fast pumps (~ 50, 100, 200, 300, and 400 $L \cdot min^{-1}$) of the syringe were performed to tell the pneumotach device of different air flows. The second thing that was calibrated was the oxygen analyzer. Gas from a tank that contained a known gas concentration of 16% oxygen, same as exhaled air, was shot through the analyzer. Additionally, the carbon dioxide analyzer was also calibrated from a gas tank with a known concentration of 4% carbon dioxide, same as exhaled air. After the calibration was completed, the calibration syringe was detached and the hose was then attached to a Rudolph Model 2700 two-way non-rebreathing respiratory valve (Rudolph, Model 2700, Kansas City, MO).

Data collection took place at the Center for Exercise & Health Fitness Research in Trees Hall at the University of Pittsburgh. Subjects signed an informed consent (Appendix C) approved by the Institutional Review Board at the University of Pittsburgh. Subjects wore comfortable athletic clothing and shoes during the test. Prior to the test, the principal investigator explained to the subjects that by placing their hands on the side rails of the treadmill was an indication to stop the test. The investigator also explicated to the subject to try and

continue walking/running on the treadmill until they felt too uncomfortable to continue due to extreme fatigue, pain, or breathlessness. The termination criterion for attaining a maximal threshold was defined to the subject through the following statement: "Continue walking/running on the treadmill until you feel too uncomfortable to continue due to extreme fatigue, pain, or breathlessness. To indicate that you want to stop, place your hands on the side railing of the treadmill". The subjects were then fitted with a strap-on Heart Rate Monitor (Polar Electro., Kenpele, Finland) across the xiphoid process. Electro gel was applied to attain a better conduction signal of the heart. The height (inches), age (years), sex and mass (kg) of the subject were also taken. Another device on the Parvo Medics Truemax 2400 Respiratory Metabolic Analyzer (TrueMax 2400, Parvo Medics Inc., Sandy, UT) took room temperature, barometric pressure, and relative humidity into account to determine that the environment was thermoneutral. A mouthpiece was attached to a Hans Rudolph 2-way Non-Rebreathing Valve that fit comfortably within the subject's mouth and was also large enough so as not to restrict air movement. The headgear was securely attached to the subject's head and was also connected to the two-way valve to hold it comfortably in place. The hose ran through a metal arm that helped to hold the hose up. A nose clip was used on each subject to prevent inhalation and exhalation of ambient air through the nose, which provided more accurate data. In addition, for the test results to be accurate, the subject had to keep a tight seal around the mouthpiece with his/her mouth so that air would not leak out.

Subjects performed a multi-stage Bruce maximal stress test on a Trackmaster motor driven treadmill (Fullvision Inc., Model TMX425C, Newton, KS). The test was volitionally terminated by the subject owing to exhaustion. Volitional failure was determined by the subject placing their hands on the rail of the treadmill while continuing to run as the researchers

decreased the speed and the grade. Beginning at the third stage until completion, all subjects were given the following verbal encouraging statements every 20-60 seconds: 'Way to go!', 'Come on!', 'Good job!', 'Excellent!', 'Come on, push it!', 'Keep it up!', 'Push it!', and 'Let's go!' [2]

Table 1. Bruce treadmill protocol descriptive characteristics

Stage	Speed ($km \cdot hour^{-1}$)	Incline (%)	Time (min)
Warm-up	Self-determined (HR $\leq$100 $beats \cdot min^{-1}$)	0	5
I	2.7	10	3
II	4.0	12	3
III	5.5	14	3
IV	6.8	16	3
V	8.0	18	3
VI	8.9	20	3
VII	9.7	22	3
VIII	10.5	24	Remain at speed until volitional failure
Cool-down	4.0 - 5.0	0	5

3.2.4 Measurements

HR was measured every 10-15 seconds during the exercise test with a Polar Heart Rate Monitor (Polar Electro., Kenpele, Finland). HR was also measured immediately post exercise to determine the highest HR_{max}. During that period of time, HR continued to be recorded until a decline was seen. VO_2 and RER were measured by the Parvo Medic's computer software approximately every 15 seconds. Upon completion of the study, a data report of each subject was printed and saved on the Parvo Medic's computer system. The principal investigator then

averaged 30 second values of VO_2 and RER. The VO_{2max} and RER values at the end of the test were recorded. The differences between the final stages of the maximal treadmill stress test were calculated to determine that the VO_2 values were $\leq$ 2.1 ml · kg^{-1} · min^{-1}, which was one determinant of VO_{2max}. Likewise, the average RER values were calculated similarly to determine that the value was $\geq$ 1.1.

3.3 DATA ANALYSIS

The data analysis was performed in three stages. First, descriptive statistics were assessed. In the second, the effect of gender and aerobic training status on measured HR_{max} was explored. In the third comparison, the effect of gender, aerobic training status, and prediction equation on the prediction equation accuracy was assessed. Prior to performing the statistical analysis, an exploratory data analysis was conducted to determine whether the statistical assumptions were fulfilled for the planned ANOVAs. Measures of central tendency, such as means, and measures of dispersion (i.e. standard deviations and ranges) were calculated for the measured heart rate and predicted heart rate variables. To screen for marked departures from normality, histograms of the dependent variables were examined along with skewness and kurtosis values.

The statistical analyses were performed using SPSS 16.0 statistical software (SPSS, Inc., Chicago, IL). First, one factor ANOVA's (with the four groups being active males, sedentary males, active females, and sedentary females) were carried out to determine group differences between the following variables : Age (yrs), height (m), mass (kg), BMI (kg · m^{-2}), total walking (min · $week^{-1}$), total moderate running (min · $week^{-1}$), total vigorous running (min · $week^{-1}$), HR_{rest} (beats · min^{-1}), HR_{max} (beats · min^{-1}), VO_{2max} [(ml · kg^{-1}) · min^{-1}], and RER. Tukey post

hoc analysis was used to follow significant results. Secondly, a two factor ANOVA (gender X aerobic training status) for measured HR_{max} was performed. For our third aim, a three factor (gender X aerobic training status X prediction equation) ANOVA with repeated measures on the third factor was performed on the predicted HR_{max} data. The alpha value for the three factor ANOVA analysis was set at $P < 0.05$. Aerobic training status had two levels (active and sedentary). Prediction equation had three levels (220-age, 226-age, 208-.7·age). The two dependent variables for this ANOVA were signed residuals (observed HR_{max} - predicted HR_{max}) and unsigned residuals [the absolute value of (observed HR_{max} - predicted HR_{max})].

Prior to data collection it was planned to transform both signed and unsigned residuals because it was expected that the distributions would be highly skewed and therefore that the assumption of normality would be violated. The residual for each participant would be divided by the standard error of prediction for each participant, yielding a (signed or unsigned) t-score.

The gender x aerobic training status interaction was included in the model, as was the effects of the prediction equation, prediction equation x gender, prediction equation x aerobic training status, and prediction equation x gender x aerobic training status. If any interactions were significant, this indicated that the relative accuracy of the three prediction equations varied according to gender, aerobic training status, or the combination of gender and aerobic training status. Post hoc tests were done to follow significant interactions.

4.0 RESULTS

4.1 DESCRIPTIVE STATISTICS

Table 2. D escriptive statistics for four gr oups: ac tive (act.) males, sedentary (sed.) females, act. females, & sed. females

Variable		Group		Mean	Std. Dev.	Min	Max	Med.
Age (yrs)		*Act. Male*		21.4	1.7	19	24	21
		Sed. Male		21.8	2.6	18	25	23
		Act. Female		20.1	2.3	18	25	20
		Sed. Female		20.9	1.9	18	25	21
Height (m)		*Act. Male*		1.80	0.060	1.70	1.90	1.79
		Sed. Male		1.77	0.059	1.64	1.84	1.76
		Act. Female		1.64	0.048	1.52	1.70	1.63
		Sed. Female		1.61	0.067	1.50	1.72	1.61
Total Body Mass (kg)		*Act. Male*		76.0	6.0	65.5	86.0	75.7
		Sed. Male		67.1	6.9	52.3	75.2	66.4
		Act. Female		61.2	6.1	52.7	76.8	60.0
		Sed. Female		54.7	5.5	46.4	68.0	54.5
BMI ($kg \cdot m^{-2}$)		*Act. Male*		23.5	1.8	20.9	27.0	22.9
		Sed. Male		21.4	1.2	19.4	23.8	21.1
		Act. Female		22.8	1.8	20.3	26.6	22.5
		Sed. Female		21.2	2.0	18.7	25.0	20.5

Table 3. Demographic one-way ANOVA between groups, significance determined by Tukey HSD post hoc, level of significance p<.05

Variable		F	P		Actv M *v.* Sed M	Actv M *v.* Actv F	Actv M *v.* Sed F	Sed M *v.* Actv F	Sed M *v.* Sed F	Actv F *v.* Sed F
Age (yrs)		1.43	0.244		**(NS)**	**(NS)**	**(NS)**	**(NS)**	**(NS)**	**(NS)**
Height (m)		33.34	0		**(NS)**	*	*	*	*	**(NS)**
Total Body Mass (kg)		30.94	0		*	*	*	*	*	*
BMI ($kg \cdot m^{-2}$)		5.32	0.003		*	**(NS)**	*	**(NS)**	**(NS)**	**(NS)**

Denotes significant contrast

Subject demographics are shown in Tables 2 & 3. In order to better describe the active and sedentary groups, the amount of walking, moderate running, and vigorous running performed by each subject was assessed with one-way ANOVA. However, examination of the distributions indicated that the assumption of normality was not met for the physical activity variables: total walking, moderate running, and vigorous running (absolute value of skewness $\geq$ 1.5). The square root transformation was applied to the total walking variable and the transformed data were approximately normal. One-way ANOVA was applied to the transformed data which yielded significant results (F=5.74, p=.002). Tukey post hoc comparisons showed a significant difference between the active males and sedentary females and between the active females and sedentary females.

Due to the extreme departure from normality for the variables moderate and vigorous running because most participants in the sedentary groups reported 0 hours of running, two nonparametric tests (Mann-Whitney *U* Test) for each variable assessed the differences between active males and females. The results were not significant in either the moderate (p=.267) or vigorous activity levels (p=.512).

Descriptive statistics for the physical activity variables are presented in Table 4a. A one-way ANOVA showed no statistical differences between in age between the groups but did demonstrate significant differences between the following variables: total walking, HR_{rest}, HR_{max}, VO_{2max}, and RER (Table 4b). Results of the ANOVA's and Tukey post hoc comparisons for the above variables are summarized in Table 5.

Table 4a. Descriptive independent variables for four groups

Variable		Group		Mean	Std. Dev.	Min	Max	Med.
Total Walking (min · wk^{-1})		*Act. Male*		339.5	338.8	53	1260	210.0
		Sed. Male		138.9	117.3	0	300	120.0
		Act. Female		409.4	413.6	30	1680	262.5
		Sed. Female		91.0	80.1	0	280	75.0
Mod Run (min · wk^{-1})		*Act. Male*		119.30	178.0	0	735	90
		Sed. Male		17.80	39.3	0	120	0
		Act. Female		82.70	121.7	0	450	45
		Sed. Female		11.54	28.8	0	90	0
Vig Run (min · wk^{-1})		*Act. Male*		187.90	171.5	75	780	140
		Sed. Male		0.00	0.00	0.00	0.00	0.00
		Act. Female		147.50	101.3	0	360	120
		Sed. Female		3.46	12.5	0	45	0

Comparisons also revealed that active and sedentary males had a significantly higher VO_{2max} than the females indicating a higher VO_{2max} in association with a higher total body mass. Both active males and females demonstrated a larger VO_{2max} than their counterparts signifying a difference between activity levels (see Table 5).

Table 4b. Descriptive dependent physiological variables for the four groups

Variable		Group		Mean	Std. Dev.	Min	Max	Med.
HR_{rest} (beats · min^{-1})		*Act. Male*		70.5	7.10	59	83	70.0
		Sed. Male		86.0	9.99	70	102	89.0
		Act. Female		72.3	10.20	59	97	68.0
		Sed. Female		76.7	9.60	57	95	76.5
HR_{max} (beats · min^{-1})		*Act. Male*		194.5	5.79	182	203	196
		Sed. Male		202.1	8.30	187	212	204
		Act. Female		188.3	6.20	179	201	187
		Sed. Female		192.5	6.49	184	203	190
VO_{2max} [(ml · kg^{-1}) · min^{-1}]		*Act. Male*		55.6	8.14	42.1	71.0	55.7
		Sed. Male		42.6	4.19	37.1	47.8	44.0
		Act. Female		41.6	6.54	29.0	50.6	42.7
		Sed. Female		34.6	4.81	24.7	40.2	35.9
RER		*Act. Male*		1.16	0.052	1.10	1.25	1.15
		Sed. Male		1.25	0.079	1.13	1.37	1.28
		Act. Female		1.20	0.052	1.11	1.30	1.18
		Sed. Female		1.26	0.122	1.11	1.47	1.23

Table 5. One-way ANOVA between groups, significance determined by Tukey HSD post hoc, level of significance α<.05, (NS) = not-significant.

Variable		F	P		Actv M *v.* Sed M	Actv M *v.* Actv F	Actv M *v.* Sed F	Sed M *v.* Actv F	Sed M *v.* Sed F	Actv F *v.* Sed F
Total Walking (min · wk^{-1})		5.74[1]	0.002		**(NS)**	**(NS)**	*	**(NS)**	**(NS)**	*
Mod Run (min · wk^{-1})		2.52	0.069		**(NS)**	**(NS)**	**(NS)**	**(NS)**	**(NS)**	**(NS)**
Vig Run (min · wk^{-1})		10.34	0.000		*	**(NS)**	*	*	**(NS)**	*
HR_{rest} (beats · min^{-1})		5.89	0.002		*	**(NS)**	**(NS)**	*	**(NS)**	**(NS)**
HR_{max} (beats · min^{-1})		8.57	0.000		*	**(NS)**	**(NS)**	*	*	**(NS)**
VO_{2max} [(ml · kg^{-1}) · min^{-1}]		26.86	0.000		*	*	*	**(NS)**	*	*
RER		4.34	0.009		**(NS)**	**(NS)**	*	**(NS)**	**(NS)**	**(NS)**

Denotes significant contrast
[1]Square root transformation

4.2 TWO-WAY ANOVA BETWEEN GENDER AND ACTIVITY

Two-way ANOVA found significance for gender and activity but not the gender by activity interaction (see Tables 6 & 7). Therefore, males had the higher HR_{max} regardless of activity level. In addition, sedentary participants had higher HR_{max} regardless of gender.

Table 6. Two-way ANOVA Summary Table: Measured HR_{max}

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	P
Gender	774.12	1	774.12	18.031	< .001
Activity Level	441.85	1	441.85	10.290	0.002
Gender by Activity Level	35.4	1	35.40	0.820	0.368
Error		48			

Table 7. Table of Marginal Means: Measured HR_{max}

Effect	Category	Marginal Mean
Gender	*Male*	198.29
	Female	190.40
Activity Level	*Active*	191.37
	Sedentary	197.33
Gender by Activity Level	*Active Male*	194.45
	Sedentary Male	202.11
	Active Female	188.27
	Sedentary Female	192.54

4.3 THREE-WAY ANOVA FOR SIGNED RESIDUALS

To assess the accuracy of the prediction equations, the residuals, or the difference between the measured HR_{max} and estimated HR_{max} from each of the prediction equations, were calculated. Residuals with a negative sign over predicted the true HR_{max}, while positive residuals under predicted HR_{max}. Within the "between subjects effects" of the signed residuals (Table 8), the males, within the gender group, and those who were sedentary, within the activity level group, demonstrated a significantly better accuracy than their counterparts respectively (see Table 9a) based on the application of the average predicted HR_{max} across all three equations being measured. However, these results do not give insight to the degree of accuracy within gender and activity level status based on the predictive capability of each single MHRE being studied. The purpose of the study was to examine the accuracy of each individual equation without the involvement of a conglomeration of all three MHREs. Only the effect of equation had a significant result in determining the accuracy of prediction across the three equations (p=.000). The summary table for the three-way ANOVA for the signed raw residuals is presented in Table 8. On average, $HR_{max} = 208 - (0.7 \cdot age)$ (Equation 3) under predicted by 1.09 beats $\cdot$ min^{-1} whereas the other two equations over predicted by a greater margin (Table 9a). Tukey post hoc analysis revealed significance for $HR_{max} = 220 - age$ (Equation 1) when compared to $HR_{max} = 226 - age$ (Equation 2) and $HR_{max} = 208 - (0.7 \cdot age)$ (Equation 3). Moreover, Equation 2 was significantly different from Equation 3.

Table 8. ANOVA summary table: signed raw residuals
[a]P-values for within subjects effects are based on Huynh-Feldt adjustment

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	P
Between Subjects Effects					
Gender	2,918.61	1	2,918.61	22.15	0.000
Activity Level	1,569.64	1	1,569.64	11.91	0.001
Gender by Activity Level	84.12	1	84.82	0.64	0.428
Error	6,326.23	48	131.80	----	----
Within Subjects Effects[a]					
Equation	3,398.30	2	1,699.15	12,715.10	0.000
Equation by Gender	0.84	2	0.42	3.14	0.080
Equation by Activity Level	0.25	2	0.13	0.95	0.339
Equation by Gender by Activity Level	0.03	2	0.02	0.12	0.748
Error	12.83	96	0.13	----	----

Table 9a. Table of marginal means: signed raw residuals

Effect	Group	Marginal Mean
Gender	*Male*	-0.28
	Female	-9.12
Activity Level	*Active*	-7.94
	Sedentary	-1.46
Equation	*220 - age (1)*	-4.60
	226 - age (2)	-10.60
	208 - (0.7 · age) (3)	1.09

Table 9b. Table of interaction marginal means: signed raw residuals

Effect	Group	Marginal Mean
Gender by Activity Level	*Active Male*	-4.27
	Sedentary Male	3.71
	Active Female	-11.61
	Sedentary Female	-6.63
Equation by Gender	*Male x 1*	-0.12
	Male x 2	-6.12
	Male x 3	5.40
	Female x 1	-9.07
	Female x 2	-15.07
	Female x 3	-3.23
Equation by Activity Level	*Active x 1*	-7.87
	Active x 2	-13.87
	Active x 3	-2.10
	Sedentary x 1	-1.33
	Sedentary x 2	-7.33
	Sedentary x 3	4.27
Equation by Gender by Activity Level	*Active Male x 1*	-4.13
	Active Male x 2	-10.13
	Active Male x 3	1.45
	Sedentary Male x 1	3.89
	Sedentary Male x 2	-2.11
	Sedentary Male x 3	9.36
	Active Female x 1	-11.60
	Active Female x 2	-17.60
	Active Female x 3	-5.64
	Sedentary Female x 1	-6.54
	Sedentary Female x 2	-12.54
	Sedentary Female x 3	-0.82

4.4 THREE-WAY ANOVA FOR UNSIGNED RESIDUALS

An additional measurement was used to assess the accuracy of the prediction equations, the unsigned residuals, or the absolute value of the residuals. Such a measure prevents a cancellation of signs through the summation process, which may otherwise cause an average close to zero, and provides the total number of beats $\cdot$ min^{-1} by which the MHREs inaccurately predicts. As seen in the ANOVA summary table (Table 10), the equation by gender and equation by activity level interactions were both significant. These interactions were graphed to facilitate interpreting them (See Figure 1 and Figure 2). Regarding the equation by gender interaction, the graph (Figure 1) as well as the table of marginal means (Table 11b) reveal that for males the average unsigned residual for $HR_{max} = 220 - age$ (Equation 1) was closest to 0, while for females the average unsigned residual for $HR_{max} = 208 - (0.7 \cdot age)$ (Equation 3) was closest to 0. In addition, there was a greater difference among the average unsigned residuals for the three equations for females than there was for males. Regarding the equation by activity level interaction, the graph (Figure 2) and the table of marginal means (Table 11b) revealed that for active participants the average unsigned residual for Equation 3 was clearly closest to 0, whereas for sedentary participants the average unsigned residuals for Equations 1 and 3 were virtually equal. However, for both levels of activity the average unsigned residual for $HR_{max} = 226 - age$ (Equation 2) was furthest from 0, indicating that Equation 2 produced the least accurate predictions. Tukey post hoc tests indicated significance between Equations 1 and 2 for males and between all pairs of equations for females. Likewise, a significanct difference was found between Equations 1 and 2 for sedentary and between all pairs of equations for active.

The "between subjects effects" were significant for gender and gender by activity interaction (P=.04 & P=.028 respectively) (see Table 10). The males and active males were

considered to have the greatest accuracy (see Tables 11a & 11b). However, the same problem applies wherein the basis of these results lies in the accuracy of the calculated average predictions of the three MHRE models, which was assessed with this study.

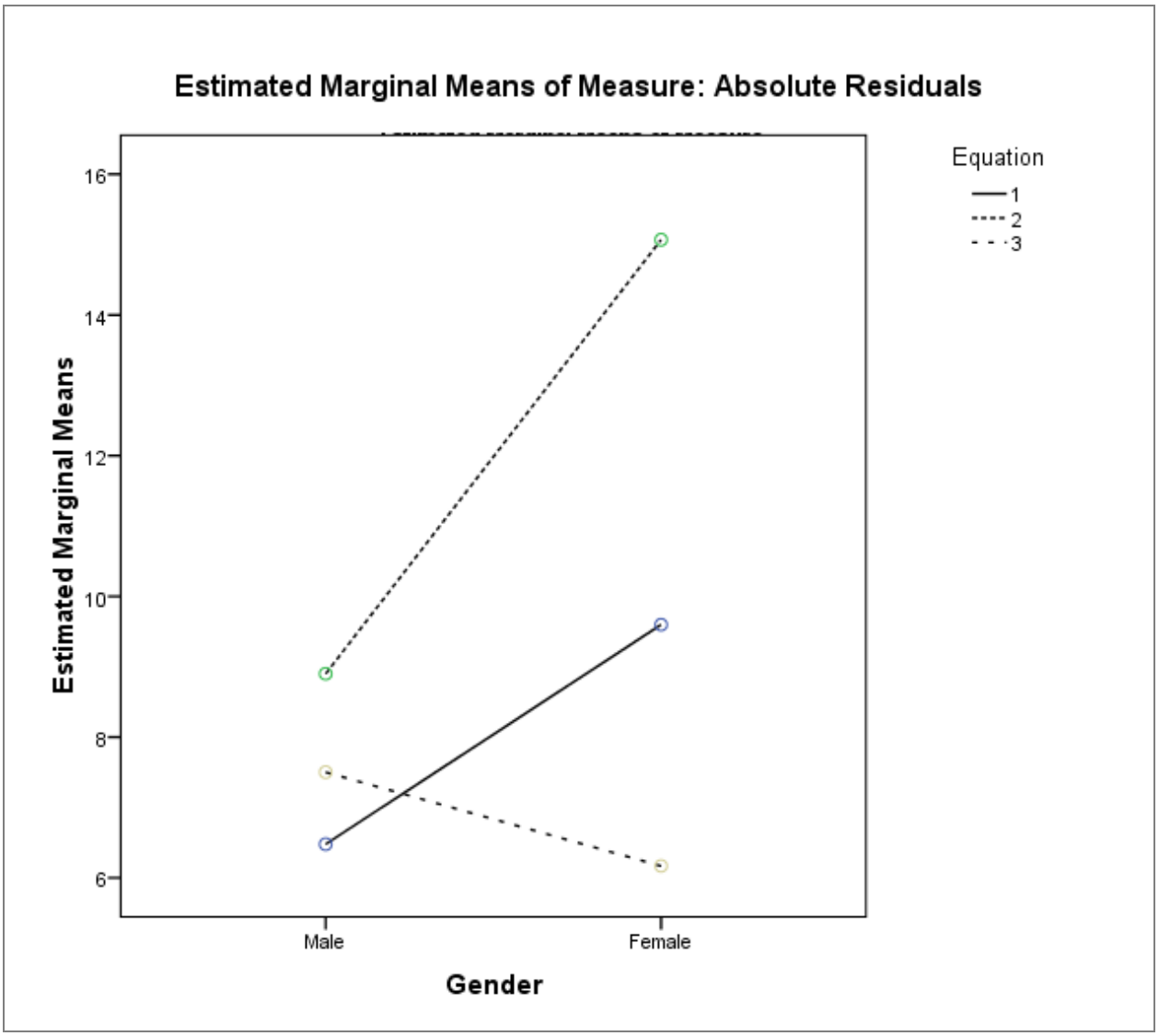

Figure 1. Profile plot for absolute residuals based on gender interaction

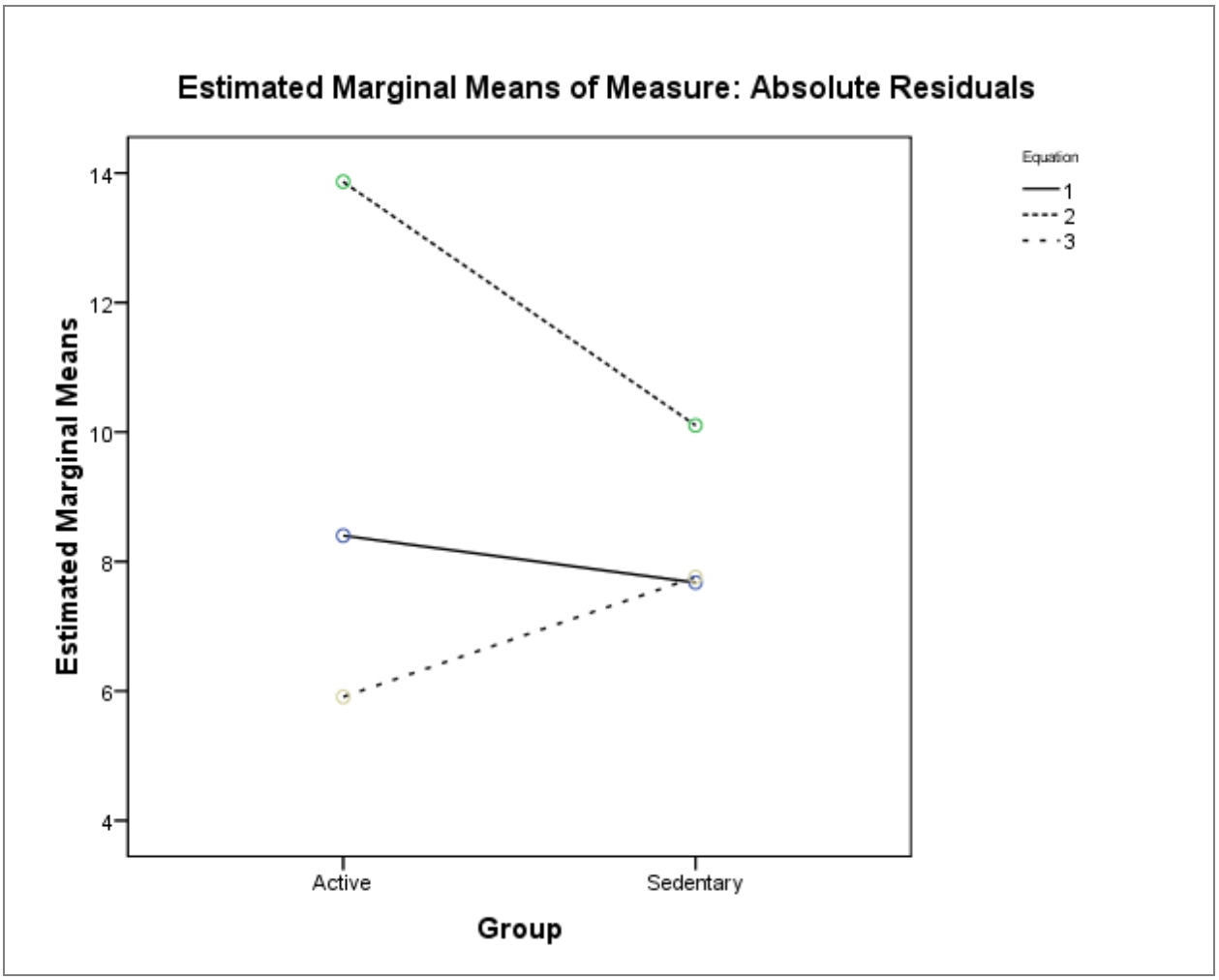

Figure 2. Profile plot for absolute residuals based on group interaction

Table 10. ANOVA summary table: unsigned raw residuals
[a]P-values for within subjects effects are based on Huynh-Feldt adjustment

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	P
Between Subjects Effects					
Gender	262.65	1	262.65	4.45	0.040
Activity Level	28.90	1	28.90	0.49	0.488
Gender by Activity Level	304.73	1	304.73	5.16	0.028
Error	2,836.45	48	59.09	----	----
Within Subjects Effects[a]					
Equation	722.66	2	361.33	30.11	0.000
Equation by Gender	354.30	2	177.15	14.76	0.000
Equation by Activity Level	196.59	2	98.29	8.19	0.003
Equation by Gender by Activity Level	45.59	2	22.80	1.90	0.171
Error	1,151.93	96	12.00	----	----

Table 11a. Table of marginal means: unsigned raw residuals

Effect	Group	Marginal Mean
Gender	*Male*	7.63
	Female	10.29
Activity Level	*Active*	9.39
	Sedentary	8.51
Equation	*220 - age (1)*	8.04
	226 - age (2)	11.99
	208 - (0.7 · age) (3)	6.84

Table 11b. Table of interaction marginal means: unsigned raw residuals

Effect	Group	Marginal Mean
Gender by Activity Level	*Active Male*	6.64
	Sedentary Male	8.62
	Active Female	12.15
	Sedentary Female	8.41
Equation by Gender	*Male x 1*	6.48
	Male x 2	8.90
	Male x 3	7.50
	Female x 1	9.60
	Female x 2	15.07
	Female x 3	6.17
Equation by Activity Level	*Active x 1*	8.40
	Active x 2	13.87
	Active x 3	5.91
	Sedentary x 1	7.68
	Sedentary x 2	10.10
	Sedentary x 3	7.76
Equation by Gender by Activity Level	*Active Male x 1*	5.07
	Active Male x 2	10.13
	Active Male x 3	4.71
	Sedentary Male x 1	7.89
	Sedentary Male x 2	7.67
	Sedentary Male x 3	10.29
	Active Female x 1	11.73
	Active Female x 2	17.60
	Active Female x 3	7.11
	Sedentary Female x 1	7.46
	Sedentary Female x 2	12.54
	Sedentary Female x 3	5.23

5.0 DISCUSSION

5.1 EFFECT OF SEX AND ACTIVITY LEVEL ON MEASURED HR_{MAX}

The first purpose of the study was to determine the effects of fitness level and sex on measured HR_{max}. In the current study, gender and training status affected HR_{max} independently from one another. A higher HR_{max} was noted among the sedentary participants when compared to their active counterparts. Spina et al. [86] noted a 3% decrease in HR_{max} with training. In another study, the researchers noted a lower HR_{max} accounting for 26-30% and 40% difference in cardiac output (Q) between trained and untrained respectively [68]. Other studies have noted lower HR_{max} values with active participants [55, 61]. The lower HR_{max} values for the active group in the current study may demonstrate an inhibition from the parasympathetic nervous system, a carry-over effect from HR_{rest} to HR_{max}. However, the physiological responses of the heart conduction system were not directly measured indicating that origins for such a response remain unknown.

The current study also noted a higher HR_{max} among males than females within the same age group. Ogawa et al. showed similar results between men and women within the same age group [68]. Other studies also showed no statistical differences between males and females [33, 39, 88]. It is difficult to ascertain the factors behind such differences between males and females as explanations could revolve around the differences in physiology. Such results may indicate

that differing MHREs are necessary to account for these differences. Yet, the current study did not examine correlational differences between sex and training status to account for such a factor and no equation out of the three studied was found to account for these differences.

5.2 ACCURACY OF THE PREDICTION EQUATIONS

The second purpose of the study was to determine the accuracy of three commonly used MHREs to determine gender or training affects the accuracy of the prediction. When the signed residuals were considered, only equation was found to affect the accuracy of the prediction equations. In addition, different results were yielded from the unsigned residuals to suggest that equation by gender and the equation by activity level interactions were also significant. Equation 2 had no impact within any of the significant interactions. For both signed and unsigned residuals, $HR_{max} = 208 - (0.7 \cdot age)$ (Equation 3) was shown to be the most overall accurate equation [Table 9a (signed) and 11a (unsigned)], which agrees with the results of Tanaka et al. (2001) despite data collection differences [88]. Moreover, in the unsigned residual analysis, two additional interactions were found to be significant: equation by activity level and equation by gender. For the equation by gender interaction, Equation 1 and Equation 3 were both suited for the males and females respectively. However, a difference of 1.02 beats $\cdot$ min^{-1} separated Equation 1 and Equation 3 for the males between the marginal means (Table 11b). For males and females alike, Equation 3 proved to be the best equation for those considered active, but Equation 1 was better for the sedentary sample. Again, the difference separating the sedentary group from Equation 1 and Equation 3 was a .08 beat $\cdot$ min^{-1} difference. Although the significance between these differences was not analyzed, analyzing such a minute difference (eight hundredths of a beat per

minute) remains unnecessary as there would likely be no significant difference. Therefore, Equation 1 is just as good as employing Equation 3. As a result, Equation 3 has also been shown to be reliable under sedentary conditions.

Analysis of signed residuals takes direction of error as well as size of error into account, that is whether predicted values of HR are greater than or less than observed values, on the average. If the average of the signs equates to zero, then there is an equal amount of error between over and under predictions. Yet, such results do not determine the degree of error by which the over and under predictions result (i.e. ±1, ±20, or ±40 beats $\cdot min^{-1}$). Equation 2 over predicted, on average, by 10.6 beats $\cdot$ min^{-1} (see Table 9a), indicating that this particular equation had more over predictions than under predictions or had excessively large over predictions and small under predictions. After examining Equation 3 (see Table 9a), on average, the equation under predicted by 1.09 beats $\cdot$ min^{-1}. Such a value much closer to zero indicates a more balanced scale of over and under predictions. However, examining signed residuals alone again does not indicate the severity by which the over and under predictions occur but rather demonstrates a consistency of over and under predicting.

Therefore, an analysis of unsigned residuals is necessary. Analysis of unsigned residuals ignores direction of error and considers only size of error. Size of error thus seems to be an important factor in determining the maximization of the benefits and reducing error. A value of zero within the unsigned residuals would indicate that the MHRE was off by 0 beats $\cdot min^{-1}$ thereby indicating an accurate MHRE with no error. Equation 2 was off, on average, by approximately 12 beats $\cdot$ min^{-1} whereas Equation 3 was off, on average, by approximately 7 beats $\cdot$ min^{-1} (see Table 11a).

Equation 3 is the more accurate equation under signed and unsigned residuals despite minute differences between Equation 1 with the marginal means within the unsigned residuals. For the unsigned measures, the overlapping of line segments found in Figures 5 & 6 demonstrate the close proximity in the size of error within gender and group levels. The slopes of the segments are also illustrated to indicate the total amount of change between the variables within the different levels.

The greater amount of weight given to the comparisons made between signed and unsigned residuals is dependent upon the difference of treatment of the client from the clinician. The rationale for using residuals as dependent variables is that since smaller residuals indicate more accurate prediction, the prediction equation that produced the smallest residuals, on the average, would be considered the "best". It was decided to analyze both signed and unsigned residuals because the two types of residuals provide different perspectives on accuracy of prediction.

5.3 DESCRIPTIVE STATISTICS

The variable "age" within the one-way ANOVA was determined to be insignificant across all variations within the study as purposely designed (see Table 5). The purpose of such a design was to eliminate age as an accountable factor for any results proven to be significant since age is the main component of the MHREs and the link between age and HR_{max} has already been proven and, therefore, unnecessary to demonstrate [77, 78, 87, 98]. The insignificance of age allows for a greater emphasis to be placed on a gender and training effect with regards to the use of certain MHREs. Additionally, the variables HR_{rest} and VO_{2max} were utilized to express the activity level

of the participants. Although there was insignificance between groups, the trend of HR_{rest} was lower among the active groups compared to their inactive counterparts (see Table 4b). VO_{2max} proved to be more significant across groups, revealing a higher level of aerobic fitness in the active group when compared to the sedentary (see Table 5). A bradycardiac response at rest [53] and a higher VO_{2max} [69, 84, 86] have been shown to be significantly different when comparing active to sedentary individuals.

5.4 COMPARISONS BETWEEN STUDIES

Tanaka et al. [88] performed a meta-analysis study between men and women and between sedentary, active, and endurance-trained participants, which had similar rates of decline when comparing HR_{max} and age (years). Furthermore, similar regression equations were found between sedentary ("no performance of any aerobic exercise"), active ("referring to occasional or irregular performance of aerobic exercise $\leq$ 2 times/week"), and endurance-trained ("referring to regular performance of vigorous endurance exercise $\geq$ 3 times/week for over one year") men and women. The study pooled data from both maximal cycle and treadmill ergometer protocols after no significance was found between the two groups. The meta-analysis portion involved 492 subject groups and 18,712 subjects for a combined regression equation of $HR_{max} = 208 - (0.7 \cdot age)$. Additionally, a laboratory-based study involving 514 subjects was engaged. The laboratory-based portion only involved a continuous incremental treadmill protocol and generated a combined equation of $HR_{max} = 209 - (0.7 \cdot age)$. Thus, an endorsement of $HR_{max} = 208 - (0.7 \cdot age)$, with the diminutive difference of 1 beat·min^{-1} and that between marginal means of the unsigned residuals with the gender by equation interaction indicate "virtually identical"

results and a gender neutral equation [88]. Although the current study found similar results between overall subject accuracy, gender, and activity level, the observed HR_{max} was placed into the three commonly employed MHREs for further validation by using different statistical procedures rather than allowing the results to dictate exactness of the produced MHRE equation. Moreover, the current study employed runners of the aerobically active group as opposed to cyclists or swimmers to avoid a testing effect. Tanaka et al. categorized endurance-trained individuals and avoided the specification as to the identity of the general exercise modality by each participant.

In 1982, Londeree et al. [57] studied 18,155 subjects also with a meta-analytic approach. Many regression equations emerged that considered such factors as nationality, ergometer type, fitness level, type of exercise protocol, and much more. Such factors were placed into the regression equations as constants and multiple variables (i.e. nationality, age, age^2, age^4, testing protocol, fitness level, etc…) reducing the simplicity of such equations. However, one of the more simple regression equations did emerge: $HR_{max} = 206.3 - (0.711 \cdot age)$. Unlike Tanaka et al. [88], Londeree et al. found that an increase in fitness level reduced HR_{max} with both sexes, which was a similar trend in the current study. The study also demonstrated an ergometer protocol effect with a higher HR_{max} on the treadmill than the cycle ergometer, which also disagrees with Tanaka et al. Such disagreements may be explained by enhanced technological systems and statistical analyses. Londeree et al. also noticed a testing effect with swimmers having a lower HR_{max} and rationalized this effect with the following statement: “The lower HR_{max} in water may be due to the reflex bradycardia with immersion in cool water”. Yet, such results indicate that cautionary methods employed in the current study helped to eliminate such factors as exercise protocol and exercise modality with the active group by limiting the exercise

type to only running. Londeree et al. also noticed sex as an insignificant factor, thereby agreeing with the current study under the results of the signed residuals.

Gellish et al. [33], in 2007 published a longitudinal study over a 25 year span that involved an average of approximately 7 Balke maximal treadmill protocol for each subject over their history with the fitness center of Oakland University. A total of 132 men and women participated in the study. Factors taken into account within the statistical models accounted for differences administration of the tests over the years, testing conditions (i.e. calibration of equipment, environmental setting, etc…), random effects (i.e. genetics and other variability), and much more. The initial test for each subject was tossed out to account for the learning curve. In this study, sex was not attributable to the prediction of HR_{max}. The equation generated from this study was $HR_{max} = 207 - (0.7 \cdot age)$. The results from this study are interesting as they bridge the gap between cross-sectional studies and longitudinal studies by affirming the accuracy of the results of Tanaka et al. [88] and Londeree et al. [57]. Such results remain important as it provides a thorough understanding of what occurs with exercise over time. Therefore, these results validate the results of other researchers that performed cross-sectional studies and discovered similar conclusions. These results are important for the current study as the sole basis of such a study was to determine the accuracy between MHREs that are well favored in the scientific community versus the MHREs that have been scientifically researched.

Robergs et al. [76] also found the equation $HR_{max} = 208.754 - (0.754 \cdot age)$, which is also similar to the previous studies mentioned and within the current study. Robergs et al. utilized 30 different regression equations, disregarding those equations influenced by cardiac diseases. The limitation of the current study, as previously mentioned, is the generalizability of the results. A small sample was used to validate three commonly employed MHREs. With the

exception of the two active groups, the other groups contained an uneven number of participants, thereby weakening the statistical power. Also, an insignificant age factor did produce benefits but limited application only college-aged students. The age variable in the current study also limited understanding across all age ranges. The results deferred $HR_{max} = 208 - (0.7 \cdot age)$ as the best equation across group and gender interactions and under equation alone. Therefore, MHREs such as $HR_{max} = 220 - age$ and $HR_{max} = 226 - age$ provide no scientific merit, which agrees with Robergs et al. [76] and Tanaka et al. [88].

5.5 TECHNICALITIES

5.5.1 Maximal Respiratory Exchange Ratio

Respiratory exchange ratio (RER) is a common variable measured to indicate maximal effort. RER is a ratio of the volume of carbon dioxide (CO_2) expired to the volume of oxygen (O_2) inspired and used by the muscles. One carbohydrate molecule (glucose) requires 6 O_2 molecules under aerobic conditions to generate 38 molecules of adenosine triphosphate (ATP) and 6 molecules of CO_2:

$$6\ O_2 + C_6H_{12}O_6 \rightarrow 6\ CO_2 + 6\ H_2O + 38\ ATP$$

During exercise, both fat and carbohydrates are used. At rest, more fat is utilized than carbohydrate and RER will range from .78 to .80. As intensity is increased during exercise, the muscle cells rely more heavily on carbohydrates. RER values will near 1.0 to indicate that 100% of carbohydrates are being used under aerobic conditions. As exercise increases further in intensity and nears maximal levels, lactate accumulates in the blood and to avoid further

acidification, more CO_2 is released from the blood to the lungs where it is expired. Therefore, an RER value over 1.0 would indicate such results [11, 97]. An RER range between 1.1 – 1.15 has been used in many studies to indicate a maximal effort [41, 54, 59, 87]. Therefore, maximal RER values between 1.4 - 1.6, and especially under submaximal conditions, are highly unlikely. Unfortunately, during the process of the study, technical difficulties arose with the gas analyzers and therefore a few participants went through the study with higher-than-normal maximal RERs. Such high values would have met data inclusion requirements and may have corresponded to an offset within the descriptive statistics. Outliers that rest within the RER variable data set are most likely associated to such an error.

5.5.2 Questionnaires

In 1996, the Surgeon General published a report on physical activity. One portion of the report concerned the lack of the measurements of the dimensions of intensity while other scientists placed higher emphasis elsewhere (i.e. frequency, duration, total caloric expenditure, etc…) [81]. In 1998, the International Consensus Group met in Geneva for the purpose of creating the IPAQ, which specifically measures intensity of exercise [5, 18]. Eight different forms of the IPAQ were validated on three levels across 14 centers in 12 different countries: 1) test-retest reliability (same forms of IPAQ measured two separate times), 2) concurrent validity (long and short forms measured the same day to determine accuracy), and 3) criterion validity (comparison between self-reported data and amount of actual physical activity performed). Both long and short forms of the IPAQ were found to produce reasonable measurement properties as other physical activity questionnaires, and have been modified to avoid superfluous data that may result in confusion of the participant [18]. The results have been met with praise [5] and criticism [37]. The IPAQ has

also been employed in other studies to determine its reliability [12], and for the determination of concurrent and criterion validation of newly formed questionnaires [60]. However, Craig et al. [18] noted the inability of subjects to differentiate between moderate and vigorous intensity levels of physical activity, which was of great concern in the current study.

Part 4 of the Long Last 7 Days Telephone Format form of the IPAQ was incorporated into the current study (see Appendix B). The IPAQ was not used for its original intention and was therefore modified to be utilized as an eligibility factor within the study. For example, only part 4 of the IPAQ was employed as all the other parts did not pertain to the study. Such modifications of the IPAQ were not previously studied to determine such effects with accuracy of self-reporting. Certain wordings and phrasing of part 4 of the IPAQ referencing other parts that were not employed were deleted to provide a greater comprehensibility to the subject. Changes within the numbering pattern occurred to avoid confusion on behalf of the investigator(s) interviewing the subject. Participants were instructed after the Phone Screening Participant Information form (see Appendix A) to answer the questions on the IPAQ only as their activities were regarded towards running. Such questioning was essential to prevent a testing effect by allowing only active runners to be considered active within the qualifications of the ACSM [1]. The Phone Screening Participant Information form created by the principal investigator, although not scientifically validated, was used to determine other types of physical activity and the frequency of such activity. Such methods may have resulted in the increase of uncertainty with the subjects when told “As you answer the questions on the International Physical Activity Questionnaire, please answer the questions only as they refer to running”, on the Phone Screening Participant Information form.

5.5.3 Subjects

Large samples always run the risk for greater number of outliers than smaller samples. Within the current study, 5.4% of the subjects performed the required testing but did not meet data inclusionary requirements (i.e. RER $\geq$ 1.1, etc…). Many other subjects had a desire to participate but never appeared for the physical testing component of the study. Two sedentary males expressed a $HR_{max} \geq 210$ beats $\cdot$ min^{-1}, while another active female expressed a low HR_{max} at 179 beats $\cdot$ min^{-1}. Such abnormal extremes from the rest of the group may be explained by genetics. However, as the study was limited to studying MHREs, the exact cause remains unknown. These outliers indicate that a common MHRE may not be the best solution for each individual and may even underpredict their HR_{max}.

5.6 FUTURE INVESTIGATION

A future investigation would include a greater sample with equal groups over a greater age range to achieve greater degrees of freedom within subjects to achieve greater statistical power. Statistical design would include a 4-way ANOVA with the added variable ergometer protocol (i.e. maximal treadmill and cycle ergometers) with sub protocol types examined such as a Balke (easy intensity), Bruce (moderate intensity), and Astrand (high intensity) for the maximal treadmill protocols. Such a study would involve more correspondence between the principal investigator and the participants for multiple visits to perform all tests. An additional regression analysis for each test (i.e. young active male on a Balke maximal treadmill protocol, old sedentary female on a maximal cycle ergometer, etc…) would give greater insight in the clinical

field with clients as to what MHRE would be best suited for the type of individual and on what protocol certain MHREs should be used for that specific individual. However, such a study would take more time and money allotted than for the current study.

APPENDIX A

PHONE-SCREENING PARTICIPANT INFORMATION

Read: Hello, thank you for calling to find out more about our research study. My name is _____ and I am a researcher at the University of Pittsburgh School of Education. The protocol of the study requires you to walk/run on a treadmill. The purpose of the study is to examine the effects of gender and training status on maximal heart rate prediction equations. Heart rate prediction equations are used to estimate maximal heart rate. This is necessary when we want to calculate percentages of maximal heart rate to determine a safe submaximal value at which the individual can exercise without first performing a maximal treadmill test.

If you decide that you want to participate in the study, you would be required to come into the Center for Exercise & Health Fitness Research in Trees Hall for a period of 45 minutes. We would begin the study by looking over the informed consent and will give you an opportunity to ask me any questions regarding the study. Once you are ready to begin the study, we will begin by placing a Polar Heart rate monitor across your chest. If you are uncomfortable with the assistance of the research staff, then you will be able to put it on by yourself, once you've received proper instruction on how to do so. Then we will hook you up to a machine that measures the volume of air that you inhale and exhale. You would be required to bite onto a mouthpiece, much like the mouthpiece of a snorkel, which is connected to a hose. The mouthpiece will not restrict any air movement. Headgear will hold the hose in place while you are running on the treadmill. A nose clip would be placed over your nose to prevent any airflow through the nose. Once we begin the study, we will give you five minutes to warm up on the treadmill, which will also help familiarize you to the treadmill if you are not used to running on one. After the five minute warm-up period, we will begin the test and you will continue the test until you cannot continue the test any further. More than one researcher will be there to assist you and prevent any injury from the treadmill. After completion of the test, you will cool down for a five-minute period. Do you think you might be interested in participating in the study?

{If No}: Thank you very much for calling.

{If Yes}: Before enrolling you into the study we need to determine if you are eligible. What I would like to do now is to ask you a series of questions about yourself. There is a possibility that

some of these questions may make you uncomfortable or distressed but are necessary to determine eligibility; if the questions make you uncomfortable, please let me know. You do not have to answer any questions if you don't want to. You also need to understand that all information that I receive from you by phone, including your name and any other identifying information, will be strictly confidential and will be kept in a locked file cabinet. The purpose of these questions is only to determine whether you are eligible for our study. The questions include being overweight, taking birth control, if you are pregnant, if you are too old or too young, and some medical information. Remember, your participation is voluntary; you do not have to complete these questions. If you are not eligible then your information will be destroyed. Do I have your permission to ask you these questions?

{If No}: Thank you very much for calling.

{If Yes}: If you are eligible, then we will set up an appointment for a 45-minute period and you will be required to abstain from caffeine or alcohol intake and abstain from exercise for 24 hours and also abstain from food intake 3 hours prior to testing. Furthermore, you will need to wear or bring athletic clothing and laced up athletic shoes for running. This portion of the phone screening process will take approximately 10 minutes, the entirety of the phone screen process will take between 20-25 minutes.

Date _____

Time _____ am or pm

Name of research staff _____

If the subject answers any of the questions below that make them ineligible, then please read the following statement: *"From the information that you have given me, you will not be eligible for the study at this time. Thank you for your time."*

1. What is your name?: _____

2. What is your sex?: Male Female

3. What is your age?: _____ years
(Must be between the ages of 18-25, if not then they cannot participate in the study)

4. How much do you weigh?: _____ lbs.

    a. How tall are you?: _____ ft. _____ inches

    b. Calculated BMI: _____ kg/m^2
    [18.5-24.9 (Normal), 25.0-29.9 (Overweight), 30.0-35.4 (OB1), 35.5-39.9 (OB2)] (If BMI is over 24.9 or less than 18.5, then they cannot participate in the study)

5. Are you currently pregnant?: Yes No
   (If subject answers "yes", then they cannot participate in the study)

6. Are you currently taking any pharmacological birth control?: Yes No
   *(If subject answers "yes"or "no", then they **can** participate in the study)*

7. Do you currently have any of the following conditions: Coronary artery disease, prior myocardial infarction, peripheral vascular disease, chronic obstructive pulmonary disease, diabetes type I or II, and/or any other physiological or psychological diseases that may prevent you from exercising?: Yes No
   (If the subject has any of the following conditions, then the subject is ineligible)

8. Are you currently taking any prescription medications for your heart, lungs, nervous system, and/or muscles?: Yes No
   (If subject answers "yes, then they cannot participate in the study)

9. Do you smoke?: Yes No
   (If subject answers "yes", then they cannot participate in the study)

10. Are you aerobically active?: Yes No
    a. If you are aerobically active, please list the types of aerobic activity and frequency that you do the activities within a week:
       _____
       _____
       _____
       _____

    b. Please list the activities that you have performed on a regular basis for the past six months:
       _____
       _____
       _____
       _____

       Read: As you answer the questions on the International Physical Activity Questionnaire, please answer the questions only as they refer to running. Also, please listen carefully to the definitions of terms, which will be important with how you answer the questions.

APPENDIX B

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE
(November, 2002)

LONG LAST 7 DAYS TELEPHONE FORMAT

Note: Only part 4, out of 5 parts, of the IPAQ was applicable to the investigator's thesis. Part 4's numbering scheme was changed and some information in the brackets following some of the questions was deleted as they were numbers that had no effect on the study. Partial portions of some of the questions were abolished as it did not pertain to the study but no questions were reworded.

PART 4: RECREATION, SPORT, AND LEISURE-TIME PHYSICAL ACTIVITY

READ: Now, think about all the physical activities that you did in the last 7 days solely for recreation, sport, exercise or leisure.

1. During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time **in your leisure time**?

_____ Days per week *[If respondent answers 0, skip to Question 3]*

a. Don't Know/Not Sure *[Skip to Question 3]*

b. Refused *[Skip to Question 3]*

[**Interviewer clarification**: Think about only the walking that you did for at least 10 minutes at a time.]

2. How much time did you usually spend on one of those days **walking** in your leisure time?

___ ___ Hours per day

___ ___ ___ Minutes per day

a. Don't Know/Not Sure

b. Refused

[**Interviewer clarification**: Think about only the walking that you did for at least 10 minutes at a time.]

[**Interviewer probe**: An average time per day is being sought. If the respondent can't answer because the pattern of time spent varies widely from day to day, ask: "What is the total amount of time you spent **over the last 7 days** walking in your leisure

time?"

___ ___ Hours per week

___ ___ ___ ___ Minutes per week

a. Don't Know/Not Sure

b. Refused

READ: Now think about other physical activities you did in your leisure time for at least 10 minutes at a time.

READ: First, think about *vigorous* activities which take hard physical effort that you did in your leisure time. Examples include aerobics, running, fast bicycling, or fast swimming.

[**Interviewer clarification**: Vigorous activities make you breathe much harder than normal.]

3. During the **last 7 days**, on how many days did you do **vigorous** physical activities **in your leisure time**?

_____ Days per week *[If respondent answers 0, skip to Question 5]*

a. Don't Know/Not Sure *[Skip to Question 5]*

b. Refused *[Skip to Question 5]*

[**Interviewer clarification**: Think about only those vigorous physical activities that you did for at least 10 minutes at a time.]

4. How much time did you usually spend on one of those days doing **vigorous** physical activities in your leisure time?

___ ___ Hours per day

___ ___ ___ Minutes per day

a. Don't Know/Not Sure

b. Refused

[**Interviewer clarification**: Think about only those physical activities that you did for at least 10 minutes at a time.]

[**Interviewer probe**: An average time per day is being sought. If the respondent can't answer because the pattern of time spent varies widely from day to day, ask: "What is the total amount of time you spent **over the last 7 days** doing vigorous physical activities in your leisure time?"

___ ___ Hours per week

___ ___ ___ ___ Minutes per week

a. Don't Know/Not Sure

b. Refused

READ: Now think about activities which take *moderate* physical effort that you did in your leisure time. Examples include bicycling at a regular pace, swimming at a regular pace, and doubles tennis. Again, include only those moderate activities that you did for at least 10 minutes at a time.

[**Interviewer clarification**: Moderate physical activities make you breathe somewhat harder than normal.]

5. During the **last 7 days**, on how many days did you do **moderate** physical activities **in your leisure time**?

_____ Days per week

a. Don't Know/Not Sure

b. Refused

[**Interviewer clarification**: Think about only those physical activities that you did for at least 10 minutes at a time.]

6. How much time did you usually spend on one of those days doing **moderate** physical activities in your leisure time?

___ ___ Hours per day

___ ___ ___ Minutes per day

a. Don't Know/Not Sure

b. Refused

[**Interviewer clarification**: Think about only those physical activities that you did for at least 10 minutes at a time.]

[**Interviewer probe**: An average time per day is being sought. If the respondent can't answer because the pattern of time spent varies widely from day to day, ask: "What is the total amount of time you spent **over the last 7 days** doing moderate physical activities in your leisure time?"

___ ___ Hours per week

___ ___ ___ ___ Minutes per week

a. Don't Know/Not Sure

b. Refused

APPENDIX C

INFORMED CONSENT

School of Education

Department of Health and Physical

Consent to Act as a Subject in a Research Study

TITLE: Validation of Maximal Heart Rate Regression Equations

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SOURCE OF SUPPORT: School of Education Student Research Award

Why is this research being done?

Maximal heart rates are used to determine a good intensity at which to exercise. The intensity is determined by calculating a certain percentage of the maximal heart rate. It is impossible to measure everyone's maximal heart rate by having them run until they reach their highest potential. We also cannot measure everyone's maximal heart rate because it would be time consuming, expensive, and dangerous to those who have certain medical issues. Therefore, we use equations to estimate, or predict, their highest heart rate.

Maximal heart rate prediction equations use age to determine what an individual's maximal heart rate should be, without having to go through the process of a maximal stress test. However, these equations can come with many errors. Therefore, the purpose of this study is to examine how gender differences and whether or not someone exercises affects maximal heart rate. In addition, we will also determine the accuracy of three commonly used equations to predict maximum heart rate:

- *Max heart rate = 220 - age*
- *Max heart rate = 226 – age*
- *Max heart rate = 208 – (.7 x age)*

Who is being asked to participate in the research study?

Sixty individuals between the ages of 18 and 25 are being asked to participate. Both males and females are eligible for participation. We are recruiting individuals with a Body Mass Index (BMI), which is commonly used to distinguish those with a healthy weight versus those with an unhealthy weight, between 18.5 and 24.9 kg/m^2. In addition, individuals that are classified as sedentary (engage in exercise less than 20 minutes per week for less than or equal to 3 days per week and walk less than 8000 steps per day over the course of one week, for a minimum period of 6 months) or active runners (running greater than or equal to 30 minutes per day for 5 days per week at moderate intensity, or greater than or equal to 20 minutes per day for 3 days per week at vigorous intensity, for a minimum period of 6 months) will be enrolled in this study.

What procedures will be performed for research purposes?

If you decide to take part in this research study, you will undergo the following procedures listed below:

Experimental Procedures:

Eligible subjects will report to the Center for Exercise & Health Fitness Research in Trees Hall at the campus of the University of Pittsburgh for testing. This visit will last approximately 45 minutes. After the experimental methods are explained to you, you will be asked to sign this informed consent and agree to participate in the study. You are encouraged to ask questions as they arise.

You will be asked to abstain from caffeine intake, alcohol intake, and vigorous exercise 24 hours and to abstain from food 3 hours prior to the test. You will also be asked to change into comfortable athletic clothing and laced-up athletic shoes. We will then measure height and body mass. The investigator will then assist you in positioning the Polar Heart Rate Monitor. If you are uncomfortable with the investigator's help, the investigator will instruct you in positioning of the monitor and you can put it on yourself. You will then be fitted with headgear and will place the mouthpiece of the valve into your mouth through which you will breathe, which is similar to a mouthpiece found on a snorkel. In addition, a nose clip will be placed over the nose to prevent you from breathing through your nose.

Bruce Treadmill Protocol:

You will begin the maximal stress with a 5 minute warm-up stage at a velocity with which you are comfortable, but does not cause your heart to beat more than 100 beats per minute. The warm-up stage will also serve as your familiarization period to the treadmill. The investigator will then set the treadmill to correct speed and percent incline to initiate the test. Each stage will last for a period of 3 minutes. After each stage, moderate increases of speed and incline will proceed until you can no longer continue due to extreme exhaustion and/or pain. You will not be allowed to hold onto the side rails of the treadmill while the test is in session. You will be asked to place your hands on the side rail of the treadmill when you can no longer continue due to extreme fatigue, pain, or breathlessness in order to stop the test. At this point, the investigator will stop the test. The investigator also has the right to stop the test at any point in time. Once the test is complete a 5-minute cool-down period will be required.

What are the qualifications of the research staff that will be assisting you during the test?

Research staff personnel are certified in CPR by the American Red Cross or the American Heart Association. In addition, the research staff has been rigorously trained in handling of the equipment and effectively carrying out the testing procedures, which will aid in minimizing the risk of injury.

What are the possible risks, side effects, and discomforts of this research study?

Abnormal responses, such as excessive rises in blood pressure, mental confusion, shortness of breath, chest pain, heart attack, and death, to maximal exercise tests in young healthy adults are rare, occurring in less than 1% of people (less than 1 out of 100 people tested). However, some common risks, occurring in 1% to 25% of people (1 to 25 out of 100 people tested), of maximal exercise testing include: Heavy breathing, dizziness, muscle fatigue, headache, and overall fatigue. To minimize risks associated with maximal exercise testing, you will be asked to complete a Physical Activity Readiness Questionnaire which asks questions about your current health status. If you have any orthopedic, cardiovascular, and/or metabolic problems that may be worsened by maximal exercise (e.g., coronary artery disease, prior

myocardial infarction, peripheral vascular disease, chronic obstructive pulmonary disease, and diabetes mellitus) you will be excluded from participation in this research. If you are a female, you will be asked if you are currently pregnant. If you are pregnant, you will be excluded from participation in this research study. Risks associated with study monitors (e.g. heart rate monitor, mouth piece, etc.) include redness, irritation, and chafing from any straps used to hold the items in place. Other risks include muscle soreness, joint pain, falling while the test is in session and difficulty staying on the treadmill caused by lack of familiarization, which may cause other injuries. To minimize these risks, two research staff will be present during the test as the protocol requires. If an abnormal response occurs during exercise, the test will be immediately stopped and you will be given proper medical attention. Emergency equipment will be on site for all testing procedures. If you have an abnormal response to the treadmill test, you will be told of the findings and will be encouraged to contact your primary care clinician.

What are the possible benefits from taking part in this study?

You may not derive personal benefit from this study, other than gaining knowledge about your maximum heart rate and aerobic capacity. The knowledge gained in this study will lead to a better understanding of how measured maximal heart rate relates to predicted maximal heart rate, as well as which equation best predicts maximal heart rate.

If I agree to take part in this research study, will I be told of any new risks that may be found during the course of the study?

You will be promptly notified if any new information develops during the conduct of this research study that may cause you to change your mind about continuing to participate.

Will my insurance provider or I be charged for the costs of any procedures performed as part of this research study?

Neither you nor your insurance provider will be charged for participation in this study.

Will I be paid if I take part in this research study?

You will be paid $15 for your participation in this study.

Who will pay if I am injured as a result of taking part in this study?

University of Pittsburgh investigators and their associates who provide services at UPMC recognize the importance of your voluntary participation in their research studies. These individuals and their staffs will make reasonable efforts to minimize, control, and treat any injuries that may arise as a result of this research. If you believe that you are injured as a result of the research procedures being performed, please contact immediately the Principal Investigator listed on the cover sheet of this form.

Emergency medical treatment for injuries solely and directly relating to your participation in this research will be provided to you by UPMC. It is possible that UPMC may bill your insurance provider for the costs of this emergency treatment, but none of these costs will be charged directly to you. If your research-related injury requires medical care beyond this emergency treatment, you will be responsible for the costs of this follow-up care unless otherwise stated below. There is no plan for monetary compensation. You do not, however, waive any legal rights by signing this form.

Who will know about my participation in this research study?

Any information about you obtained from this research will be kept as confidential (private) as possible. All records related to your involvement in this research study will be stored in a locked file cabinet. Your identity on these records will be indicated by a case number rather than by your name, and the information linking these numbers with your identity will be kept separate from the research records. Your research records will be maintained for at least 5 years following study completion, as per University policy. You will not be identified by name in any publication of research results unless you sign a separate form giving your permission (release).

Who will have access to identifiable information related to my participation in this research study?

In addition to the investigators listed on the first page of this authorization (consent) form and their research staff, the following individuals will or may have access to identifiable information related to your participation in this research study:

> Authorized representatives of the University of Pittsburgh Research Conduct and Compliance Office may review your identifiable research information for the purpose of monitoring the appropriate conduct of this research study.
>
> In unusual cases, the investigators may be required to release identifiable information related to your participation in this research study in response to an order from a court of law. If the investigators learn that you or someone with whom you are involved is in serious danger or potential harm, they will need to inform, as required by Pennsylvania law, the appropriate agencies.

Is my participation in this research study voluntary?

Your participation in this research study, to include the use and disclosure of your identifiable information for the purposes described above, is completely voluntary. (Note, however, that if you do not provide your consent for the use and disclosure of your identifiable information for the purposes described above, you will not be allowed, in general, to participate in the research study.) Whether or not you provide your consent for participation in this research study will have no effect on your current or future relationship with the University of Pittsburgh. Whether or not you provide your consent for participation in this research study will have no effect on your current or future medical care at a UPMC hospital or affiliated health care provider or your current or future relationship with a health care insurance provider.

May I withdraw, at a future date, my consent for participation in this research study?

You may withdraw, at any time, your consent for participation in this research study, to include the use and disclosure of your identifiable information for the purposes described above. (Note, however, that if you withdraw your consent for the use and disclosure of your identifiable information or the purposes described above, you will also be withdrawn, in general, from further participation in this research study.) Any identifiable research or medical information recorded for, or resulting from, your participation in this research study prior to the date that you formally withdrew your consent may continue to be used and disclosed by the investigators for the purposes described above.

If I agree to participate in this research study, can I be removed from the study without my consent?

You may be removed from this study in the event that you are unable to perform any of the tasks being analyzed in this study.

VOLUNTARY CONSENT

All of the above has been explained to me and all of my current questions have been answered. I understand that I am encouraged to ask questions about any aspect of this research study during the course of this study, and that such future questions will be answered by the researchers listed on the first page of this form.

Any questions I have about my rights as a research participant will be answered by the Human Subject Protection Advocate of the IRB Office, University of Pittsburgh (1-866-212-2668). By signing this form, I agree to participate in the research study. A copy of this consent form will be given to me.

_____
Participant's Name (Print)

_____ _____
Participant's Signature Date

CERTIFICATION OF INFORMED CONSENT

I certify that I have carefully explained the nature and purpose of this research study to the above named individual(s) and I have discussed the potential benefits and possible risks of study participation. Any questions the individual(s) have about this study have been answered, and we will always be available to address future questions as they arise. I further certify that no research component of this protocol was begun until after this consent form was signed.

_____ _____
Printed Name of Person Obtaining Consent Role in Research Study

_____ _____
Signature of Person Obtaining Consent Date

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