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PREDICTING MAXIMAL HEART RATE USING AGE, RESTING HEART RATE, AND WEIGHT

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ABSTRACT

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Purpose: The purpose of this study was to develop an accurate, yet concise, maximal heart rate (HR_{max}) prediction equation with a standard error of less than ± 7 beats per minute using the prediction variables of age, weight, and resting heart rate. **Methods:** Data was gathered from 262 previously completed VO_2 max tests from apparently healthy men and women (women $N=121$, men $N=141$; mean $\pm SD$, age 29.8 ± 11.1 , weight 80.7 ± 30.5 , resting heart rate 71.3 ± 10.2). The subjects performed specific elliptical cross-trainer, cycle ergometer, and treadmill VO_2 max protocols according to gender and aerobic activity participation. **Results:** The analyses yielded four separate HR_{max} prediction equations. The multiple regression equation developed from the overall data was significant ($p < 0.05$), $R^2 (.702)$ and SEE (10.3 bpm). The resulting equation was $226.067 - |(Wt^* - 0.112) + (age^* - 0.625) + (RHR^* - 0.194)|$. The multiple regression equation developed from the data from the treadmill tests was significant ($p < 0.05$), $R^2 (.575)$ and SEE (11.9 bpm). The resulting equation was $214.203 - |(age^* - 0.765) + (Wt^* - 0.093)|$. The multiple regression equation developed from the data from the cycle ergometer tests was significant ($p < 0.05$), $R^2 (.465)$ and SEE (6.6 bpm). The resulting equation was $248.195 - |(RHR^* - 0.794) + (age^* - 0.230)|$. The multiple regression equation developed from the data from elliptical cross-trainer tests was significant ($p < 0.05$), $R^2 (.224)$ and SEE (7.8 bpm). The resulting equation was $180.632 - |(age^* - 0.531) + (RHR^* - 0.247)|$. **Conclusion:** Although the HR_{max} prediction equation “220-age” is commonly used, it is not accurate and not well researched. Our findings suggest that using age, weight, and resting heart rate as prediction variables, improved HR_{max} prediction equations result. Future research is required to develop multiple regression equations that improve the accuracy of HR_{max} prediction through specific population and demographic data.

Key Words: Cardiovascular function, Fitness, Exercise prescription, Estimation, Error, Oxygen consumption.

INTRODUCTION

The American College of Sports Medicine (ACSM) recommends an exercise intensity of 40-85% heart rate reserve (HRR) or 55-90% HR_{max} for training intensities for the improvement in

cardiorespiratory fitness (1). Cardiorespiratory fitness, measured by VO_2 max, is one of the most important components of fitness and is the most important predictor of longevity (1). Both HRR and HR_{max} percentage intensity methods for exercise prescription rely on maximal heart rate, either tested directly through a graded exercise test, or predicted through generalized equations. The use of predicted HR_{max} is more commonly used because of the convenience; however less accuracy is the drawback to this approach.

An accurate predicted HR_{max} is a vital component to any exercise prescription (1). The ACSM suggests the use of the equation “220-age” to predict HR_{max} , however there is no published record of research for this equation (1). The concept of “220-age” originated in 1971 from a linear best-fit to a series of raw and mean data which was based on observation (5). This commonly used formula is often presented in textbooks without sufficient explanation or citation to original research (2,3,4,5). It was found that several commonly used exercise physiology texts acknowledge that this equation can be off by 12-20 beats per minute, although a wide discrepancy exists concerning the actual variance in beats per minute (3,4,5,6). Although this prediction equation is commonly used, it is not well researched and fails to provide evidence of accuracy.

A complex review on predicted HR_{max} by Robergs and Landwehr summarized that the standard error is 7-10 bpm using multiple prediction equations (5). One example of a previously researched HR_{max} prediction equation is Inbar’s equation $205.8-0.865*\text{age}$. This equation has a standard error of estimate of ± 6.4 bpm. The prediction variables of height, weight, leisure time activity, place of residency, and smoking were used to formulate the equation (2). Whaley et al also performed research and formulated a HR_{max} prediction equation of $214-0.8*\text{age}$ for men, and $209-0.7*\text{age}$ for women. The standard error of estimate for this prediction equation is ± 10.7 bpm for men, and ± 10.5 bpm for women. The predictors in formulating this equation were age, resting heart rate, body weight, and smoking status (7).

Without an accurate maximal heart rate prediction, exercise prescriptions could potentially be inaccurate and optimal benefits would not be obtained. For example, a sedentary younger individual may have a predicted HR_{max} greater than their actual HR_{max} , which could lead to overtraining or a dangerous situation. The purpose of the present study was to formulate a new prediction equation for HR_{max} using data collected from 262 VO_2 max tests. It was hypothesized that age, body weight, and resting heart rate as variables in the equation would best correlate to formulating a more accurate and convenient HR_{max} prediction equation.

METHODS

Experimental Approach to the Problem

Although there are several prediction equations for HR_{max} , there is no accurately researched equation with a standard error of less than ± 7 bpm. In this study, our goal was to develop a concise yet accurate prediction equation for maximal heart rate. We obtained previously documented data from subjects used in the study of “Development of a Submaximal Test to Predict Elliptical Cross-Trainer VO_2 Max” by Dalleck et al. (5).

Subjects

Data was gathered from 262 previously completed VO_2 max tests from apparently healthy men and women (women $N=121$, men $N=141$; mean \pm SD, age 29.8 ± 11.1 , weight 80.7 ± 30.5 , resting heart rate 71.3 ± 10.2). The subjects performed specific elliptical cross-trainer, cycle ergometer, and treadmill VO_2 max protocols according to gender and aerobic activity participation.

The subjects from study (5) were apparently healthy men and women ($N=48$) recruited from the faculty and student population of the university as well as the surrounding community. These

subjects signed an informed consent and completed a health history questionnaire before participating in the study. The university's Institutional Review Board approved this study.

Instruments

Instruments used included: stadiometer, Lange caliper (Cambridge Scientific Industries, Columbia, MD), Precor EFX 546 Elliptical Fitness Cross-trainer (Precor Inc., Woodinville, WA), metronome, nose clip (Hans Rudolph Inc., Kansas City, MO), three-way valve mouthpiece (Hans Rudolph Inc., Kansas City, MO), fast-response turbine flow transducer (K.L. Engineering Model S-430, Van Nuys, CA), custom-developed software with AEI oxygen and carbon dioxide electronic gas analyzers (Model S-3A and Model CD-3H; AEI Technologies, Pittsburgh, PA), junction box via computer with a data-acquisition card (National Instruments, Austin, TX), and ECG (Quinton 4000; Quinton, Seattle, WA).

Procedures

The subjects were instructed to refrain from eating 4 hours prior to testing. They were also instructed to avoid any strenuous exercise 12 hours prior to the study. Their weight was measured to the nearest 0.1 kg, and height taken to the nearest 0.5 cm. Skinfold measurements were measured to the nearest ± 0.5 mm. All measurements were taken on the right side of the body with 3 standardized anatomical sites for men and women. The measurements were performed until 2 measurements were taken that were within 10% of one other.

VO₂ max Test

A specific elliptical cross-trainer VO₂ max protocol was selected according to gender and aerobic activity participation: trained (aerobic exercise 3-5 h/wk) and recreationally active (aerobic exercise 2-3 h/wk). Each test began with subjects resting for 5 minutes while resting physiological data was collected. Resting expired gases were measured for 2 minutes, followed by a 2-minute warm-up at a light workload before the start of the exercise protocol. An incremental protocol was used in which the workload increased in cadence or resistance each minute, which incline remaining at level 6 during the entire test. A metronome was used to ensure a consistent and correct cadence. The criterion for termination of the exercise test was failure of the subject to maintain within 20 strides per minute of target cadence on the elliptical cross-trainer or volitional fatigue. After maximal exercise tests, each subject exercised at a self-selected intensity until HR recovered to less than 120 b/min. The criteria for attainment of VO₂ max consisted of 2 of 3 of the following: a) a plateau ($\Delta\text{VO}_2 \leq 150 \text{ ml} \cdot \text{min}^{-1}$) in VO₂ with increases in workload, (b) maximal respiratory exchange ratio (RER) ≥ 1.1 , and (c) maximal HR within 15 b/min of the age-predicted maximum ($220 - \text{age}$).

Each subject wore a nose clip and 3-way valve mouthpiece (Hans Rudolph Inc., Kansas City, MO) so that gas exchange data could be recorded and analyzed. During the exercise test, VO₂, VCO₂, expire volume per unit time, and RER were measured breath-by-breath with a fast-response turbine flow transducer (K.L. Engineering Model S-430, Van Nuys, CA) and by custom-developed software with AEI oxygen and carbon dioxide electronic gas analyzers (Model S-3A and Model CD-3H; AEI Technologies, Pittsburgh, PA). Raw signals were acquired through a junction box via computer and integrated with a data-acquisition card (National Instruments, Austin, TX). Heart rate and electrocardiogram (ECG) readings were monitored continuously (Quinton 4000; Quinton, Seattle, WA) by using a 3-lead ECG configuration. Standard VO₂ max test protocols were used for treadmill and cycle ergometer tests.

Statistical analyses

All analyses for the original study were performed by using the Statistical Package for the Social Sciences, Version 14.0 (SPSS Inc., Chicago, IL). Multiple regression analyses were used to develop an equation for estimating HR_{max}. Standard error of the estimate (SEE) was calculated to determine

the accuracy of estimated vs. measured HR_{max} . The probability of making a type I error was set at $p \leq 0.05$ for all statistical analyses.

RESULTS

The multiple regression equation developed from the overall data was significant ($p < 0.05$), $R^2 (.702)$ and SEE (10.3 bpm). The resulting equation was $226.067 - |(Wt^* - 0.112) + (age^* - 0.625) + (RHR^* - 0.194)|$.

The multiple regression equation developed from the data from the treadmill tests was significant ($p < 0.05$), $R^2 (.575)$ and SEE (11.9 bpm). The resulting equation was $214.203 - |(age^* - 0.765) + (Wt^* - 0.093)|$.

The multiple regression equation developed from the data from the cycle ergometer tests was significant ($p < 0.05$), $R^2 (.465)$ and SEE (6.6 bpm). The resulting equation was $248.195 - |(RHR^* - 0.794) + (age^* - 0.230)|$.

The multiple regression equation developed from the data from elliptical cross trainer tests was significant ($p < 0.05$), $R^2 (.224)$ and SEE (7.8 bpm). The resulting equation was $180.632 - |(age^* - 0.531) + (RHR^* 0.247)|$.

Table 1. Descriptive data of subjects.

Group	N	Age (years)	Weight (kg)	Resting Heart Rate (RHR)	Heart Rate Max (HR_{max})
Overall	262	29.8 ± 11.1	80.7 ± 30.5	71.3 ± 10.2	184.5 ± 14.5
Treadmill	125	31.3 ± 14.1	87.4 ± 40.7	71.5 ± 10.6	182.0 ± 18.3
Cycle Ergometer	88	27.2 ± 6.3	74.8 ± 14.1	67.2 ± 7.4	188.6 ± 9.0
Elliptical Cross-Trainer	47	30.6 ± 7.8	74.3 ± 14.2	78.1 ± 10.2	183.6 ± 9.1

DISCUSSION

Although there are many HR_{max} prediction equations, including the most commonly used “220-age,” more research is needed to validate these prediction equations. Without an accurate maximal heart rate prediction, exercise prescriptions could potentially be inaccurate and optimal benefits would not be obtained. The purpose of this study was to formulate a new prediction equation for HR_{max} using data collected from 262 VO_2 max tests. The data was collected using three different modes: a treadmill, cycle ergometer, and elliptical cross trainer. The variables that were obtained from these tests were age, height, weight, body composition, resting heart rate, VO_2 max and HR_{max} . When first starting to analyze the data, all three modes were looked at together to formulate a more general HR_{max} prediction equation. By using SPSS version 14.0 to analyze all of the collected data, it was determined that the most significant variables were age, weight, and resting heart rate. All three variables are easily obtained both the general population and trained professionals. The prediction equation “220-age” has a reported SEE of 12-20 bpm (3), but there is a wide discrepancy concerning the actual variance in beats per minute. In using all three variables in the prediction equation formulated in this study, the equation has a SEE of 10.3 bpm, which is more accurate than the “220-age” prediction equation. After looking at the overall equation, an analysis of the three different modes separately seemed appropriate in an effort to obtain a more accurate prediction equation specific to each mode.

In formulating each individual prediction equation, resting heart rate and age were significant in both the cycle ergometer and elliptical cross trainer. For the treadmill, resting heart rate was not significant, but weight and age were significant. The significance of weight in the overall and treadmill equations may be due to the fact that a relative workload is incorporated, whereas a lesser percent of

relative body weight is moved on an elliptical machine, and workload on a cycle ergometer is absolute. When using the treadmill for a VO_2 max test, weight becomes a substantial factor to consider when formulating a prediction equation because of the relative workload influence.

The calculated SEE's for the cycle ergometer at 6.6 bpm, the elliptical cross-trainer at 7.8, for all modes at 10.3, and the treadmill at 11.9 fall below the SEE for "220-age" and appear to be rather accurate in terms of convenience of needed data. The prediction equations generated by Whaley et al are only slightly more accurate than the all-modes prediction equation with an SEE of 10.5 for women and 10.7 for men, respectively (7). However, these equations require more data and have a larger SEE than the mode-specific prediction equations proposed for the current study. Similarly, the prediction equation generated by Inbar et al has a reported SEE of 6.4 (2), but this also requires more data. Most importantly, all four prediction equations generated by the current study have significantly lower SEE's than the most popular "220-age" prediction equation.

It should be noted that the data used for this study was gathered by other researchers, therefore a large assumption concerning the validity of the data has been made. Calibration of the equipment, correct VO_2 max test procedures, appropriate protocols used for all individuals, subject adherence to pre-test guidelines, and a maximal effort given by subjects have also been assumed. Another delimitation to consider is the 18-45 age-range used for the study; certainly individuals who fall outside of this range also need to have an estimate of their HR_{max} for multiple reasons. Smoking status and training status of the individuals used for the studies was not recorded, which have large impacts on aerobic capacity and HR_{max} , and may warrant alternative prediction equations.

CONCLUSIONS

The main outcome of this investigation was the development of more accurate HR_{max} prediction equations for men and women ages 18 to 45. Such developments are then applicable in sports performance and training intensity, medical stress tests, and exercise program design. Further research is necessary to determine the inclusion of weight in a prediction equation for the treadmill versus other modes of exercise during a VO_2 max test. Additionally, the formation of prediction equations with known training and smoking statuses will serve a larger population. Lastly, such a study with additional demographic information including ethnicity and family history for genetic factors in prediction equations may result in greater accuracy.

The practical application of the current study may also be best represented through specific examples of potential under- and over-estimation of HR_{max} using "220-age" when determining exercise intensity. Both examples use Karvonen's method of heart rate reserve (HRR).

A 20-yr-old individual with a measured HR_{max} of 184 and a RHR of 78 would be following an intensity of 133-151 bpm at 45-60% HRR using "220-age." With the known measured HR_{max} , the individual should actually be exercising at an intensity of 126-142 bpm (45-60% HRR). The use of "220-age" in this example illustrates potential danger and over-exertion through over-estimation of HR_{max} .

Finally, a 27-yr-old individual with a measured HR_{max} of 205 and a RHR of 56 would be following an intensity of 159-172 bpm at 75-85% HRR using "220-age." With the known measured HR_{max} , the individual should actually be exercising at an intensity of 168-183 bpm (75-85% HRR). The use of "220-age" in this example illustrates potential insufficiency and under-training through under-estimation of HR_{max} .

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