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Maximal Heart Rate Prediction in Adults that are Overweight or Obese

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Abstract

An accurate predictor of maximal heart rate (MHR) is necessary to prescribe safe and effective exercise in those considered overweight and obese when actual measurement of MHR is unavailable or contraindicated. To date, accuracy of MHR prediction equations in individuals that are overweight or obese has not been well established. The purpose of this study was to examine the accuracy of three equations for predicting MHR in adults that are overweight or obese. One-hundred seventy three sedentary adults that were overweight or obese enrolled in weight loss study and performed a VO₂peak treadmill test prior to the start of the weight loss treatment. A total of 132 of the 173 participants met conditions for achieving maximal exercise testing criteria and were included in this study. MHR values determined from VO₂peak treadmill tests were compared across gender, age and weight status to the following prediction equations: 1) $220 - \text{age}$, 2) $208 - 0.7 \times \text{age}$, and 3) $200 - 0.48 \times \text{age}$. Among 20-40 year old participants, actual MHR averaged 180 ± 9 beats per minute (BPM) and was overestimated ($p < 0.001$) at 186 ± 5 BPM with the $220 - \text{age}$ equation. Weight status did not affect predictive accuracy of any of the three equations. For all participants, the equation, $200 - 0.48 \times \text{age}$ estimated MHR to be 178 ± 4 BPM, which was greater than the actual (175 ± 12 , $p = 0.005$). Prediction equations showed close agreement to actual MHR, with $208 - 0.7 \times \text{age}$ being the most accurate.

Keywords

obesity; exercise prescription; exercise testing; accuracy; equations

INTRODUCTION

According to the latest NHANES data, over 60% of adults in the United States are classified as overweight (Body Mass Index (BMI) $> 25\text{kg/m}^2$), while fully 30% now meet the criteria for obese (BMI $> 30\text{kg/m}^2$) (6). Considering individuals that are obese are more likely to remain inactive (3), there is a need to develop programs to prevent weight gain, which also

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lead to long-term weight loss (8). Consideration of the appropriate intensity, amount and type of exercise is important in a population whose principle objectives are long-term weight loss and maintenance.

Typically, exercise intensity is prescribed by using a training heart rate (THR), determined by taking a percentage of the maximal heart rate (MHR) of an individual. The Karvonen formula is commonly used to prescribe exercise, where $THR = [(MHR - \text{Resting Heart Rate}) \times .60 \text{ to } .80] + \text{Resting Heart Rate}$ (12). Therefore, an accurate prediction of MHR is needed in order to clearly define exercise prescriptions that ensure safety while eliciting desired training effects. When maximal exercise testing is not available or is contraindicated, health care professionals most often rely on the age-predicted equation, $220 - \text{age}$, to predict MHR without regard for the gender of the individual, or the presence of overweight or obesity. Tanaka and colleagues (14) found the age-predicted equation to significantly underestimate MHR in healthy, non-medicated adults above the age of 40 years. Using regression analysis on data from a large sample of men and women, they reported that $208 - 0.7 \times \text{age}$ was a more accurate predictor of MHR (14). To our knowledge, Miller et al. (12) were the first to describe the relationship between MHR and age in adults that are obese. Based on results of a study by Miller and colleagues, $220 - \text{age}$ can be used to predict MHR in individuals of normal weight, but the authors propose that health care professionals use $200 - 0.48 \times \text{age}$ for predicting MHR in participants considered to be obese.

Further study is required to validate the accuracy of these new equations before they can replace $220 - \text{age}$ as part of the common protocol for exercise prescriptions designed for obese adults. Accordingly, the purpose of the present investigation was to compare the accuracy of the Tanaka et al. (14), Miller et al. (12) and $220 - \text{age}$ equations for predicting MHR in a group of men and women with a wide age range considered sedentary and overweight or obese.

METHODS

Experimental Approach to the Problem

The traditional $220 - \text{age}$ MHR equation is commonly used by trainers and therapists to prescribe aerobic exercise intensity ranges for individuals that are overweight or obese, yet limited information exists on the accuracy of the equation for this population. Previous researchers have advocated that MHR equations derived from adults that are obese (12) and individuals of a wide age range (14) be used to predict MHR. However, no studies exist examining the accuracy of these formulated equations and the traditional $220 - \text{age}$ equation when evaluated in a wide range of gender, age and weight subgroups. Therefore, in a sample of individuals that are overweight or obese, an investigation was constructed to test the accuracy of the $220 - \text{age}$ MHR equation and the two derived MHR equations against MHR values from $VO_{2\text{peak}}$ treadmill tests. To carry out this experiment, the accuracy of the three MHR prediction equations in a large sample and subgroup samples (gender, BMI range, and age range) were examined as independent variables and compared to actual MHR, which was set as the dependent variable.

Subjects

One hundred seventy three healthy men ($n = 29$) and women ($n = 144$) who were overweight and obese were recruited to participate in a 16-week weight loss intervention. All participants were screened to determine that they were: 1) 15 to 50 pounds over ideal body weight (11), 2) not involved in regular exercise (performing < 2 programmed bouts of aerobic exercise per week) and 3) not meeting ACSM/CDC physical activity

recommendations (performing ≤ 30 minutes of accumulated moderate intensity activity on most days a week) (13).

A medical physical exam, blood pressure screening and fasting blood draw was performed on each participant. Individuals were excluded if they had the following: uncontrolled blood pressure (systolic ≥ 160 mm HG and/or diastolic ≥ 90 mm Hg using automated Dinamap MPS Select blood pressure cuff; Johnson and Johnson, New Brunswick, NJ), undiagnosed type II diabetes (fasting plasma glucose ≥ 126 mg/dL using Beckman Glucose Analyzer II, Beckman Corp., Pittsburgh, PA), diagnosed coronary heart disease, angina, metabolic, pulmonary, or orthopedic condition that would affect ability to achieve maximal exertion during exercise testing. Subjects taking pharmacologic agents affecting MHR such as beta blockers ($n = 10$) and calcium channel blockers ($n = 7$) were excluded due to their potential influence on MHR. Furthermore, two female participants were discovered to have fasting glucose levels above 126 mg/dL, bringing total participants performing MHR testing to one hundred fifty-four. This sample ranged in age from 20 to 60 and had a BMI of 30.5 ± 3.1 (Mean $\pm$ SD). The investigation was approved by the Institutional Review Board at Johns Hopkins Bayview Medical Center and written informed consent was obtained from each subject prior to participation.

Procedures

Weight was measured on a Detecto medical electronic scale (Webb City, MO) without shoes in normal clothing, and height was measured without shoes using a wall stadiometer. BMI was calculated as weight (kilograms) divided by height (meters) squared.

MHR was determined using a modified Balke protocol on a treadmill integrated with Sensormedics Vmax229 metabolic and ECG system (Sensormedics, Inc., Yorba Linda, CA). The protocol began at 3 mph, 0% grade, and grade increased by 2.5% every 3 minutes until volitional fatigue was reached. Beyond 12 minutes, the treadmill speed increased to 3.5 mph and the grade increased 2.5% each minute thereafter. Heart rates were continuously monitored with electrocardiography. The Rating of Perceived Exertion (RPE) using the Borg 6 to 20 scale was obtained during each exercise stage (4). MHR was defined as the highest value recorded during the test. To ensure that each participant achieved maximal exertion during the treadmill test, two of the following three criteria were met by each participant: 1) a respiratory exchange ratio (RER) of at least 1.1; 2) a rating of perceived exertion of at least 17 on the Borg scale, and 3) a respiratory rate > 35 breaths per minute. Eight individuals did not exceed an RER of 1.1 and did not report a value > 17 on the RPE scale or respiratory rate > 35 breaths per minute. Four individuals did not meet any criteria for maximal exertion on the treadmill. Subsequently, twelve individuals were excluded from the analysis. An additional ten individuals were excluded because they did not have a BMI ≥ 25 kg/m². The demographic and maximal exercise variables of the remaining individuals ($n = 132$) are presented in Table 1. There is often concern that individuals who are overweight or obese do not push themselves to their true maximal effort. As a result, we compared baseline maximal heart rates to the maximal heart rate measured upon completion of the 16-week weight loss intervention. Of those that completed the 16-week weight loss intervention ($n = 109$), there was no significant difference between the maximal heart rates for the individuals, suggesting similar efforts at both time points.

Prediction of Maximal Heart Rate

The following MHR prediction equations were compared against actual maximal heart rate response on the treadmill.

- 1) $220 - \text{age}$

2) Tanaka et al. (14); $208 - 0.7 \times \text{age}$

3) Miller et al. (12); $200 - 0.48 \times \text{age}$

Statistical Analyses

Repeated measures ANOVA was used to compare mean MHR measured during a graded exercise treadmill test and the mean MHR predicted by the equations highlighted above. Bland-Altman analyses (2) were done to examine the accuracy and variability of the MHR prediction equations. The observed differences for each equation were plotted against the mean of both values to allow us to investigate any possible relationship between the measurement error and the true value. Bland and Altman note that, it would be a mistake to plot the difference against either value separately because the difference will be related to each, a well-known statistical artifact (2). Statistical significance was set at $p \leq 0.05$. Analyses were conducted using SPSS version 11.5 (SPSS, Chicago, IL).

RESULTS

MHR values obtained on a symptom limited graded exercise test were compared to estimates from MHR prediction equations. Additionally, comparisons were made between men and women, across age categories and BMI categories. These data are displayed in Table 2.

Both $220 - \text{age}$ and the Tanaka et al. (14) equation, $(208 - 0.7 \times \text{age})$ accurately predicted MHR obtained on a graded exercise test in our sample population of men and women that were overweight and obese. In contrast, the Miller et al. (12) equation, $(200 - 0.48 \times \text{age})$ over predicted the actual MHR of the sample (178 ± 4 vs. 175 ± 12), ($p = 0.005$). Repeated measures ANOVA revealed no significant effect for gender or any gender by equation interactions in any of the equations tested.

To examine the relationship between weight status and accuracy of the prediction equations, we placed participants into weight categories according to WHO guidelines (16): overweight (BMI = 25-29.9 kg/m²), obese I (BMI = 30-34.9 kg/m²), and obese II (BMI = 35-40 kg/m²). No differences were observed across weight categories for $220 - \text{age}$ and $208 - 0.7 \times \text{age}$. In contrast, $200 - 0.48 \times \text{age}$, over-predicted actual heart rate for overweight (178 ± 4 vs. 176 ± 12), obese I (178 ± 4 vs. 173 ± 10) and obese II (178 ± 4 vs. 177 ± 16), (all p values < 0.014), but no differences were observed across weight category groups.

Because MHR is largely predicted by age, we divided our sample into three age categories (20-40 years, 41-50 years and 51-60 years) and compared actual MHR to the predicted MHR. Once again, $208 - 0.7 \times \text{age}$ accurately predicted MHR across all age categories. While $220 - \text{age}$ accurately predicted MHR in the 41-50 years and 51-60 years categories, it significantly over-predicted MHR in the 20-40 years age category, (186 ± 4 vs. 180 ± 9), ($p = 0.02$). Similarly, $200 - 0.48 \times \text{age}$ significantly over-predicted actual MHR for 20-40 years (183 ± 2 vs. 180 ± 9), 41-50 years (178 ± 1 vs. 177 ± 12), and 51-60 years (174 ± 1 vs. 169 ± 11), (All p values < 0.001). No between group differences were observed using the $200 - 0.48 \times \text{age}$ equation.

Plots based on the graphical techniques suggested by Bland and Altman (2) were constructed to compare actual MHR and MHR estimates obtained using each of the three prediction equations (Figure 1.). The difference, or “bias”, between actual and predicted MHR (Actual – Predicted) is plotted against the mean of the actual and predicted MHR. The mean bias for the $220 - \text{age}$ equation (panel 1) was 0.8 beats per minute (BPM), but ranged from - 29 to 27 BPM. Similarly, the mean bias for the $208 - 0.7 \times \text{age}$ equation (panel 2)

was 0.6 BPM, but ranged from -29 to 26 BPM. Last, the mean bias for the $200 - 0.48 \times \text{age}$ equation (panel 3) was 2.7 BPM, but ranged from -31 to 24 BPM. Pearson correlation coefficients computed between the bias and the mean of the actual and predicted MHR values were $r = 0.37$ ($220 - \text{age}$), $r = 0.65$ ($208 - 0.7 \times \text{age}$) and $r = 0.82$ ($200 - 0.48 \times \text{age}$). All correlation coefficients were statistically significant (all p values < 0.001).

DISCUSSION

The present study confirms the equation $208 - 0.7 \times \text{age}$, reported by Tanaka and colleagues (14), is an accurate predictor of MHR in men and women aged 20 to 60 years that were sedentary and overweight or obese. Thus, health care practitioners may choose to employ this new equation in order to help guide exercise prescriptions for this clinical population, in which compliance to a weight loss program is of utmost importance. The equation has already been suggested for use in the general population (15).

While the traditional equation, $220 - \text{age}$, provided accurate predictions of MHR in the older adults, it was not as precise in individuals younger than 40 years. Our data replicate those of Tanaka et al. (14), which show that $220 - \text{age}$ was most accurate when predicting heart rate for individuals between 40 and 50 years of age. However, Tanaka et al. also reported that on average, the equation over-predicted heart rate in young adults. This may be of importance since a position stand on effective weight loss strategies suggests that a sufficient amount of moderate-intensity (55-69% of MHR) exercise can be beneficial for management of body weight (7), while limited evidence supports the need for more vigorous exercise intensities (7). In fact, higher intensities may be perceived by the obese individuals as too painful or uncomfortable and may ultimately lead to program drop out (8). By using the $220 - \text{age}$ equation, the health care provider may inadvertently prescribe exercise intensity that is too intense for an adult that is younger and overweight or obese, ultimately leading to the unfavorable outcomes described above.

Upon reviewing the literature, we discovered a weight specific equation, $200 - 0.48 \times \text{age}$, developed by Miller and colleagues (12) to predict MHR in individuals that are obese, defined as $> 30\%$ body fat. Contrary to the findings of Miller et al. (12), we did not find this equation to accurately predict MHR for individuals of any age considered to be overweight or obese. Tanaka and colleagues found that the rate of decline in MHR was not associated with either gender or physical activity status and is primarily due to age alone (14), which they attribute to a reduction in intrinsic heart rate with age (14). In addition, our results suggest that the degree of overweight does not have a significant effect on MHR. Consequently, use of a weight specific equation to predict MHR in this clinical population does not appear to be necessary.

The Tanaka et al. equation (14) performed the best in terms of predicting mean MHR values for men and women, young and old and overweight and obese. In fact, graphical representation using plots of Bland and Altman reveal that the mean MHR values produced by all three equations were fairly close to the actual MHR values across the entire sample, thereby demonstrating their utility as part of an exercise prescription for this clinical population. However, the plots also illustrate the limits of agreement between the actual and predicted MHR values were broad for each equation.

Attaining an accurate MHR is of important clinical relevance for prescribing an exercise prescription in sedentary adults that are overweight or obese. Regardless of weight status, exercise prescriptions for these individuals are designed to optimize both training response and safety. Identifying an accurate percentage of MHR improves the chance of optimizing fitness for individuals that are obese, which could possibly have implications for

improvements in exercise adherence (5). Furthermore, improvements in the accuracy of obtaining MHR will provide better estimations of upper limits of the THR zone. Accurate estimations of percentage of MHR can also serve as an important indicator to track fitness improvements in overweight and obese individuals, whereby clinicians can evaluate improvements in fitness over time when these individuals are able to exercise at a lower percentage of MHR for fixed exercise workloads (1).

We acknowledge that this study does have limitations. First, our modest number of men participating in this study may limit the ability to detect small differences between genders. Nonetheless, there is a paucity of information regarding weight management in men since they often do not seek treatment, and therefore felt it was clinically important to include men in the analysis of our data. Additionally, we acknowledge that previous researchers have suggested that the type of treadmill testing protocol could potentially affect overall evaluation of MHR (10). Lastly, previous studies investigating MHR prediction equations (12,14) focused solely on the application of these equations on obese samples, while our sample contained subjects that were overweight and obese. Given the increasing prevalence of adults that are both overweight and obese in the United States and the inherent risk of individuals that are overweight to become obese, we felt investigation of individuals that are both overweight and obese warranted attention. Clinically, this may be especially important considering that a recent study (9) revealed that in a sample of women that were overweight and obese, the likelihood of women who were overweight (89%) to engage in exercise as a weight loss strategy was greater than their obese counterparts (81%). Hence, indicating that individuals who are overweight may use formalized exercise as a preventative measure to reduce the chance of becoming obese and consequently this population deserves investigation.

In summary, our findings indicate that differences in actual MHR and estimates of MHR from prediction equations are minimal. However, the limits of agreement between actual MHR and predicted values can be quite broad among individuals. While the traditional $220 - \text{age}$ equation tended to overestimate MHR in individuals between 20 and 40 years of age, the $208 - 0.7 \times \text{age}$ equation was accurate across all gender, age and weight status groups that were investigated.

PRACTICAL APPLICATIONS

Exercise programming is well regarded as a principle component of a comprehensive treatment for short and long term weight loss (7). The challenge facing health care practitioners is to design an exercise prescription which is both efficacious (i.e., of adequate intensity to facilitate weight loss) and safe (i.e., limits the risk of orthopedic injury or adverse cardiac event). An additional concern is to avoid prescribing an intensity of training which may increase the likelihood of discontinuing the weight loss program. When working with clients that are overweight or obese, practitioners often establish training heart rate intensities for aerobic exercise based on MHR. However, several barriers may preclude practitioners from establishing the MHR of individuals via peak aerobic capacity, including lack of resources, lack of medical supervision or contraindications to maximal exercise testing. Therefore, several MHR prediction equations have been proposed to accurately estimate MHR in individuals that are overweight or obese. The results of this study indicate that the Tanaka et al. (14) MHR prediction equation ($208 - 0.7 \times \text{age}$) was the best predictor of the actual MHR achieved during a maximal exercise stress test in this cohort. Importantly, this was found independent of gender, age or severity of overweight/obesity. Based on these findings, it is recommended that the Tanaka et al. equation (14) be used to establish MHR in individuals who are overweight or obese for the purpose of prescribing an aerobic exercise program, which is both safe and effective.

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Figure 1.

Observed differences between the actual maximal heart rate from peak VO_2 treadmill testing and predicted maximal heart rate for each of the three equations tested in this investigation were plotted against the mean value of the actual and predicted maximal heart rate (actual + predicted / 2) to evaluate any possible relationship between the measurement error and the true value. The “mean” labels on the right side of the figure indicate the mean of the difference (bias) plus or minus two standard deviations as previously described by Altman and Bland (2). The layout of the three panels are as follows: 220 – age (panel 1); 208 – 0.7 × age (panel 2), Tanaka et al, 2001; and 200 – 0.48 × age (panel 3), Miller et al, 1993.

Table 1

Descriptive characteristics and maximal exercise data of overweight and obese participants who performed peak treadmill testing prior to undergoing weight loss treatment.

Characteristic	Participants (<i>n</i> = 132)
Age (yr)	46 ± 0.70
Height (cm)	166.5 ± 0.70
Weight (kg)	85.4 ± 1.02
% Female	80%
Body Mass Index (kg/m ²)	30.7 ± 0.24
Peak VO ₂ (l.min ⁻¹)	2.08 ± 0.06
Peak RPE	18.2 ± 0.12
Peak RR	40.8 ± 0.55
Peak RER	1.12 ± 0.006

Data are presented as mean ± *SEM*.

RPE = Rating of Perceived Exertion, RR = Respiratory Rate,

RER = Respiratory Exchange Ratio

Table 2

Comparisons between gender, weight and age subgroups for actual maximal heart rate obtained from peak VO_2 treadmill testing and maximal heart rate produced from the three prediction equations tested in this investigation.

Participants	n	Actual	220 - Age	Tanaka et al.	Miller et al.
All	132	175 ± 12	176 ± 8	176 ± 6	178 ± 4*
Men	26	177 ± 13	175 ± 8	175 ± 6	177 ± 4*
Women	106	175 ± 12	176 ± 8	176 ± 6	178 ± 4*
Weight Category [†]					
Overweight	58	176 ± 12	176 ± 9	176 ± 6	178 ± 4*
Obese I	63	174 ± 10	176 ± 8	176 ± 5	178 ± 4*
Obese II	11	177 ± 16	175 ± 8	176 ± 5	178 ± 3*
Age Category					
20-40 Yrs	35	180 ± 9	186 ± 5*	183 ± 3	183 ± 2*
41-50 Yrs	51	176 ± 12	176 ± 3	176 ± 2	178 ± 1*
51-60 Yrs	46	169 ± 11	167 ± 3	170 ± 2	174 ± 1*

Data are presented as mean ± SD.

* Different from actual, $p < 0.05$.

[†] According to WHO guidelines; Overweight, BMI 25-29.9 kg/m², Obesity I, BMI 30-34.9 kg/m², Obesity II BMI 35-39.9 kg/m².