*Original Research*

# Validation of Maximal Heart Rate Prediction Equations Based on Sex and Physical Activity Status

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ABSTRACT

***International Journal of Exercise Science 8(4): 318-330, 2015.*** The purpose of the study was to determine if measured maximal heart rate ($HR_{max}$) was affected by sex or aerobic training status, and to determine the accuracy of three common clinical age-prediction maximal heart rate regression equations used to predict $HR_{max}$: $HR_{max} = 220 - age$, $HR_{max} = 226 - age$, and $HR_{max} = 208 - (0.7 \cdot age)$. Fifty-two participants in total, 30 of which were in the active group (15 M, 15 F) and 22 subjects in the sedentary group (9 M, 13 F), within the 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. The effect of sex and training status on $HR_{max}$ was analyzed through a two-way ANOVA, and the effect of sex, aerobic training status, and regression equation on accuracy of the $HR_{max}$ prediction was assessed with a three-way ANOVA ($\alpha$=0.05). Overall, males had a higher $HR_{max}$ than females (198.3 v. 190.4 beats • $min^{-1}$ , $p<.001$) and sedentary individuals had higher measured $HR_{max}$ than active individuals (197.3 v. 191.4 beats • $min^{-1}$, $p=.002$). Furthermore, $HR_{max} = 208 - (0.7 \cdot age)$*(equation 3)* calculated the smallest signed and unsigned residuals from the difference between observed $HR_{max}$ and predicted $HR_{max}$ values for the significant main effects of equation (3), equation x sex (females x 3), and equation x activity level (active x 3). Therefore, based on our results, we conclude that $HR_{max} = 208 - (0.7 \cdot age)$ has greater accuracy than the other two equations studied for predicting observed values of $HR_{max}$ in 18-25 year olds.

KEY WORDS: Maximal heart rate, maximal heart rate prediction equations, age, active, inactive, male, female

## INTRODUCTION

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 (21). Since a plateau-effect of SV occurs at a level > 50% $VO_{2max}$ (30), 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 $VO_{2max}$ (30, 31, 38, 42). Moreover, $HR_{max}$ decreases with increasing age (33, 34, 38, 42). Thus, $HR_{max}$ is indicative of cardiorespiratory function. However, we may not always be able to measure $HR_{max}$ or $VO2_{max}$ values **directly**, and rely upon $HR_{max}$

regression equations (MHREs) to estimate our $HR_{max}$.

Since the early work of Robinson on the effects of age on maximal heart rate ($HR_{max}$) (33), researchers have fashioned numerous linear MHREs based on age (7, 10, 11, 16, 23, 27, 29, 32). In 1971, Fox et al. published the 220-age MHRE (13, 32) yet no statistical analysis backed the equation. In 2002, Robergs et al. exposed the precise MHRE from a line of best fit, from which 220-age was derived by Fox et al. (13): 215.4 - 0.9147 x age (32). Today, it is a common practice of athletes and scientists alike to incorporate apocryphal MHREs in a generic manner that lacks scientific merit such as 220-age and 226-age (4, 32, 40).

Another common problem is the failure to utilize MHREs in accordance with the specifications from which they were derived. For example, generalizability of 220-age is lacking as it has been shown to over or under predict based on age (15, 39, 41), smoking (41), bodyweight (26, 41), and conditions such as mental retardation (12). Furthermore, empirical $HR_{max}$ values may (19) or may not (10, 15, 39) vary between sexes, may (19, 22, 27) or may not (10, 30, 38, 39) vary based on physical activity status, and may (24) or may not (39) vary based on testing protocol (i.e., treadmill stress test vs. cycle ergometer stress test), which may not always be taken into account when applying or creating MHREs to predicted $HR_{max}$.

In 2001, Tanaka et al. (39) reported a neutral MHRE with respect to sex, physical activity status, and testing protocol for which no differences could be seen: $HR_{max}$ = 208 - 0.7 x age. Other MHREs published by Londeree and Moeschberger (24) ($HR_{max}$ = 206 – 0.7x age) and Gellish et al. (9) ($HR_{max}$ = 207 – 0.7 x age) resemble the MHRE reported by Tanaka (39). Furthermore, Robergs and Landwehr (32), through regression analysis of 30 different MHREs, reported the MHRE of 208.754 – 0.734 x age, which is also similar to that of Tanaka et al. (39). Therefore, the research supporting 208 – 0.7 x age has been well established despite the many MHREs that exist within the scientific community. The current study focused on the ability of scientifically merited and unmerited MHREs to predict $HR_{max}$ based on sex and physical activity specifications.

The purpose of this study was twofold: 1) to determine the effects of sex and training status on measured $HR_{max}$ and 2) to determine the accuracy of three commonly used MHREs (e.g. 220 – age, 226 – age, and 208 – 0.7 x age) to predict $HR_{max}$ for females and males, aerobically active and sedentary. We hypothesized that sex would 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. Furthermore, we also hypothesized that there would not be a significant training effect on measured and estimated $HR_{max}$.

## Methods

*Participants*

All potential participants were screened for inclusion prior to testing. Specifically, the screening included questions from Part 4 of the International Physical Activity Questionnaire (IPAQ): Long Last 7 Days Telephone Format (8) as well as the Physical Activity Readiness Questionnaire (PAR-Q & YOU) (1). Inclusion criteria for the sedentary and active participants included the following: body mass index (BMI) between 18.5-24.9 (kg · $m^{-2}$), age of 18-25 years, and demonstration of a sedentary lifestyle through IPAQ or active running lifestyle. Exclusion criteria for any participants consisted of the following: answering "yes" to any of the questions on the PAR-Q & YOU questionnaire, diabetes, cancer, and/or any other disease that may have prevented them from exercising to maximal intensity, an eating disorder, abnormal menstrual cycle, currently pregnant, and the use of any medications that affected cardiac, neurological, musculoskeletal, or cognitive function.

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 <3 days · $week^{-1}$ and <8000 steps · $day^{-1}$ over the course of one week (6), for a minimum period of 6 months. Aerobically active included participants that were engaged in running > 30 min · $day^{-1}$ for 5 day ·$week^{-1}$ of moderate intensity, or > 20 min · $day^{-1}$ for 3 day · $week^{-1}$ of vigorous intensity (18), for a minimum period of 6 months. Moderate and vigorous intensity guidelines were established through the American College of Sports Medicine (ACSM) and defined as bouts of physical activity lasting longer than ten minutes [20]. Those that fell between the two classifications were considered recreationally active and were not included in the study. Subject demographics are detailed in Table 1.

*Protocol*

Data were collected in the Center for Exercise and Health Fitness Research at the University of Pittsburgh. Following the participant's arrival in the laboratory, experimental procedures were explained and the subject signed an Informed Consent approved by the Institutional Review Board of the University of Pittsburgh. All subjects abstained from alcohol consumption, caffeine, and vigorous exercise for 24 hours and from food intake 3 hours prior to testing. Subjects were instructed to wear comfortable exercise clothes and running shoes. Height, mass, and age were recorded for each subject. The subjects were then fitted with a strap-on Heart Rate Monitor (Polar Electro., Kenpele, Finland) and instructed to be seated for 5 minutes to establish resting HR ($HR_{rest}$). The mouthpiece, attached to a Rudolph Model 2700 two-way non-rebreathing respiratory valve (Rudolph, Model 2700, Kansas City, MO), was fitted comfortably within the subject's mouth to measure respiratory values through the Parvo Medics Truemax 2400 Respiratory Metabolic Analyzer (TrueMax 2400, Parvo Medics Inc., Sandy, UT). The subjects were then familiarized to the treadmill during a 5 minute warm-up period at a pace with which they were comfortable and did not allow their HR to be greater than 100 beats · $min^{1}$. During this time, they were also given proper instruction on how to prevent injury.

Subjects performed a standard Bruce maximal stress test (5) on a Trackmaster motor driven treadmill (Fullvision Inc., Model TMX425C, Newton, KS). The test was volitionally terminated by the subject due to exhaustion. Beginning at the third stage until completion, all subjects were given verbal statements of encouragement every 20-60 seconds (2).

HR was measured every 10-15 seconds during the exercise test with the HR monitor. HR was

**Table 1.** Demographic one-way ANOVA between groups, significance determined by Tukey HSD post hoc.

| | P | Act. Males n = 15 | Sed. Males n = 9 | Act. Females n = 15 | Sed. Females n = 13 |
|---|---|---|---|---|---|
| Age (yr) | 0.2 | 21.4 ± 1.7 | 21.8 ± 2.6 | 20.1 ± 2.3 | 20.9 ± 1.9 |
| Height (m) | 0 | 1.80 ± 0.060*,‡ | 1.77 ± 0.059*,‡ | 1.64 ± 0.048 | 1.61 ± 0.067 |
| Mass (kg) | 0 | 76 ± 6*,**,‡ | 67.1 ± 6.9*,‡ | 61.2 ± 6.1** | 54.7 ± 5.5 |
| BMI ($kg \cdot m^{-2}$) | 0.003 | 23.5 ± 1.8**,‡ | 21.4 ± 1.2 | 22.8 ± 1.8 | 21.2 ± 2 |

Values are mean ± SE.

* Significance for sex of same training group (male vs female), $P < 0.05$.

** Significance for training group of same sex (active vs sedentary), $P < 0.05$.

‡ Significance for opposing sex + opposing training group, $P < 0.05$.

also measured immediately post exercise to determine the highest HR value obtained. $HR_{max}$ was defined as the highest HR value attained. During that period of time, HR continued to be recorded until a decline was seen. $VO_2$ and RER measured by the Parvo Medic's computer software approximately every 15 seconds was averaged to 30 second values. The $VO_{2max}$ and RER values at the end of the test were recorded. To determine that the subjects achieved a maximal cardiorespiratory effort, the following was required: $VO_2 < 2.1$ ml $\cdot$ kg$^{-1}$ $\cdot$ min$^{-1}$ between stages indicative of a plateau and RER $\geq$ 1.1. The authors realize such liberally set values to determine a plateau in $VO_2$ and an RER may underestimate true maximal effects, but were deemed necessary for the sedentary group (20).

*Statistical Analysis*

Data analysis was performed in three stages: 1) descriptive statistics, 2) effect of sex and aerobic training status on measured $HR_{max}$, and 3) effect of sex, aerobic training status, and prediction equation on the prediction equation accuracy. 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, a series of single factor ANOVAs were performed to determine group differences between the following variables: age (yrs), height (m), mass (kg), BMI (kg $\cdot$ m$^{-2}$), total leisure walking time (min $\cdot$ week$^{-1}$), total moderate running time (min $\cdot$ week$^{-1}$), total vigorous running time (min $\cdot$ week$^{-1}$), $HR_{rest}$ (beats $\cdot$ min$^{-1}$), $HR_{max}$ (beats $\cdot$ min$^{-1}$), $VO_{2max}$ [(ml $\cdot$ kg$^{-1}$) $\cdot$ min$^{-1}$], and RER. The four groups included active males, sedentary males, active females, and sedentary females. Secondly, a two factor ANOVA (sex x aerobic training status) for measured $HR_{max}$ was performed. For our third aim, a three factor (sex 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 each statistical analysis was set at 0.05. Aerobic training status had two levels (active and sedentary). Prediction equation had three levels (220 - age, 226 - age, 208 - 0.7 x 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 $HR_{max}$)].

The residual for each participant would be divided by the standard error of prediction for each participant, yielding a signed or unsigned t-score, depending on whether the signed or unsigned residual was used. The sex x aerobic training status interaction was included in the model, as was the effects of the prediction equation, prediction equation x sex, prediction equation x aerobic training status, and prediction equation x sex x aerobic training status. If any interactions were significant, this indicated that the relative accuracy of the three prediction equations varied according to sex, aerobic training status, or the combination of sex and aerobic training status. Post hoc tests were done to follow significant interactions.

**RESULTS**

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 (see Table 2). 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 (P = .002) (see Table 2).

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

One-way ANOVA showed no statistical differences in age between the groups (see Table 1) but did demonstrate significant differences between the following variables: total walking (after square root transformation), vigorous running, $HR_{rest}$, $HR_{max}$, $VO_{2max}$, and RER (Table 2). Comparisons also revealed that active and sedentary males had a significantly higher $VO_{2max}$ than the females. Both active males and females demonstrated a larger $VO_{2max}$ than their sedentary counterparts signifying a difference between activity levels (see Table 2).

Two-way ANOVA found significance for sex and activity but not the sex by activity interaction (see Tables 3). Therefore, males had the higher HRmax regardless of activity level. In addition, sedentary participants had higher HRmax regardless of sex.

For the signed residuals, the males and sedentary participants for 'Sex' and 'Activity Level' respectively demonstrated the least

**Table 2.** Descriptive independent and dependent variables one-way ANOVA between groups, significance determined by Tukey HSD post hoc.

| | F | P | Act. Males n = 15 | Sed. Males n = 9 | Act. Females n = 15 | Sed. Females n = 13 |
|---|---|---|---|---|---|---|
| **Independent Variables** | | | | | | |
| Walking ($min \cdot wk^{-1}$)[1] | 5.7 | 0.002 | 339.5 ± 338.8‡ | 138.9 ± 117.3 | 409 ± 413.6** | 91.0 ± 80.1 |
| Moderate ($min \cdot wk^{-1}$) | 2.5 | 0.069 | 119.3 ± 178.0 | 17.8 ± 39.3 | 82.7 ± 121.7 | 11.5 ± 28.8 |
| Vigorous ($min \cdot wk^{-1}$) | 10.3 | 0 | 188 ± 171.5**,‡ | 0 ± 0‡ | 148 ± 101.3** | 3.5 ± 12.5 |
| **Dependent Variables** | | | | | | |
| $HR_{rest}$ ($beats \cdot min^{-1}$) | 5.9 | 0.002 | 70.5 ± 7.1** | 86.0 ± 10.0‡ | 72.3 ± 10.2 | 76.7 ± 9.6 |
| $HR_{max}$ ($beats \cdot min^{-1}$) | 8.6 | 0 | 194.5 ± 5.8** | 202.1 ± 8.3*,‡ | 188.3 ± 6.2 | 192.5 ± 6.5 |
| $VO_{2max}$ [$(ml \cdot kg^{-1}) \cdot min^{-1}$] | 26.9 | 0 | 55.6 ± 8.14*,**,‡ | 42.6 ± 4.19* | 41.6 ± 6.54** | 34.6 ± 4.81 |
| RER | 4.3 | 0.009 | 1.16 ± 0.05‡ | 1.25 ± 0.08 | 1.20 ± 0.05 | 1.26 ± 0.12 |

Values are mean ± SE.

[1] Significance is based on square root transformation

* Significance for sex of same training group (male vs female), $P < 0.05$.

** Significance for training group of same sex (active vs sedentary), $P < 0.05$.

‡ Significance for opposing sex + opposing training group, $P < 0.05$.

**Table 3.** Differences in measure $HR_{max}$ between sex and activity using two-way ANOVA.

| SEX* | | ACTIVITY LEVEL** | |
|---|---|---|---|
| **Male n = 24** | **Female n = 28** | **Active n = 30** | **Sedentary n = 22** |
| 198.3 ± 1.4 | 190.4 ± 1.2 | 191.4 ± 1.2 | 197.3 ± 1.4 |

Values are mean ± SE.
* Significant main effect for sex, $P < .05$.
** Significant main effect for activity level, $P < 0.05$.

amount of variability with predictions when averaged over all three MHREs (see Table 4). Furthermore, under 'Equation' $HR_{max} = 208 - (0.7 \cdot age)$ (Equation 3) under predicted by 1.09 beats $\cdot$ $min^{-1}$ whereas the other two equations over predicted by a greater margin (Table 4) when averaging all subjects' data thereby disregarding sex and activity level.

## DISCUSSION

For 'Sex' males had the least amount of total error when averaged across the three MHREs. When averaging all subjects' data and disregarding sex and activity level, equation 3 had the least total error (Table 4). However, once sex was taken into account (see Table 4 – 'Equation x Sex' interaction), Equation 1 and 3 had the least total error for the males and females respectively. When activity level was taken into account (see Table 4 – 'Equation x Activity Level' interaction), Equation 3 was the most accurate for the active subjects. Interestingly, for the sedentary group, both Equation 1 and 3 seemed to have the same amount of accuracy in predicting observed

**Table 4.** Signed and unsigned raw residuals using three-way ANOVA, P-values are based on Huynh-Feldt adjustment.

| | | SIGNED | F | P | UNSIGNED | F | P |
|---|---|---|---|---|---|---|---|
| **Sex*,**** | Male | -0.3 ± 1.4 | 22.2 | 0 | 7.6 ± 0.9 | 4.45 | 0.04 |
| | Female | -9.1 ± 1.3 | | | 10.3 ± 0.8 | | |
| **Activity Level*** | Active (Act.) | -7.9 ± 1.2 | 11.9 | 0.001 | 9.4 ± 0.8 | 0.49 | 0.49 |
| | Sedentary (Sed.) | -1.5 ± 1.4 | | | 8.5 ± 1.0 | | |
| **Equation*,**** | 220 - age (1) | -4.6 ± 1.0 | 1.3E4 | 0 | 8.0 ± 0.8 | 30.1 | 0 |
| | 226 - age (2) | -10.6 ± 1.0 | | | 12.0 ± 0.8 | | |
| | 208 - (0.7 · age) (3) | 1.1 ± 0.9 | | | 6.8 ± 0.6 | | |
| **Sex x Activity Level** | Act. Male | -4.3 ± 1.7 | 0.64 | 0.43 | 6.6 ± 1.1 | 5.16 | 0.03 |
| | Sed. Male | 3.7 ± 2.2 | | | 8.6 ± 1.5 | | |
| | Act. Female | -11.6 ± 1.7 | | | 12.1 ± 1.1 | | |
| | Sed. Female | -6.6 ± 1.8 | | | 8.4 ± 1.2 | | |
| **Equation x Sex**** | Male x 1 | -0.1 ± 1.4 | 3.14 | 0.08 | 6.5 ± 1.1 | 14.8 | 0 |
| | Male x 2 | -6.1 ± 1.4 | | | 8.9 ± 1.2 | | |
| | Male x 3 | 5.4 ± 1.4 | | | 7.5 ± 1.0 | | |
| | Female x 1 | -9.1 ± 1.3 | | | 9.6 ± 1.0 | | |
| | Female x 2 | -15.1 ± 1.3 | | | 15.1 ± 1.1 | | |
| | Female x 3 | -3.2 ± 1.2 | | | 6.2 ± 0.9 | | |
| **Equation x Activity Level**** | Act. x 1 | -7.9 ± 1.2 | 0.95 | 0.34 | 8.4 ± 1.0 | 8.2 | 0.003 |
| | Act. x 2 | -13.9 ± 1.2 | | | 13.9 ± 1.1 | | |
| | Act. x 3 | -2.1 ± 1.2 | | | 5.9 ± 0.8 | | |
| | Sed. x 1 | -1.3 ± 1.5 | | | 7.7 ± 1.2 | | |
| | Sed. x 2 | -7.3 ± 1.5 | | | 10.1 ± 1.3 | | |
| | Sed. x 3 | 4.3 ± 1.4 | | | 7.8 ± 1.0 | | |
| **Equation x Sex x Activity Level** | Act. Male x 1 | -4.1 ± 1.7 | 0.12 | 0.75 | 5.1 ± 1.4 | 1.9 | 0.17 |
| | Act. Male x 2 | -10.1 ± 1.7 | | | 10.1 ± 1.5 | | |
| | Act. Male x 3 | 1.5 ± 1.7 | | | 4.7 ± 1.2 | | |
| | Sed. Male x 1 | 3.9 ± 2.2 | | | 7.9 ± 1.8 | | |
| | Sed. Male x 2 | -2.1 ± 2.2 | | | 7.7 ± 2.0 | | |
| | Sed. Male x 3 | 9.4 ± 2.2 | | | 10.3 ± 1.5 | | |
| | Act. Female x 1 | -11.6 ± 1.7 | | | 11.7 ± 1.4 | | |
| | Act. Female x 2 | -17.6 ± 1.7 | | | 17.6 ± 1.5 | | |
| | Act. Female x 3 | -5.6 ± 1.7 | | | 5.1 ± 1.4 | | |
| | Sed. Female x 1 | -6.5 ± 1.9 | | | 10.1 ± 1.5 | | |
| | Sed. Female x 2 | -12.5 ± 1.9 | | | 4.7 ± 1.2 | | |
| | Sed. Female x 3 | -0.8 ± 1.8 | | | 7.9 ± 1.8 | | |

Values are mean ± SE.

* Significant main effect for signed raw residuals, P < 0.05.

** Significant main effect for unsigned raw residuals, P < 0.05.

$HR_{max}$. Tukey post hoc tests indicated significance between Equations 1 and 2 for males and between all pairs of equations for females. Likewise, a significant difference was found between Equations 1 and 2 for sedentary and between all pairs of equations for active.

The specific aims of the study were to determine whether there was an effect of sex and/or training status with observed $HR_{max}$ and if there was a significant difference between three popular MHREs versus observed $HR_{max}$ when sex and training status were taken into account.

For the first purpose of the study, activity level and sex affected $HR_{max}$ independently from one another. Though the physiological responses of the heart were not directly measured in the current study, lower $HR_{max}$ values were demonstrated in active participants suggesting a training effect in our sample. However, such data are controversial as Spina et al. demonstrated a decrease in $HR_{max}$ as a direct result of training (37), others noted lower $HR_{max}$ values with active participants (22, 25), and some have shown no effect in $HR_{max}$ between either active or sedentary participant (10, 30, 38, 39). Likewise, a significantly higher $HR_{max}$ is seen in males, indicating a sex effect, which is also conflicting. Hermansen and Andersen (19), suggest sedentary females have highest $HR_{max}$, based on averages, not significance, while more studies claim no significance (10, 15, 39).

Lester et al. (22) utilized cross-sectional data to show an indirect relationship with age for both aerobically active and sedentary males having identical slopes but different intercepts. Such results demonstrate the sedentary to be at a greater disadvantage in regard to a greater blunted $HR_{max}$ with increasing age in opposition to the aerobically active. The results of the current study have been recorded while controlling for age. Within our study, only speculation could account for the $HR_{max}$ response that led to significance within the aerobically active subjects such as increased parasympathetic response (9), reduced baroreflex sensitivity due to decreased baroreceptor density (36), increase in left ventricular wall thickness (16), increase in peak filling rates of blood into the heart (23), increased stroke volume (28), among other parameters not measured. A decrease in $HR_{max}$ as a result of training is inconsistent among athletes (9) and, therefore, such significance may be the result of randomly aerobically active subjects fitting such a profile.

Literature may suggest a carry-over effect from $HR_{rest}$ to $HR_{max}$, thereby establishing cause for lower $HR_{max}$ seen among physically active. However, Whaley et al. (41) implied a lower $HR_{rest}$ relating to a lower $HR_{max}$ from three studies whose data never supports such a conclusion (3, 17, 35). Though $HR_{rest}$ may have been measured among such studies the resting values were never reported among sedentary and active females (3) or active males (17), nor emphasized, though measured, among healthy sedentary females (35). Grimby and Saltin (17) did note a stark contrast in $HR_{max}$ (203 and 148 beats/min) between two males of near similar $VO_{2max}$ (l/min) and blood volume (l/min) and corresponding submaximal HR values at the same workload (155 and 120 beats/min respectively). A training effect cannot explain such results as all the males that took part in the study were considered to be aerobically active.

Nevertheless the concept of a carry-over effect from $HR_{rest}$ to $HR_{max}$ is a concept not to be ruled out even though not significantly validated in the present study. The significance observed in the active vs. sedentary and male vs. female groups independently, does not remain significant when broken down into dependent groups (i.e. active females, inactive females, active males and inactive males)(Table 3). An additional observance to a carry-over effect might lay in trending patterns. In other words, the lowest mean $HR_{max}$ was demonstrated in the active female sample, but the $HR_{rest}$ was lowest in the active male sample. Therefore, a lower $HR_{rest}$ does not correspond to a lower $HR_{max}$ in this study (Table 3).

The second purpose of the study was to determine the accuracy of three commonly employed MHREs to determine sex and/or training effects. Overall, the equation $HR_{max} = 208 - (0.7 \cdot \text{age})$ (equation 3) rendered the most accuracy utilizing these two separate measures for college-age participants. When considering signed residuals a negative mean value specifies the ability of the equation, on average, to over predict, a positive value under predicts, and a value of zero represents perfect accuracy of the MHRE to predict the observed. Signed residuals take direction of error as well as size of error into account. Therefore, when sex and activity level groups were combined under the "equation" effect, equation 3 produced the slightest amount of error representing the more accurate equation over the sample as a whole (see Table 4). A value of zero with the signed residuals indicates the same degree of over and under predictions.

Because signed residuals do not measure the severity by which the over and under predicting of MHREs occurs, the analysis of unsigned residuals is necessary. Using unsigned residuals ignores direction of error and considers only size of error. Therefore, the closer to zero, the more accurate the MHRE. Under the "equation", "equation by sex", and "equation x activity level" effects, equation 3 remains closest to zero. Despite $HR_{max} = 220 - \text{age}$ (equation 1) being lower under the "equation x sex" (for males) and "equation x activity level" (for sedentary) effects, the mean differences demonstrated between equation 1 and 3 is 1.02 and .08 beats $\cdot$ $min^{-1}$ respectively. It may be argued that small differences seen between the two equations are unlikely to make for significant differences. Combining the effects we would suspect that equation 1 is of better use for the sedentary males, but when examining the non-significant trends of "equation x sex x activity level" effect, we see $HR_{max} = 226 - \text{age}$ (equation 2) is associated with the least error which is highly inconsistent. Yet, if we combined the "equation x sex" and "equation x activity level" active females, sedentary females, and active males the non-significant trends of "equation x sex x activity level" follow through as equation 3 having the least error for signed and unsigned residuals alike (see Table 4). In conclusion, we may derive from the data that equation 3 is the better equation to use with the possible exception of sedentary males for college-age participants.

In comparison to other studies, our findings are amenable with the work of others. The foundation for equation 3 is strong (15, 24, 32, 39). The results of Tanaka et al. (39) from which equation 3 was derived, demonstrated the equation to be unbiased toward sex and physical activity level with regard to meta-analysis and a laboratory-based portion. In a longitudinal study, Gellish et al. (15) also concluded that sex was not significant factor in predicting $HR_{max}$ while finding similar MHRE to that of equation 3. Since both sexes and physical activity levels of the current investigation favor equation 3, our data validate the results of other studies concluding that 220 - age and 226 – age lacks scientific merit for general use with our sample.

Multiple variables may have impacted the study in a manner unknown to the researchers. The link between age and $HR_{max}$ has been demonstrated (33, 38), and the small age range of the subjects in this study (see Table 1) allowed for greater emphasis to be placed on sex and training effects. Differences in treadmill protocol alone (i.e. Balke vs Bruce) may elicit differing MHREs (14), but would have no bearing on the current study as only one protocol was utilized. We could not assess the effect of BMI on $HR_{max}$ and the accuracy of the MHRE. The current study was also limited in the number of tests performed on each subject. Gellish and colleagues (15) excluded initial tests due to lower $HR_{max}$ associated with a learning curve, but remains unknown as to how it has affected the current study.

While it is understood that a young healthy cohort may not be conducive toward examining cardiorespiratory health, our research allows a greater emphasis to be placed on gender and activity level with regard to the use of certain MHREs. Hopefully, such research would allow others to contemplate the use of proper MHREs in any given setting. Future research may focus on experiments involving the impact of exercise protocol to predict $HR_{max}$ for active and sedentary men and women. The small sample size is also a limiting factor as it gives us smaller statistical power. In addition, understanding the impact of a learning curve and how this may affect observational scores of $HR_{max}$ when compared to predicted values is of great value. Finally, future research should incorporate higher standards in determining $VO_{2max}$ and RER and also utilize additional measurements such as ratings of perceived exertion, blood lactate, and/or estimated $HR_{max}$ (20, 39).

In conclusion, we found the males and sedentary groups to have higher observed maximal heart rates. Furthermore, $HR_{max} = 208 - (0.7 \cdot age)$ equation overall had the most accuracy when measuring observed $HR_{max}$, with the possible exception of males and sedentary groups. Such findings validate the use of the equation in the healthy young college-aged population regardless of sex or training status.

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## CONFLICT-OF-INTEREST STATEMENT

No author has any financial or personal relationship with other people or organizations that could inappropriately influence their work.

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