Published in final edited form as:
Am J Hum Biol. 2013 ; 25(5): 695–701. doi:10.1002/ajhb.22431.

Measured Maximal Heart Rates Compared to Commonly Used Age-Based Prediction Equations in the Heritage Family Study

M.A. SARZYNSKI[1,*], **T. RANKINEN**[1], **C.P. EARNEST**[2], **A.S. LEON**[3], **D.C. RAO**[4], **J.S. SKINNER**[5], and **C. BOUCHARD**[1]

[1]Human Genomics Laboratory, Pennington Biomedical Research Center, Baton Rouge, Louisiana 70808

[2]Sport, Health and Exercise Science, Department of Health, University of Bath, Bath BA2 7AY, United Kingdom

[3]School of Kinesiology, University of Minnesota, Minneapolis, Minnesota 55455

[4]Division of Biostatistics, Washington University School of Medicine, St. Louis, Missouri 63110

[5]Professor Emeritus of Kinesiology, Indiana University, Bloomington, Indiana 47405

Abstract

Objective—The purpose of this study was to examine how well two commonly used age-based prediction equations for maximal heart rate (HR_{max}) estimate the actual HR_{max} measured in Black and White adults from the HERITAGE Family Study.

Methods—A total of 762 sedentary subjects (39% Black, 57% Females) from HERITAGE were included. HR_{max} was measured during maximal exercise tests using cycle ergometers. Age-based HR_{max} was predicted using the Fox (220-age) and Tanaka (208 – 0.7 × age) formulas.

Results—The standard error of estimate (SEE) of predicted HR_{max} was 12.4 and 11.4 bpm for the Fox and Tanaka formulas, respectively, indicating a wide-spread of measured-HR_{max} values are compared to their age-predicted values. The SEE (shown as Fox/Tanaka) was higher in Blacks (14.4/13.1 bpm) and Males (12.6/11.7 bpm) compared to Whites (11.0/10.2 bpm) and Females (12.3/11.2 bpm) for both formulas. The SEE was higher in subjects above the BMI median (12.8/11.9 bpm) and below the fitness median (13.4/12.4 bpm) when compared to those below the BMI median (12.2/11.0 bpm) and above the fitness median (11.4/10.3) for both formulas.

Conclusion—Our findings show that based on the SEE, the prevailing age-based estimated HR_{max} equations do not precisely predict an individual's measured-HR_{max}.

Maximal heart rate (HR_{max}) is commonly used in exercise physiology and clinical practice for preventive and diagnostic purposes. For example, HR_{max} is used to develop exercise prescriptions, estimate aerobic fitness levels, and is often a criterion for achieving maximal exertion in the determination of maximal aerobic capacity (Physical Activity Guidelines Advisory Committee, 2008; Thompson, 2010). Since a direct measurement of HR_{max} is not always feasible, researchers, clinicians, fitness instructors, and exercise practitioners often employ age-based prediction equations to calculate HR_{max}. The most widely used age-based HR_{max} prediction equation is the formula generated by Fox et al. (1971) of HR_{max} = 220-age. The Fox et al. formula is known to be quite variable, with a standard error of estimate

*Correspondence to: Mark A. Sarzynski, Human Genomics Laboratory, Pennington Biomedical Research Center, 6400 Perkins Road Baton Rouge, LA 70808-4124, USA. mark.sarzynski@pbrc.edu.

(SEE) of predicted HR_{max} of 7–12 beats per minute (bpm) (Robergs and Landwehr, 2002; Thompson, 2010). Several other age-based HR_{max} prediction equations have emerged from laboratory studies and are summarized by Robergs and Landwehr (2002).

In 2001, Tanaka et al. performed a meta-analysis of 351 studies involving 18,712 subjects, including objective criteria for maximal exertion, along with cross-validation in a laboratory study of 514 subjects. From this data, the authors derived the following formula to predict HR_{max}: 208 – 0.7 × age, which was the same for both men and women, and had a SEE of ~10 bpm (Tanaka et al., 2001). Currently, the Tanaka equation is becoming widely used, either alone or in combination with the Fox equation (220-age), to predict HR_{max} in clinical studies.

There is large inter-individual variation in HR_{max} values across a given population. Such a level of heterogeneity would equate to large differences in estimated HR_{max} derived from linear equations compounding the imprecision of these formulas. Estimated values of HR_{max} depend greatly on individual physiology and lifestyle factors (Whaley et al. 1992; Zhu et al., 2010). However, few well-controlled laboratory studies with actual measures of HR_{max}, including objective measures of maximal exertion, have examined the validity of these estimates, particularly those from the Tanaka formula, and factors associated with their accuracy in the general population. Furthermore, to our knowledge the accuracy of age-predicted equations to predict HR_{max} between ethnic groups has not been examined. Therefore, the purpose of the present study was to examine the association between estimated HR_{max} using the Tanaka et al. (2001) (208 – 0.7 × age) and Fox et al. (1971) (220-age) formulas and measured HR_{max} in sedentary Black and White adults from the HERITAGE Family Study.

METHODS

Heritage family study

The sample, study design and exercise training protocol of the HERITAGE Family Study has been described elsewhere (Bouchard et al., 1995). Briefly, 834 Black and White sedentary subjects (16- to 65-years-old) from 218 families were recruited to participate in an endurance exercise training study. All results presented in this manuscript are based on baseline data. The study protocol was approved by the Institutional Review Boards at each of the five participating centers. Written informed consent was obtained from each participant.

Maximal exercise tests—Details of the exercise tests, measurements, and protocols are found elsewhere (Skinner et al., 1999). Each subject completed two maximal exercise tests at baseline on a SensorMedics Ergometrics 800S cycle ergometer (Yorba Linda, CA) connected to a SensorMedics 2900 metabolic measurement cart. Before, during, and after each exercise test, heart rate and blood pressure (BP) measurements were taken. Specifically, heart rate was determined using an electrocardiogram with values recorded during the last 15 s of each stage, while BP was obtained during the last minute of each stage using a Colin STBP-780 automated BP unit (San Antonio, TX). The criteria for attaining maximal oxygen uptake (VO_2max)/maximal exertion was defined as reaching one of the following criteria: respiratory exchange ratio (RER) of > 1.1, plateau in O_2 uptake (change of <100 ml/min in the last three 20 s intervals), and HR within 10 bpm of age-predicted HR_{max} (220-age). Measured-HR_{max} was defined as the highest value attained during either of the two maximal exercise tests.

Reproducibility of HR_{max} measurements—Reproducibility of the HR_{max} measurements was determined from maximal exercise test data obtained (a) on two separate days in a sample of 390 subjects (198 men and 192 women) from the main HERITAGE cohort, (b) across four days (four separate tests) in an Intracenter Quality Control (ICQC) substudy with 55 subjects who were not part of the main study, and (c) across two weeks in a Traveling Crew Quality Control (TCQC) substudy with the same eight subjects who were tested at each of the four centers (Skinner et al., 1999). Reproducibility was evaluated using technical errors (TE): defined as the within-subject standard deviation as derived from repeated measures over a given period of time (a combination of measurement error plus day-to-day variation); coefficients of variation (CV) for repeated measures: derived from the TE and the measurement mean, and intraclass correlation coefficients (ICC): computed from the within-subject variance compared to the overall measurement variance. The reproducibility values for HR_{max} were TE = 5.4, CV = 2.9, and ICC = 0.88 in the main HERITAGE cohort; TE = 3.7, CV = 2.0, ICC = 0.88 in the ICQC substudy, and TE = 3.9, CV = 2.1, ICC = 0.87 in the TCQC substudy (Skinner et al., 1999).

Exclusion criteria and study sample—Given that we are examining the associations between measured HR_{max} and estimated HR_{max} and that one of the criteria for attaining maximal exertion was a heart rate within 10 bpm of age-predicted HR_{max}, we excluded subjects who reached maximal exertion exclusively via age-predicted HR_{max} from the analyses. A total of 832 subjects (38% Black, 56% Females) achieved VO_2max using one or more of the criteria. Of these, 70 subjects (8.4%) achieved maximal exertion based on reaching either the heart rate criteria or both the heart rate and VO_2 plateau criteria. Unfortunately, our records did not allow us to determine whether or not a subject met the VO_2 plateau criteria. Thus, in order to remain conservative, we excluded all 70 subjects from our analyses. Our final sample size was 762 subjects (39% Black, 57% Females).

Statistical analyses

All statistical analyses were performed with SAS version 9.1 (SAS Institute, Cary, NC). Pearson correlation coefficients were used to test the relationships between measured HR_{max} and age-predicted HR_{max} using the Fox et al. (Fox-HR_{max}) and Tanaka et al. (Tanaka-HR_{max}) formulas in the total sample, by ethnicity, and by sex. The differences between measured and age-predicted HR_{max} values were calculated as predicted Fox-HR_{max} – measured-HR_{max} and predicted Tanaka-HR_{max}–measured-HR_{max}. Thus, a negative value represents an underestimation of measured-HR_{max} by the age-based prediction equation and a positive value an overestimation. The correlations of Fox-HR_{max}–measured-HR_{max} and Tanaka-HR_{max}–measured-HR_{max} with age, body mass index (BMI), and fitness level (measured by VO_2max) were also tested. Differences in continuous and categorical variables between groups (e.g., ethnicity, sex, age groups, etc.) were assessed using *t*-tests and chi-square tests, respectively. The SEE was calculated as: $SEE=\sqrt{\frac{\Sigma(\mathrm{Y}-\mathrm{Y}_{\mathrm{pred}})^2}{n-2}}$, where Y = measured-HR_{max} and Y_{pred} = age-based predicted HR_{max} from either the Fox or Tanaka formula.

RESULTS

Basic characteristics

The basic characteristics of the HERITAGE subjects can be found in Table 1. Briefly, the HERITAGE cohort was comprised of 39% Black and 57% Female subjects with an average age of 34 years and body mass index (BMI) of 26.5 kg/m^2. There were significant differences between ethnic groups for age, BMI, cardiorespiratory fitness level (i.e., VO_2max) and resting and exercise BP, with Black subjects on average being younger and heavier, with lower fitness and higher resting and exercise BP levels compared to White subjects (Table 1). Similarly, significant sex differences were found, with males having significantly higher fitness, resting BP, and maximum exercise SBP levels compared to females. Lastly, as shown in Table 2, on average Blacks and females had significantly higher resting heart rate values as compared to Whites and males, respectively.

Mean values of measured and age-predicted HR_{max}

The mean values of measured and age-predicted HR_{max} values can be seen in Table 2. The mean Fox-HR_{max} value for the total group was significantly higher than the mean values of both measured-HR_{max} and Tanaka-HR_{max} ($P < 0.0001$). In the total sample, the Fox-HR_{max} formula overestimated measured-HR_{max} by 1.8 ± 12.2 bpm, as the difference with measured-HR_{max} varied from an overestimation of 49 bpm to an underestimation of 43 bpm. The mean difference between Tanaka-HR_{max} and measured-HR_{max} was 0.03 ± 11.4 bpm in the total sample, ranging from an over-estimation of 44 bpm to an underestimation of 38 bpm.

There were significant sex ($P \leq 0.04$) and ethnicity ($P < 0.0001$) differences in the mean values for the differences between both age-predicted HR_{max} formulas and measured-HR_{max} (Table 2). For example, measured-HR_{max} was significantly higher (~4 bpm) in Whites as compared to Blacks. Both formulas significantly overestimated measured-HR_{max} in Blacks, while the Tanaka-HR_{max} formula significantly underestimated measured-HR_{max} in Whites. In females the Fox-HR_{max} formula significantly overestimated measured-HR_{max}, while there were no mean differences between measured-HR_{max} and either Fox-HR_{max} or Tanaka-HR_{max} (Table 2).

Accuracy of age-predicted HR_{max}

The correlation of measured-HR_{max} with age-predicted HR_{max} was 0.60 in the total sample ($P < 0.0001$). Bland-Altman plots of the difference between age-predicted HR_{max} and measured HR_{max} values are shown in sex-ethnicity subgroups for Fox-HR_{max} and Tanaka-HR_{max} in Figures 1 and 2, respectively. Although the age-predicted HR_{max} values were similar to measured HR_{max} values on average, there was a large spread in the accuracy of the predictions. As can be seen by the slopes in Figures 1 and 2, at lower measured HR_{max} values both prediction formulas tended to overestimate measured HR_{max}, while tending to underestimate measured HR_{max} at higher measured HR_{max} values.

The lack of accuracy of the age-predicted HR_{max} formulas is further exhibited by the SEE values for the prediction formulas in the total sample and by ethnicity and sex (Table 1, Figures 1 and 2). Overall, the SEE was 12.4 and 11.4 bpm for the prediction of measured-HR_{max} using the Fox-HR_{max} and Tanaka-HR_{max} formulas, respectively. The SEE of the prediction was greater in Blacks as compared to Whites for both formulas, with the Fox-HR_{max} formula in Blacks showing the largest SEE value of 14.4 bpm (Table 1). The SEE values were similar between men and women for both the Fox- and Tanaka-HR_{max} formulas (Table 1). When divided into sex-ethnicity groups, the SEE for both formulas was highest in Black males, while the SEE values were lowest in White females (Figures 1 and 2).

Factors associated with the accuracy of age-predicted HR_{max}

There was a large difference in the performance of the prediction formulas by age, as the SEE was higher in subjects above the age median of 30.4 years (13.5 bpm for Fox-HR_{max}, 12.9 bpm for Tanaka-HR_{max}) as compared to those below the age median (11.3 bpm for Fox-HR_{max}, 9.7 bpm for Tanaka-HR_{max}) for both formulas. Since the age-HR_{max} association has been previously shown to be modified by BMI and fitness level (Zhu et al., 2010), we examined if the prediction performance of the Fox and Tanaka formulas varied as a function of these variables. Stratified analyses showed that the age-predicted formulas performed worse in larger and less fit individuals. The SEE of age-predicted HR_{max} was higher in subjects above the BMI median of 25.5 kg/m^2 as compared to those below the BMI median for both formulas (12.8 vs. 12.2 bpm for Fox-HR_{max}, 11.9 vs. 11.0 bpm for Tanaka-HR_{max}). Similarly, the SEE for both prediction formulas was higher in subjects below the cardiorespiratory fitness (measured VO_2max) median of 2171 ml O_2/min compared to subjects above the fitness median (13.4 vs. 11.4 bpm for Fox-HR_{max}, 12.4 vs. 10.3 bpm for Tanaka-HR_{max}).

DISCUSSION

Measured-HR_{max}, achieved during two maximal exercise tests that met predetermined criteria for attaining maximal exertion, was not strongly correlated with age-predicted HR_{max} using either the Fox et al. (1971) or Tanaka et al. (2001) formulas. Specifically, age-predicted HR_{max} explained only 36% and 26% of the total variance in measured-HR_{max} in the full cohort and black subjects, respectively. In the total sample, the SEE of the prediction for both formulas was between 11 and 12 bpm, which represents about 6% of the mean measured-HR_{max} in HERIT-AGE subjects and indicates a wide-spread of measured-HR_{max} values are compared to their age-predicted values. Thus, about 95% of the estimated HR_{max} values will fall within ±22 bpm of their corresponding measured-HR_{max} value. This is not very impressive considering the range of measured-HR_{max} in HERITAGE was only 79 bpm (136–216). For example, for individuals of the same age, fitness level, and BMI with a measured-HR_{max} of 200 bpm, the 95% confidence interval for the age-predicted HR_{max} value (using either the Fox or Tanaka formulas) would be 178–222 bpm, a range indicating limited clinical utility. This range would be even larger in Blacks, older adults, or individuals with high BMI and/or low fitness levels. Our results show that compared to mean values, the SEE is a more appropriate tool to compare measured and age-predicted HR_{max} values. These results are similar to a study that compared age-predicted maximum heart rate equations in college-aged subjects (N = 96) (Cleary et al., 2011). The authors found that the SEE for the Fox and Tanaka formulas was 12.7 and 9.3, respectively as compared to their criterion measure of HR_{max}.

Our findings show that the prevailing age-based estimated HR_{max} equations do not accurately predict an individual's measured-HR_{max}. Although the Tanaka-HR_{max} formula appears to slightly improve the prediction of an individual's HR_{max} as compared to the Fox-HR_{max} formula, there is still substantial interindividual variation. The age-based HR_{max} predictions performed worse in Blacks as compared to Whites, as the SEE values for both formulas was higher in Blacks. Furthermore, both formulas significantly overestimated measured-HR_{max} in Blacks, while the Fox-HR_{max} formula overestimated measured-HR_{max} in females. Similarly, in a study of over 5,000 asymptomatic women, Gulati et al. (2010) found that the Fox et al. equation overestimates HR_{max} for age in women, with their results giving a formula of: Peak HR = 206 − 0.88 × age. We found that the accuracy of the age-based HR_{max} predictions was also affected by an individual's BMI and current fitness level.

There are several possible explanations for the differences in SEE observed between ethnic groups in the present study. One possibility is that the differences are statistical in nature and driven by the sample size differences between Black and White subjects in HERITAGE. However, subsequent sub-analyses performed (e.g., within ethnic group by sex; within offspring only by ethnic group, etc.) showed that the differences in SEE between Blacks and Whites remained even when the sample sizes were similar between ethnic groups. Therefore, although sample size plays a role in the calculation of SEE, we do not believe it is the major contributing factor to the apparent differences in SEE between ethnic groups observed in the present study.

A biological explanation for the observed ethnic differences in SEE is genetic differences between Blacks and Whites. Here we report that the maximal heritability estimates for measured HR_{max} in HERITAGE are 39% for Blacks and 44% for Whites. Although the genetic component is similar between Blacks and Whites, the genetic factors contributing to the HR_{max} phenotype may not be the same between ethnic groups and thus may contribute differently to the variation in HR_{max} and accuracy of the prediction formulas. If biological factors are involved in ethnic differences of HR_{max}, the autonomic nervous system (ANS) would be a viable candidate to consider, as the ANS is known to play a role in heart rate regulation, including HR_{max} and heart rate variability (HRV). Previous studies have shown evidence of ethnic differences in HRV, with Blacks generally having higher HRV compared to Whites (Choi et al., 2006; Liao et al., 1995; Wang et al., 2005; Zion et al., 2003). Furthermore, it has been hypothesized that young Blacks may experience premature "aging" in their autonomic nervous system activity, specifically a decline in parasympathetic activity, compared to similarly aged Whites (Choi et al., 2006). Although we do not have substantive data to support the role of biological and genetic factors in HR_{max} and the accuracy of HR_{max} prediction formulas between ethnic groups, it is a hypothesis that cannot be excluded. Targeted biological studies are needed that investigate ethnic differences in HR_{max}, including examining the factors underlying the heterogeneity in predicted HR_{max} found in Blacks compared to Whites. Furthermore, given the differences in measured HR_{max} and the accuracy of HR_{max} predictions between ethnic groups, it appears that the already fairly large error in prediction equations is exacerbated further by not considering ethnic differences. Thus, there is a need for clinicians and researchers to take ethnicity into account when developing exercise prescriptions and prediction formulas.

These results have many implications for exercise programs based on age-predicted HR_{max} target heart rate prescriptions and for the estimation of aerobic fitness levels. It is not uncommon for exercise stress tests to be terminated at 85% of age-predicted HR_{max} (i.e., $FoxHR_{max}$). Accordingly, corresponding diagnostic criteria surrounding these tests may prove sub-optimal should a patient's target heart rate fall outside the mean estimates used for HR_{max} prediction (Lauer et al., 2005). In exercise programs based on age-predicted HR_{max} target heart rate prescriptions; this could result in target heart rates above or below the intended intensity, which could affect both the health benefits and safety of the participant. Similarly, these results could lead to either an over- or under-estimation of aerobic fitness levels (i.e., maximal aerobic power), which in turn may also affect exercise prescriptions. For example, in a cohort of subjects with a positive exercise ECG, patients had significantly fewer positive ECGs and less ST-segment depression at 85% of age-predicted HR_{max} than at peak exercise (Jain et al., 2011). Maximum workload was similar between patients that stopped exercise before reaching 85% of age-predicted HR_{max} and those achieving 85% of age-predicted HR_{max}. The authors postulate that these results indicate maximal exercise effort is more important for diagnostic testing than attaining an arbitrarily chosen target heart rate (Jain et al., 2011). The current evidence suggests the inability of existing and most likely future prediction formulas to capture physiologic HR_{max} through tests based only on submaximal efforts.

A true maximal exercise test is the gold standard measure of maximal aerobic power compared with symptom-limited and submaximal/predictive tests. The Fox-HR_{max} formula was based on data from 35 studies that appear to have true maximal exercise tests, although the Fox-HR_{max} formula was not based on regression analysis and may have included subjects with cardiovascular disease who smoked or were taking cardiac-related drugs, conditions that influence HR_{max} regardless of age. The Tanaka-HR_{max} formula was based on a meta-analysis of 351 studies (18,712 healthy subjects) with cycle or treadmill maximal exercise tests and a laboratory-based study of 514 healthy subjects with maximal treadmill tests. The heterogeneity between studies used to derive the Fox-HR_{max} and Tanaka-HR_{max}

formulas is not an issue in the present study. HERITAGE subjects completed two true maximal exercise tests using the same cycle ergometers in the same laboratory. Furthermore, as described in more detail in the Methods section, measured HR_{max} was shown to be highly reproducible in HERITAGE (Skinner et al., 1999).

A limitation of the present study is that for 70 subjects who achieved the age-predicted HR criteria, we could not distinguish whether they also achieved the VO_2 plateau criteria. If the exercise tests of these subjects were deemed maximal solely through reaching the age-predicted HR_{max} criterion, this would represent an obvious issue for the analyses of the associations between measured HR_{max} and age-predicted HR_{max}. Thus, we chose to exclude these 70 subjects. However, our results and interpretation did not differ in analyses including all subjects with valid maximal exercise tests ($N = 832$). Lastly, the present study is based on data from cycle ergometer maximal exercise tests. Maximal values for some physiological variables (e.g., VO_2max) obtained on a cycle ergometer may differ from values obtained on a treadmill or other exercise modalities. However, well-controlled laboratory studies of healthy adults that performed an individualized ramp exercise protocol on a bicycle ergometer and a treadmill in random order, showed that although peak VO_2 values were different between the two modes of exercise, HR_{max} and maximum RER did not differ (Bouchard et al., 1979; Maeder et al., 2005).

Despite the known limitations of age-based prediction formulas, their clinical and societal use is still wide-spread. Considering the doubtful validity of predicted HR_{max} values, as illustrated in the present study by the large SEE values, there is a need to develop alternative cardiorespiratory fitness standards and exercise prescription practices that do not require predicting HR_{max}. For instance, oxygen consumption and rating of perceived exertion (RPE) can be monitored during submaximal exercise testing, and subsequent exercise sessions can be prescribed using the power output corresponding to a certain VO_2, RPE, or energy expenditure. Nonheart rate, intensity based exercise prescriptions would be especially appropriate for those individuals who are unable to raise heart rate or have trouble with heart rate monitoring.

In conclusion, our results fail to validate the effectiveness of either of the two most widely used age-based HR_{max} prediction equations in sedentary, healthy adults. These results suggest that it may be very difficult, perhaps even impossible, to predict with a low SEE HR_{max} from age. They stress the importance of finding and validating other measures to be used in exercise prescriptions for the determination of intensity of exercise, the estimation of fitness levels, and as a criterion for achieving maximal exertion.

Acknowledgments

Thanks are expressed to Jack Wilmore for his contributions to the study.

Contract grant sponsor: National Heart, Lung, and Blood Institute; Contract grant numbers: HL-45670, HL-47323, HL-47317, HL-47327, and HL-47321; Contract grant sponsor: John W. Barton Sr. Chair and Henry L. Taylor Professorship.

LITERATURE CITED

Bouchard C, Godbout P, Mondor JC, Leblanc C. Specificity of maximal aerobic power. Eur J Appl Physiol Occup Physiol. 1979; 40:85–93.

Bouchard C, Leon AS, Rao DC, Skinner JS, Wilmore JH, Gagnon J. The HERITAGE family study. Aims, design, and measurement protocol. Med Sci Sports Exerc. 1995; 27:721–729.

Choi JB, Hong S, Nelesen R, Bardwell WA, Natarajan L, Schubert C, Dimsdale JE. Age and ethnicity differences in short-term heart-rate variability. Psychosom Med. 2006; 68:421–426.

Cleary MA, Hetzler RK, Wages JJ, Lentz MA, Stickley CD, Kimura IF. Comparisons of age-predicted maximum heart rate equations in college-aged subjects. J Strength Cond Res. 2011; 25:2591–2597.

Fox SM III, Naughton JP, Haskell WL. Physical activity and the prevention of coronary heart disease. Ann Clin Res. 1971; 3:404–432.

Gulati M, Shaw LJ, Thisted RA, Black HR, Bairey Merz CN, Arnsdorf MF. Heart rate response to exercise stress testing in asymptomatic women: the st. James women take heart project. Circulation. 2010; 122:130–137. [PubMed: 20585008]

Jain M, Nkonde C, Lin BA, Walker A, Wackers FJ. 85% of maximal age-predicted heart rate is not a valid endpoint for exercise treadmill testing. J Nucl Cardiol. 2011; 18:1026–1035.

Lauer M, Froelicher ES, Williams M, Kligfield P. Exercise testing in asymptomatic adults: a statement for professionals from the American Heart Association Council on Clinical Cardiology, Subcommittee on Exercise, Cardiac Rehabilitation, and Prevention. Circulation. 2005; 112:771–776.

Liao D, Barnes RW, Chambless LE, Simpson RJ Jr, Sorlie P, Heiss G. Age, race, and sex differences in autonomic cardiac function measured by spectral analysis of heart rate variability--the ARIC study. Atherosclerosis Risk in Communities. Am J Cardiol. 1995; 76:906–912.

Maeder M, Wolber T, Atefy R, Gadza M, Ammann P, Myers J, Rickli H. Impact of the exercise mode on exercise capacity: bicycle testing revisited. Chest. 2005; 128:2804–2811.

Physical Activity Guidelines Advisory Committee. Physical activity guidelines advisory committee report, 2008. U.S. Department of Health and Human Services; Washington, DC: 2008.

Robergs RA, Landwehr R. The surprising history of the “HRmax=220-age” equation. J Exerc Physiol online. 2002; 5:1–10.

Skinner JS, Wilmore KM, Jaskolska A, Jaskolski A, Daw EW, Rice T, Gagnon J, Leon AS, Wilmore JH, Rao DC, Bouchard C. Reproducibility of maximal exercise test data in the HERITAGE family study. Med Sci Sports Exerc. 1999; 31:1623–1628. [PubMed: 10589867]

Tanaka H, Monahan KD, Seals DR. Age-predicted maximal heart rate revisited. J Am Coll Cardiol. 2001; 37:153–156. [PubMed: 11153730]

Thompson, WR., editor. ACSM’s guidelines for exercise testing and prescription. 8th ed. Lippincott Williams & Wilkins; Philadelphia: 2010. p. 400

Wang X, Thayer JF, Treiber F, Snieder H. Ethnic differences and heritability of heart rate variability in African- and European American youth. Am J Cardiol. 2005; 96:1166–1172.

Whaley MH, Kaminsky LA, Dwyer GB, Getchell LH, Norton JA. Predictors of over- and underachievement of age-predicted maximal heart rate. Med Sci Sports Exerc. 1992; 24:1173–1179.

Zhu N, Suarez-Lopez JR, Sidney S, Sternfeld B, Schreiner PJ, Carnethon MR, Lewis CE, Crow RS, Bouchard C, Haskell WL, Jacobs DR Jr. Longitudinal examination of age-predicted symptom-limited exercise maximum HR. Med Sci Sports Exerc. 2010; 42:1519–1527.

Zion AS, Bond V, Adams RG, Williams D, Fullilove RE, Sloan RP, Bartels MN, Downey JA, De Meersman RE. Low arterial compliance in young African-American males. Am J Physiol Heart Circ Physiol. 2003; 285:H457–H462.

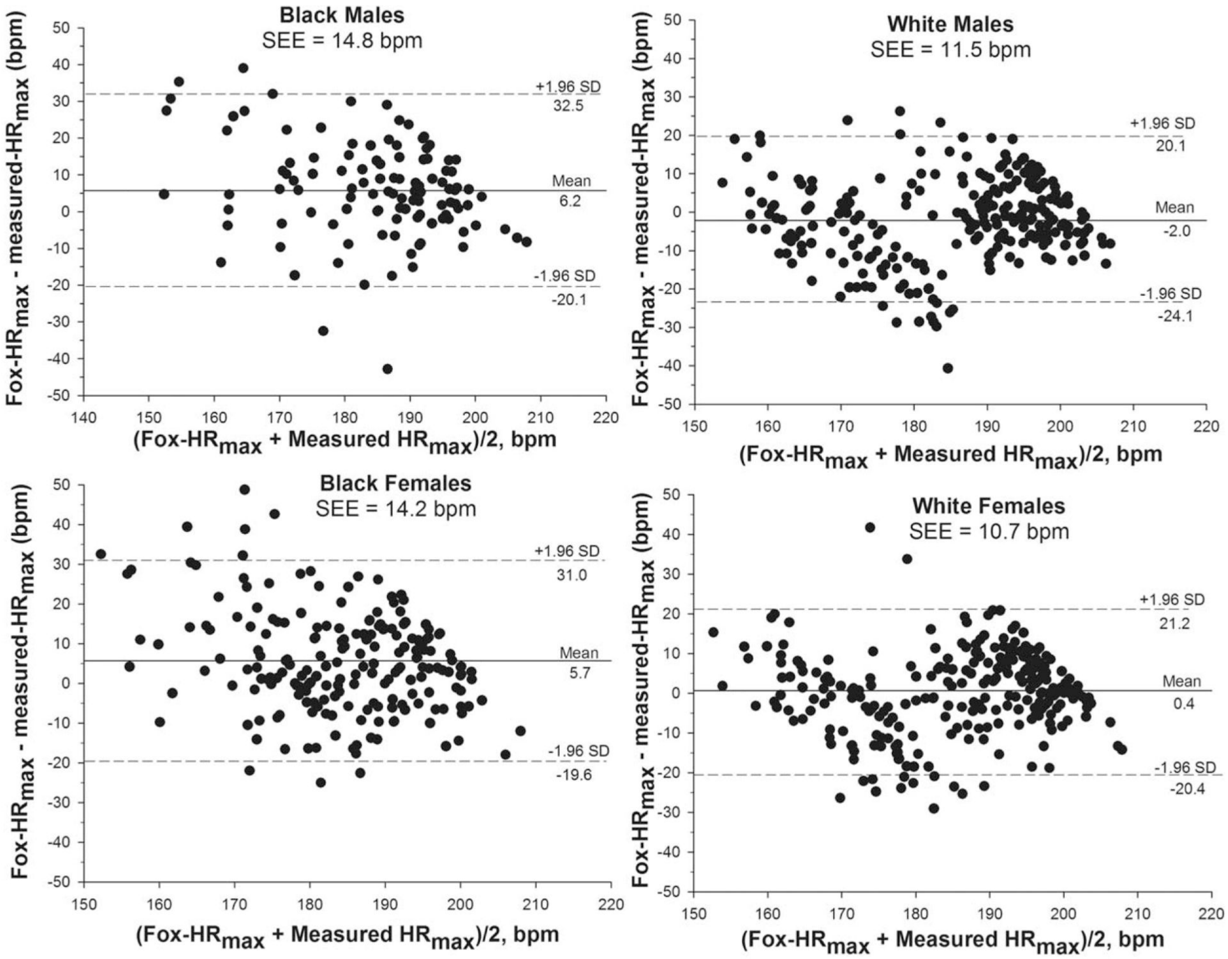

Fig. 1.

Bland-Altman plots of the difference between age-predicted HR_{max} using the Fox formula (220-age) and measured HR_{max} by ethnicity and sex subgroups in HERITAGE. Horizontal lines are shown for the mean difference and the 95% confidence intervals of the mean difference.

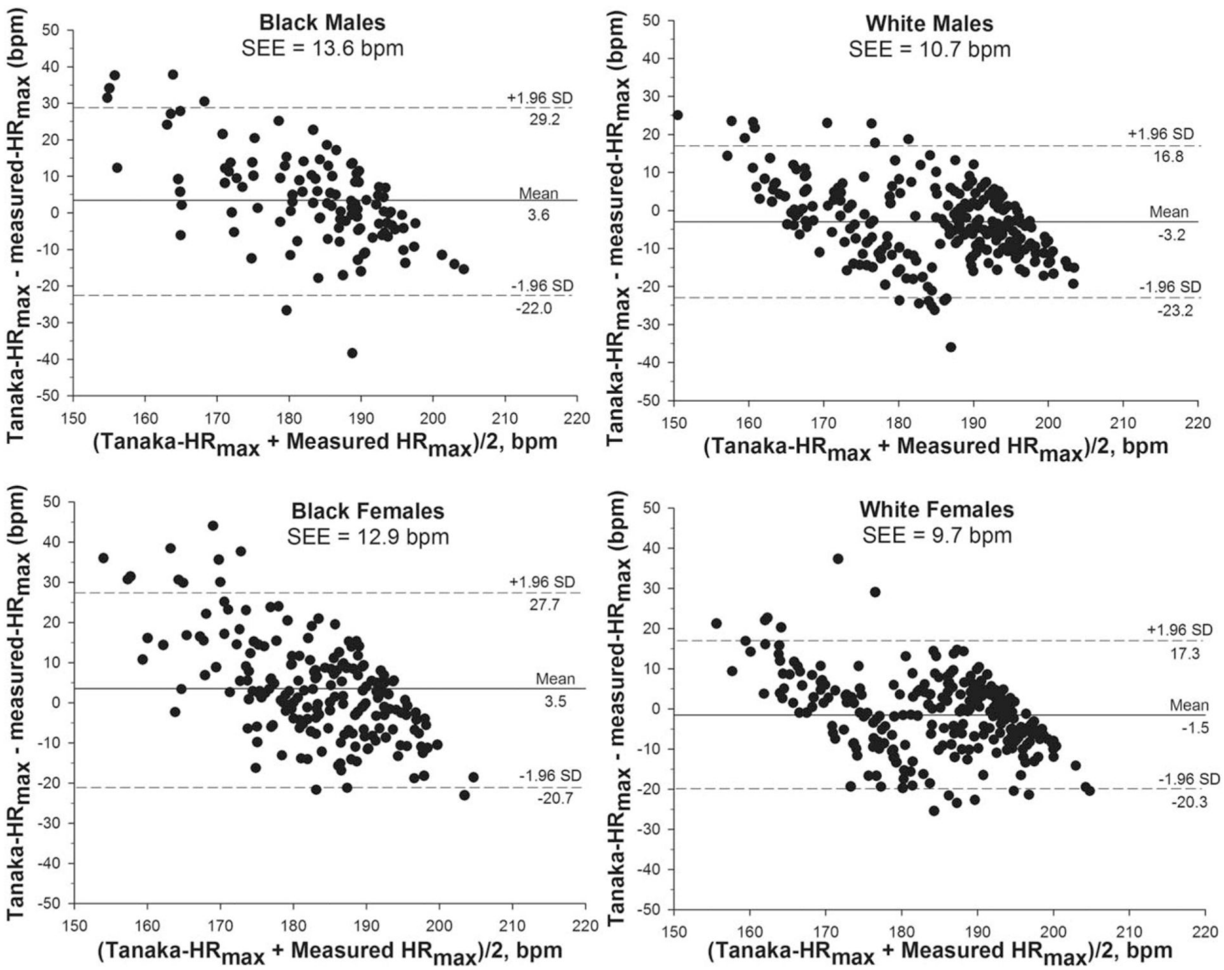

Fig. 2.

Bland-Altman plots of the difference between age-predicted HR_{max} using the Tanaka formula (208–0.7 × age) and measured HR_{max} by ethnicity and sex subgroups in HERITAGE. Horizontal lines are shown for the mean difference and the 95% confidence intervals of the mean difference.

TABLE 1

Descriptive characteristics, shown as mean (standard deviation) with minimum and maximum values of HERITAGE subjects by ethnicity and sex

Variable	Total sample (*N* = 762)	Whites (*N* = 463)	Blacks (*N* = 299)	Females {*N* = 431)	Males (*N* = 331)
Age (years)	33.8 (13.2) 15.9 to 65.2	34.9 (14.3)[a] 17.0 to 65.2	32.2 (11.0)[a] 15.9 to 64.8	33.3 (12.6) 16.4 to 65.2	34.5 (14.0) 15.9 to 64.3
BMI (kg/m^2)	26.5 (5.5) 17.0 to 50.9	25.6 (4.8)[b] 17.0 to 44.2	27.8 (6.2)[b] 17.4 to 50.9	26.3 (5.8) 17.0 to 50.9	26.7 (5.0) 17.3 to 44.2
VO_2max(l/min)	2.3 (8.7) 0.9 to 4.4	2.4 (0.7)[b] 1.2 to 4.4	2.1 (0.6)[b] 0.9 to 4.1	1.8 (0.4)[b] 0.9 to 3.1	2.9 (0.6)[b] 1.7 to 4.4
VO_2max(ml/kg/min)	31.0 (8.7) 14.3 to 57.0	33.1 (8.7)[b] 14.9 to 57.0	27.7 (7.7)[b] 14.2 to 49.7	27.3 (6.8)[b] 14.3 to 45.0	35.9 (8.5)[b] 18.6 to 57.0
Resting systolic blood pressure (SBP)(mm Hg)	119.0 (11.8) 85.7 to 165.7	116.0 (10.7)[b] 85.7 to 152.5	123.8 (12.0)[b] 93.7 to 165.7	117.2 (12.4)[b] 85.7 to 165.7	121.4 (10.5)[b] 93.0 to 154.8
Resting diastolic blood pressure (DBP),	68.5 (9.1) 43.5 to 95.7	65.7 (8.4)[b] 43.5 to 95.7	72.8 (8.5)[b] 49.7 to 94.7	67.8 (9.2)[c] 43.5 to 94.7	69.3 (9.0)[c] 44.5 to 95.7
Maximum exercise SBP (mm Hg)	195.0 (26.2) 136 to 277	191.3 (25.7)[b] 136 to 277	200.4 (26.0)[b] 142 to 275	184.9 (24.5)[b] 136 to 277	208.3 (22.1)[b] 144 to 268
Maximum exercise DBP (mm Hg)	84.4 (13.1) 44 to 127	81.2 (12.2)[b] 44 to 116	89.1 (13.0)[b] 52 to 127	84.0 (13.1) 44 to 127	84.9 (13.1) 45 to 118

[a] $P = 0.006$ for mean difference between ethnic groups.

[b] $P < 0.0001$ for mean difference between ethnic or sex groups.

[c] $P = 0.003$ for mean difference between sex groups.

TABLE 2

Means and standard deviations, with minimum and maximum and standard error of estimate values indicated for measured-HR_{max} and predicted-HR_{max} in HERITAGE subjects by ethnicity and sex

Variable	Total sample (N = 762)	Whites (N = 463)	Blacks (N = 299)	Females (N = 431)	Males (N = 331)
Resting heart rate, bpm	65.4 (9.1) 40.3 to 105.3	64.5 (9.0)[a] 40.3 to 105.3	66.8 (9.0)[a] 44.8 to 102.3	67.9 (8.7)[b] 44.0 to 105.3	62.0 (8.5)[b] 40.3 to 85.7
Measured HR_{max}, bpm	184.4 (14.2) 136 to 215	185.9 (13.8)[c] 138 to 215	181.9 (14.6)[c] 136 to 215	184.0 (13.8) 136 to 215	184.8(14.8) 137 to 213
Fox predicted HR_{max}, bpm	186.2 (13.2)[d,e] 155 to 204	185.1 (14.3)[b,e] 155 to 203	187.8 (11.0)[b,de] 154 to 204	186.7 (12.6)[d,e] 155 to 204	185.5 (14.0)[e] 156 to 204
Tanaka predicted HR_{max}, bpm	184.3 (9.2)[e] 162 to 197	183.6 (10.0)[bde] 162 to 196	185.5 (7.7)[bde] 163 to 197	184.7 (8.8)[e] 162 to 197	183.8 (9.8)[e] 163 to 197
Fox HR_{max} - Measured HR_{max}, bpm	+1.8(12.2)	−0.8 (11.0)[b]	+5.9 (13.1)[b]	+ 2.7 (12.0)[f]	+0.6(12.6)[f]
SEE of Fox-HR_{max} prediction	12.4	11.0	14.4	12.3	12.6
Tanaka HR_{max} - Measured HR_{max}, bpm	−0.03 (11.4)	−2.3 (9.9)[b]	+3.5 (12.6)[b]	+0.7 (11.2)[f]	−1.0 (11.6)[f]
SEE of Tanaka-HR_{max} prediction	−0.03 (11.4) 11.4	10.2	13.1	11.2	11.7

SEE, standard error of estimate; bpm, beats per minute; Fox-HR_{max} = 220 – age; Tanaka-HR_{max}, 208–0.7 × age.

[a] P = 0.0006 for mean difference between ethnic groups.

[b] P < 0.0001 for mean difference between ethnic or sex groups.

[c] P = 0.0002 for mean difference between ethnic groups.

[d] P < 0.0001 for mean difference between Fox-HR_{max} or Tanaka-HR_{max} and measured-HR_{max}.

[e] P < 0.0001 for mean difference between Fox-HR_{max} and Tanaka-HR_{max}.

[f] $P \leq 0.04$ for mean difference between sexes.