Evaluation of Conventional and New Maximum Heart Rate Prediction Models for Individuals

In October of 1992 I submitted an abstract to the American College of Sports Medicine, co-authored with Dr. Schork and Dr. Edington from the University of Michigan, to present our study at the 1993 Annual Meeting. A few weeks later I received Volume 24, issue 10 of Medicine and Science in Sports and Exercise, where Whaley and colleagues had published a similar paper. Discouraged by the bad timing, I never tried to publish my own paper.

Several years later, other similar papers have been published, arguing for a correction to the conventional 220-age formula for maximum heart rate. I realized I should have tried to publish my paper back in 1993! I have dug out the original poster presentation materials, scanned them, and prepared this document for the sake of teaching my students (who often quote Tanaka et al. and Gellish et al.) the importance of prompt publication of their work.

References:

Aragón-Vargas, L. F., Schork, M.A. & Edington, D.W. (1993). Evaluation of Conventional and New Maximum Heart Rate Prediction Models for Individuals. *Medicine and Science in Sports and Exercise 25*(5):S10.

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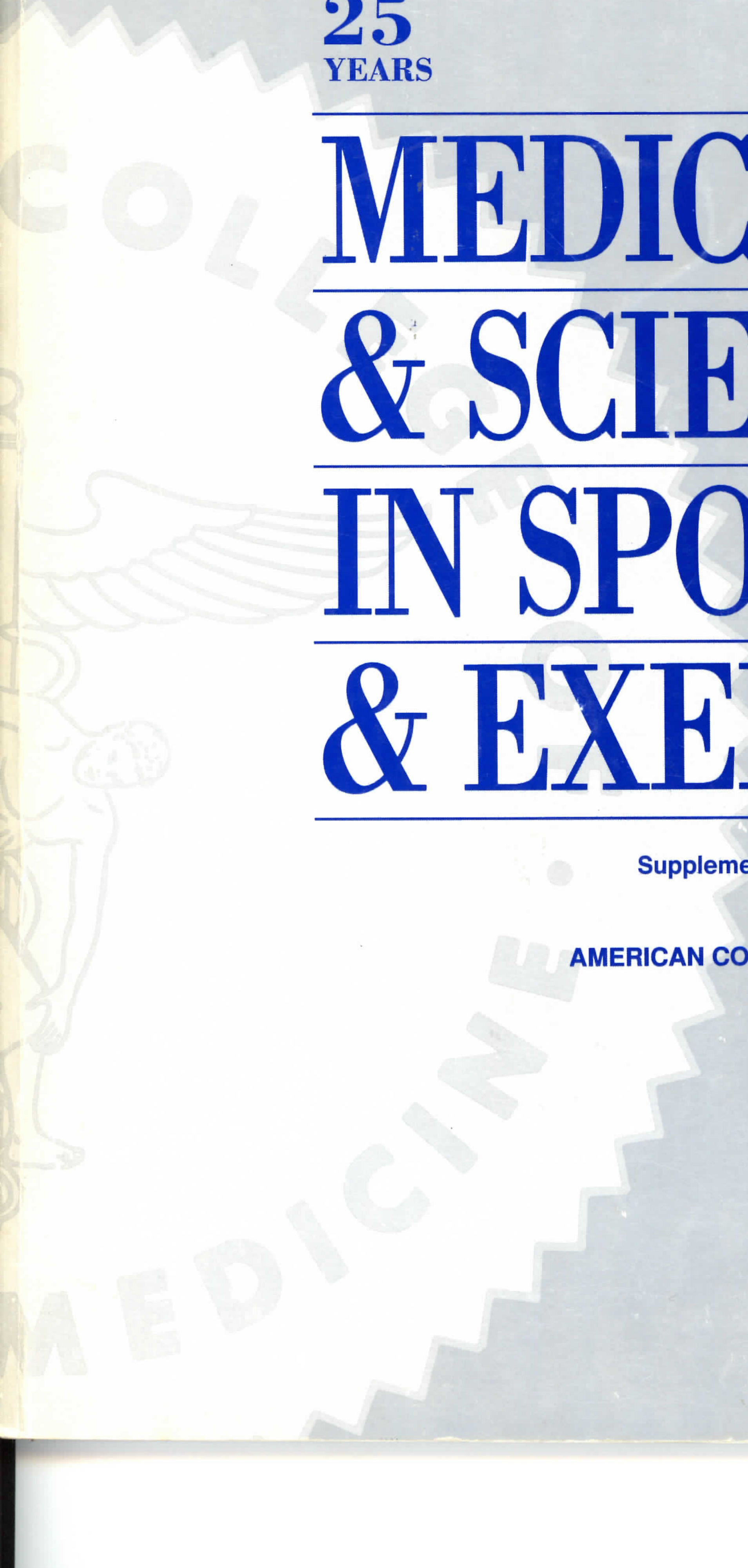

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55 PRECISION AND VARIABILITY MONITORED BY EKG, PHOTO-REFLECTANCE AND TELEMETRIZED HEART RATE MONITORS DURING EXERCISE

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The accuracy and variability of a new microcomputer photo-reflectance heart rate monitor (Computrainer, RacerMate Corp.) and a portable telemetrized microprocessor heart rate monitor (Vantage XL, POLAR USA) were compared against direct EKG measurements in a laboratory setting. Fifteen subjects (8 females, 7 males) of varying levels of fitness were studied at rest and during light-, moderate-, and high-intensity steady state exercise while riding on an electromagnetically braked bicycle ergometer. Recovery heart rates were also recorded for five minutes after exercise. Repeated measures ANOVA showed no significant differences between values at rest, recovery and at each workload between the three measuring devices. Pearson-product moment correlation coefficient values ranged from 0.94 to 0.99. Thus, the three measuring devices proved equally reliable for measuring heart rate at various intensities of aerobic activity. This study shows that the performance of the Computrainer photo-reflectance monitor is as accurate as direct EKG measurements. This breakthrough technology of improved photoelectric emitter-detector and algorithm calculations of heart rate by the microcomputer combines convenient, comfortable and inexpensive ear lobe sensor monitoring equal to chest belt monitors and direct EKG measurements.

Supported by a grant from RacerMate, Corporation.

57 CONTROL DAY VS. PRE-EXERCISE BASELINE COMPARISONS

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Investigations on resting and recovery metabolism have used both pre-exercise and separate control day measurements as a baseline for comparisons. The purpose of this study was to compare pre-exercise resting data with control day resting data. Seven men (averaging 25±5 y, 83.2±15.4 kg, and 49.2±10.9 ml/kg/min) visited the lab at the same time of day on four separate occasions after following identical diet and activity preparatory protocols. Each subject was previously habituated and scheduled to exercise for 60 min at 60% VO_2 max on a level treadmill (60J), a decline treadmill (-5%) (60DH), and a stationary cycle (60C). A fourth session involved no exercise (CON). Prior to each exercise session and on the control day, each subject sat quietly for 30 min and resting data was collected. An additional 2 h of rest was monitored on the control day. No significant differences existed among the conditions for any baseline variable. (Values are Mean±SD)

	Pre60J	Pre60DH	Pre60C	CON	CON+1h	CON+2h
VO_2	.293	.283	.291	.279	.282	.290
($l\cdot min^{-1}$)	.047	.043	.046	.029	.042	.036
RER	.790	.832	.843	.812	.802	.833*
	.056	.044	.101	.039	.043	.052
HR	58	58	59	56	56	56
($b\cdot min^{-1}$)	9	8	7	8	7	5

***RER at CON+2h was significantly higher than CON or CON+1h. These results suggest that in habituated subjects baseline data obtained during a pre-exercise session are similar to baseline data obtained during a control, non-exercise session.**

59 THE EFFECT OF EXERCISE DURATION ON ACUTE BLOOD PRESSURE REDUCTION IN HEALTHY, FIT FEMALES.

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The purpose of this study was to determine if acute blood pressure reductions occurred following dynamic exercise conducted at the same intensity (70% of VO_2 max) for different durations (20, 40 and 60 mins). Subjects were eight trained (mean VO_2max= 47.6 ml/kg/min), normotensive (110.4/72.3 mm Hg.) females (mean age=30.2 yrs., mean wt.=58.7 kg., mean ht=165.6 cm.). Subjects reported to the lab (20, 40 and 60 mins of exercise) in random fashion. Treadmill speed and grade were established to yield the appropriate intensity for each subj. All systolic (SBP) and diastolic (DBP) blood pressures were measured by the same individual according to AHA guidelines. Prior to each exercise bout, subj had BP measured every 5 mins for a 20 min period. Following each exercise bout, subj sat quietly for a 3-hr time period. Variables were measured every 5 mins for the first 30 min period followed by each 15 mins of the total recovery. An ANOVA was used to assess differences due to duration. The mean ± SD (SBP/DBP, mm Hg.) from pre-exercise to 1, 2 and 3 hrs post-exercise are:

	20 mins	40 mins	60 mins
Pre	108.0±4.9/72.0±7.5	112.0±6.9/70.6±5.0	110.8±5.6/74.3±7.7
1 hr post	98.3±4.9/67.4±5.1	101.1±6.4/67.1±6.5	96.7±8.6/65.7±10.2
2 hr post	102.3±5.1/71.6±6.0	100.0±7.5/68.3±2.1	100.6±4.7/68.3±4.7
3 hr post	105.3±7.5/70.7±5.6	104.3±10.4/69.1±2.5	104.6±8.6/70.3±7.4

There were no significant differences between the 3 pre-exercise measurements. Additionally, no significant differences were found among the 3 durations. However, the combination of a 70% intensity and either a 20, 40 or 60 min duration yielded a similar reduction in both SBP and DBP following dynamic exercise.

56 GENDER DIFFERENCES IN RUNNING ECONOMY WITH STATISTICAL CONTROL FOR PHYSIOLOGICAL AND TRAINING PARAMETERS

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The study was designed to examine gender differences in running economy. The subjects were 12 male (25.9 ± 5.3 yrs, 63.8 ± 6.9 $ml\cdot kg^{-1}\cdot min^{-1}$) and 12 female (24.8 ± 2.3 yrs, 53.7 ± 4.5 $ml\cdot kg^{-1}\cdot min^{-1}$) endurance-trained runners. The males were significantly taller, heavier, and had less percent body fat (BF(%)) ($p < .01$) than the females. The males trained at a significantly faster pace than the females, but the groups were not significantly different in years of running experience and distance trained per week (km) (DT) ($p > .01$). The running economy test was performed on a level treadmill at speeds of 160, 215, and 267 $m\cdot min^{-1}$ for 6 min at each speed. After the 267 $m\cdot min^{-1}$ stage, speed was maintained and the grade was raised 2% every 2 min until volitional exhaustion. The males had a significantly greater absolute ($L\cdot min^{-1}$) and relative ($ml\cdot kgBW^{-1}\cdot min^{-1}$) VO_2 max than the females ($p < .01$), but maximal heart rate (HR max) and VO_2 max controlled for fat-free weight were not significantly different ($p > .01$). Analysis of covariance with repeated measures was utilized to test for gender differences in submaximal VO_2 at 160 and 215 $m\cdot min^{-1}$ with VO_2 max, BF(%), and DT as covariates. No comparisons were made at 267 $m\cdot min^{-1}$ because all but one female experienced a maximal effort during this stage. No gender differences were found with submaximal VO_2 at 160 and 215 $m\cdot min^{-1}$ with the effects of the covariates partialed out ($p > .01$). In conclusion, no differences are expected in the aerobic demand of running at 160 and 215 $m\cdot min^{-1}$ between male and female runners when the effects of VO_2 max, BF(%), and DT are removed.

58 EVALUATION OF CONVENTIONAL AND NEW MAXIMUM HEART RATE PREDICTION MODELS FOR INDIVIDUALS

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The purpose of this study was to develop a regression model to predict maximum heart rate (HRmax) from basic sociodemographic variables and to compare it with the 220-age rule of thumb. Data were obtained from 635 adults of all ages, gender, and physical activity levels, rigorously tested for maximum aerobic capacity. HRmax was found to be significantly correlated ($p<.05$) to age, tobacco use in the past, current tobacco use, and self-reported physical activity. There was no evidence of a difference in HRmax between males and females ($p=.997$). Several significant ($p<.00005$) linear regression models involving these variables were developed, but their ability to explain the variation in HRmax was only slightly better than a model that relied on age alone. Based on R^2 values, the age model was able to explain 44.9% of the variation in HRmax, compared to 48% when using the most complicated model. The 220-age rule of thumb also gave an $r^2 = .449$ (44.9%), but the average estimate was biased (-8 beats per minute [bpm]). Individual estimates were highly inaccurate: 50.5% of the predicted values were off by ≥ 10 bpm, compared to 27.6% with our simplest model based on age alone. Furthermore, both the 220-age rule and our regression models were very poor predictors when applied to ten-year age subgroups. It was concluded that in spite of a significant correlation between HRmax and other variables, regression models based on these variables are highly inaccurate in the prediction of individual HRmax values. Therefore, the practice of relying on them for individualized exercise prescription and as a criterion for graded exercise test termination is not warranted.

60 QUANTIFYING LIFETIME PHYSICAL ACTIVITY IN FEMALES

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Quantifying lifetime physical activity from questionnaires is somewhat subjective and time-consuming. The purpose of this study was to develop a practical, semi-quantitative computerized method of analyzing lifetime participation in physical activities to estimate kcal expenditure. A computerized method was compared to a previously used, more subjective method using the same questionnaire data. Calculation of lifetime physical activity of 40 female subjects (ages 14 - 82) was modeled after the Paffenbarger method, classifying activities as *light*, *vigorous*, or a *mixture* of both (5, 10, or 7.5 kcal/minute, respectively). Subjects were asked about main types of physical activity during their lifetime, the number of weeks/yr, times/wk, minutes/session, and years of participation. Based on this information, kcal expenditure for each activity was calculated and then summed to provide an estimate of *cumulative lifetime kcal expenditure* (cumkcal). In addition, each weekly kcal expenditure was multiplied by the number of years of participation/age and then summed to provide an *age-adjusted, lifetime weekly average* (agelifekcal), allowing a comparison between subjects of different ages. The subjective method involved four experienced independent observers who ranked the lifetime activity of 40 subjects 1 through 5 (0.5 point increments) – from very low to very high activity. An overall average from the four raters was computed, rank ordered and correlated to the rank ordered computerized calculations using the Spearman rank correlation coefficient analysis. Results indicated relatively high correlations between the subjective and computerized methods of activity assessment (observer average vs cumkcal: $r = 0.811$; observer average vs agelifekcal: $r = 0.876$). This demonstrates that the computerized method of assessing lifetime physical activity for females compares well with the previously used more subjective method. The computerized method removes some of the subjective decision-making, requires less time for analysis, provides two very distinct estimates of kcal expenditure (cumkcal and agelifekcal), yet achieves similar results.

Abstract

The purpose of this study was to develop a regression model to predict maximum heart rate (HRmax) from basic sociodemographic variables and to compare it with the 220-age rule of thumb. Data were obtained from 635 adults of all ages, gender, and physical activity levels, rigorously tested for maximum aerobic capacity. HRmax was found to be significantly correlated ($p<.05$) to age, tobacco use in the past, current tobacco use, and self-reported physical activity. There was no evidence of a difference in HRmax between males and females ($p=.997$). Several significant ($p<.00005$) linear regression models involving these variables were developed, but their ability to explain the variation in HRmax was only slightly better than a model that relied on age alone. Based on R^2 values, the age model was able to account for 44.9% of the variation in HRmax, compared to 48% when using the most complicated model. The 220-age rule of thumb also gave an $r^2 = .449$ (44.9%), but the average estimate was biased (-8 beats per minute [$b * min^{-1}$]). Individual estimates were highly inaccurate: 50.5% of the predicted values were off by 10 $b * min^{-1}$ or more, compared to 27.6% with our simplest model based on age alone. Furthermore, both the 220-age rule and our regression models were very poor predictors when applied to ten-year age subgroups. It was concluded that in spite of a significant correlation between HRmax and other variables, regression models based on these variables are highly inaccurate in the prediction of individual HRmax values. Therefore, the practice of relying on them for individualized exercise prescription and as a criterion for graded exercise test termination is not warranted.

1 Purpose

The conventional rule of thumb for prediction of maximum heart rate, 220 - age, is widely used for exercise prescription and testing, despite some known inaccuracies. This is very likely due to the inherent simplicity in the calculation. This study intended to develop a regression model to predict maximum heart rate from basic sociodemographic variables normally available to coaches, instructors and clinicians. To be of any use, this regression model should be simple, and show more accuracy in the prediction of individual heart rates.

2 Subjects

Subjects were tested as part of a comprehensive fitness evaluation between 1990 and 1992. The group included smokers and non-smokers, young and old, fit and unfit, male and female.

VARIABLE	MEAN	STANDARD DEVIATION	MINIMUM	MAXIMUM
Age (years)	44.67	11.70	18.00	85.00
Height (meters)	175.17	8.71	150.60	196.80
Weight (kilograms)	78.89	15.29	41.20	141.60
HRmax (beats * min^{-1})	183.40	14.12	108.00	225.00
VO$_2$max(ml*kg^{-1}*min^{-1})	37.55	9.21	15.29	72.37
Vital capacity (liters)	4.26	0.91	2.00	7.02

n=635 (474 male, 161 female).

3 Methods

Multiple regression analysis techniques were used to develop a prediction model for maximum heart rate. New and conventional models were evaluated using residual analysis.

Upon arrival at the Laboratory, subjects filled out a background information form. Age, gender, tobacco use (past and present), and habitual level of physical activity (sedentary, low, moderate, high), were tabulated from this form. Maximum aerobic capacity was measured last, after a pulmonary evaluation, anthropometric measurements and underwater weighting. Resting heart rate, blood pressure, and twelve-lead ECG were obtained in a supine position prior to the graded exercise test.

VO_2max was tested on a motorized treadmill, following a free protocol of progressive speed and inclination. Subjects breathed ambient air through a mouthpiece, and expired gases were analyzed on-line on a Sensormedics 2900 Energy Expenditure Unit. Respiratory exchange ratio (RER), ventilation rate, oxygen consumption (VO_2), and heart rate were monitored throughout the test. A test was considered maximal only if it fulfilled two of three criteria: RER>1.20, maximum heart rate within 10 beats per minute of the age-predicted maximum, and a "considerable" increase in the ventilation rate. Conventional criteria were used for early termination of a test due to ECG abnormalities. Maximum heart rate was defined as the highest sinus or atrial rate (average of two sets of three consecutive beats) obtained from the ECG strip during the last minute of exercise.

Multiple regression analysis (stepwise regression) was performed using SPSSX on a mainframe computer, with maximum heart rate as the dependent variable, and age, gender, physical activity level, current tobacco use, former tobacco use, height, and weight as the potential predictor variables. Different subsets of variables were used in the model one at a time. Special variables were defined to try to improve the model as suggested by results from residual analyses: agegrp (age group by decades), hipa (1 if self-reported physical activity level is 1, 0 otherwise), tobaco (1 if current smoker, 0 otherwise).

4 Results

Correlations between single basic variables and HRmax are small, except for age. There was no evidence of a difference in HRmax between males and females (p=.997).

	Age	Gender	PA	Height	Weight	Tobacco use	Tobacco for
Age	1.000						
Gender	-0.068	1.000					
PA	-0.082	0.061	1.000				
Height	-0.098	-0.695	0.002	1.000			
Weight	-0.004	-0.584	-0.195	0.649	1.000		
Tobacco use	0.034	0.121	-0.154	-0.056	-0.028	1.000	
Tobacco for	0.191	-0.006	-0.073	0.004	0.041	0.294	1.000
HRmax	-0.671	0.001	-0.068	0.049	-0.030	-0.084	-0.168

5 Results

None of the models developed could account for more than 49% of the variation in maximum heart rate. A simple model using age alone accounted for 44.9% of the variation.

Model	R^2	Adjusted R^2	Mallow's Cp
HRmax = 227.53 - 0.75(age) - 3.23(pa) + 0.19(VO2max) - 0.06(wt) - 3.88 (tobacco use) *	0.486	0.481	5.22
HRmax = 245 - 0.83(age) - 3.24(gender) - 2.5(pa) - 0.11(wt) - 4.08 (tobacco use)	0.483	0.479	4.94
HRmax = 216.03 - 0.71(age) - 2.69(hipa) - 3.86 (tobacco use) - 5.51(agex1) + 1.9(agex3) @	0.479	0.475	-----
HRmax = 218.78 - 0.79 (age)	0.449	-----	-----

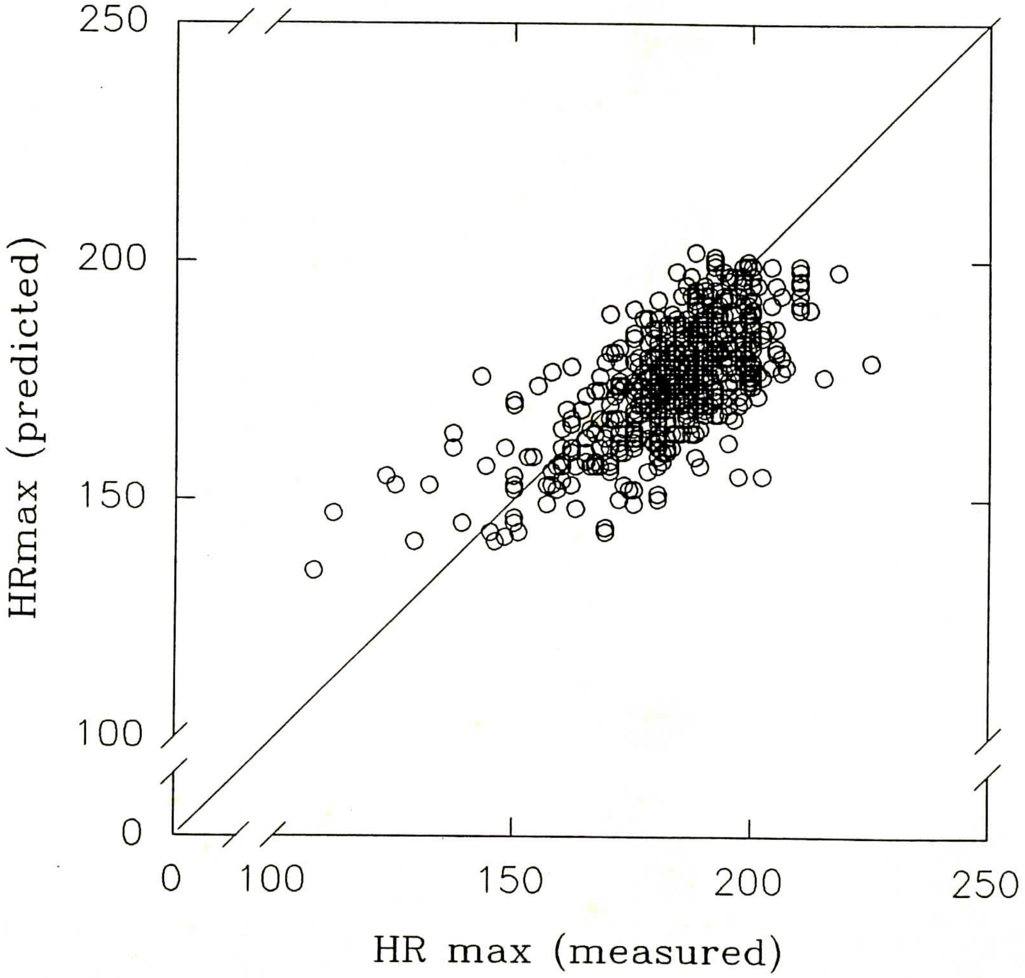
(*) VO$_2$max and vital capacity were included as potential predictors in this model for evaluati purposes.

(@) Special variables were created to try to obtain a better model.

6 Results

Using the conventional formula for this group of subjects resulted in a considerable bias of -8 beats * min-1 in the predicted values.

Predicted (220 - age) vs actual maximum heart rate.



7 Results

The conventional 220 - age calculation also resulted in a considerably wide distribution of the residuals: 50.5% of the predicted values were off by 10 beats * min^{-1} or more. Our simple model did not do much better (27.6%), considering the regression coefficients attempt to minimize the summation of squared residuals. The problem seems to be more pronounced in the older subjects.

Figure 2: Distribution of residuals
Conventional formula: 220 - age.

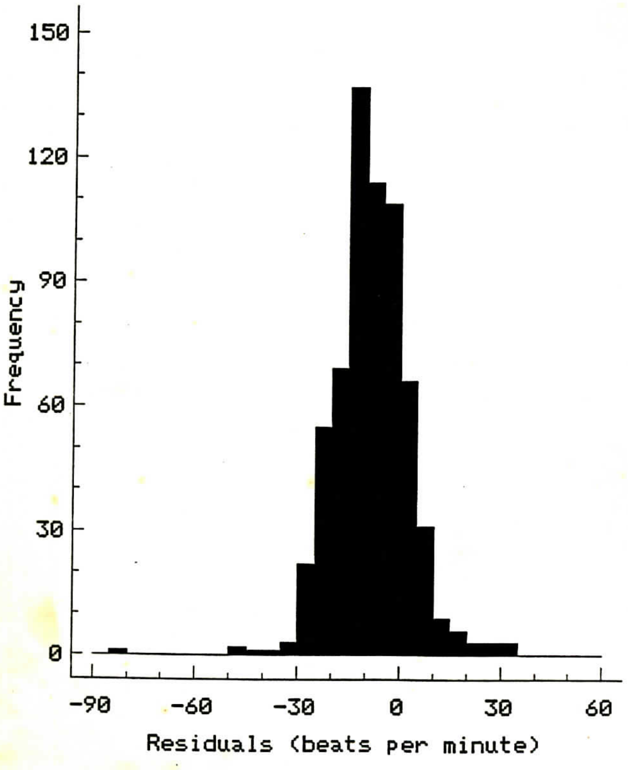


Figure 3: Distribution of residuals
Complex formula.

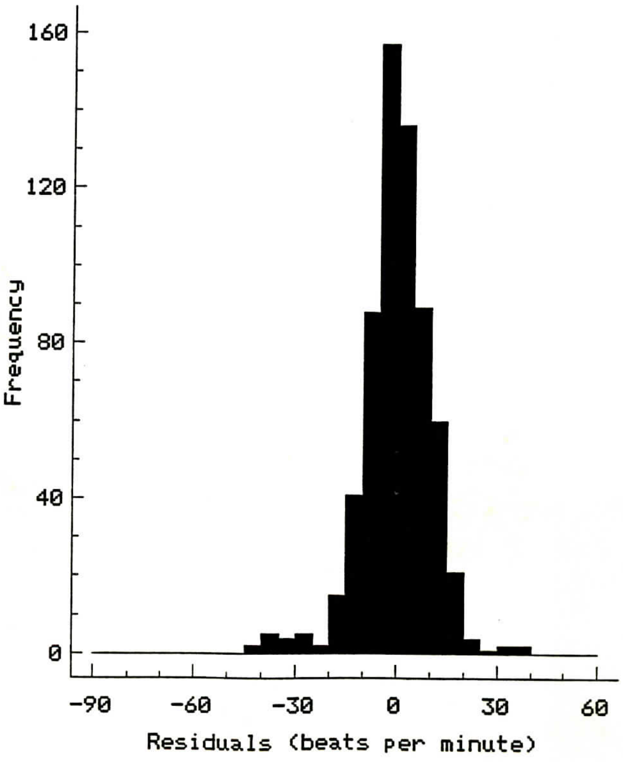
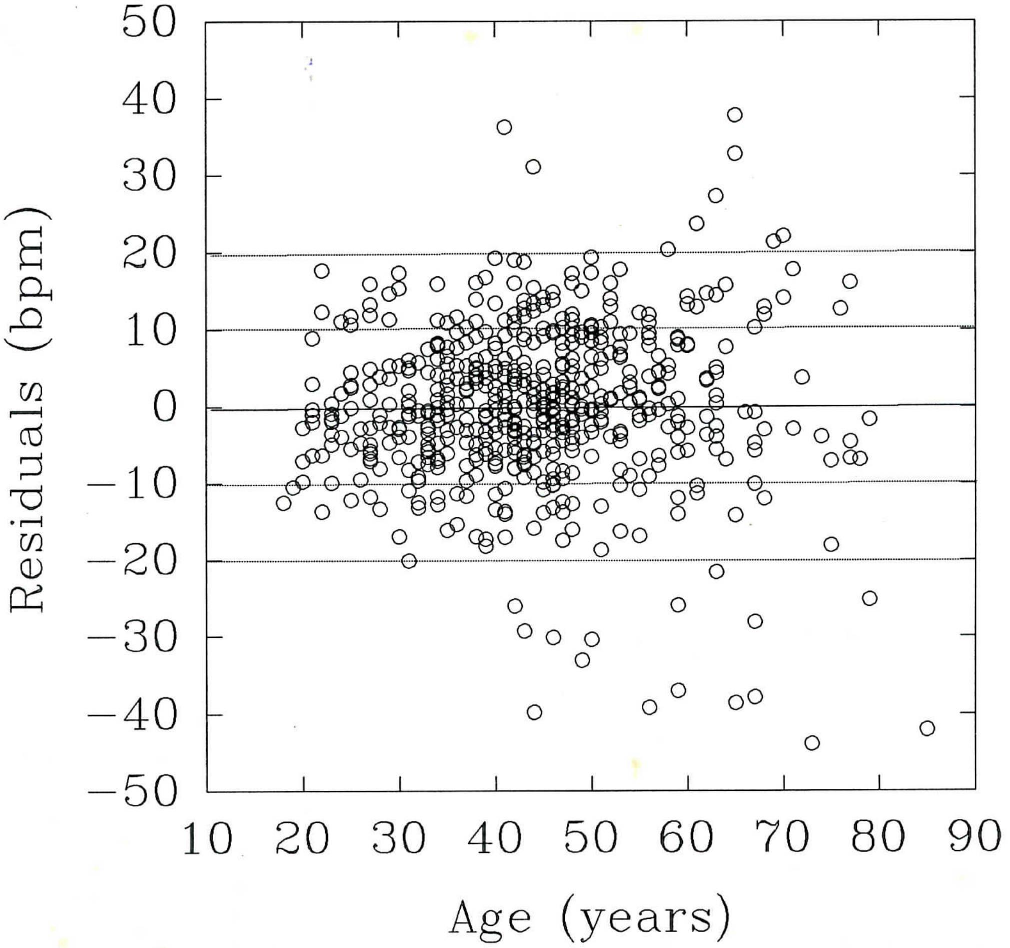


Fig. 4: Residuals vs age.



8 Summary

1. The conventional 220 - age formula for predicting maximum heart rate is biased (underestimates true HRmax on the average) and is highly inaccurate when applied to individuals.

2. Including other basic sociodemographic variables into the model does very little in terms of accounting for more of the variation in maximum heart rate, and adds complexity to the procedure. This trade-off seems to favor a simple model based on age alone.

3. Maximum heart rate, as estimated from prediction models, should not be used as a criterion for graded exercise test termination. It is preferable not to use it for exercise prescription either.

4. A simple model, $HRmax = 219 - 0.79(age)$, is proposed for further evaluation with other populations.