Age-predicted maximal heart rate in healthy subjects: The HUNT Fitness Study

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Maximal heart rate (HR\textsubscript{max}) declines substantially with age, but the magnitude and possible modifying effect of gender, body composition, and physical activity are not fully established. The present study examined the relationship between HR\textsubscript{max} and age in 3320 healthy men and women within a wide age range using data from the HUNT Fitness Study (2007–2008). Subjects were included if a maximal effort could be verified during a maximal exercise test. General linear modeling was used to determine the effect of age on HR\textsubscript{max}. Subsequently, the effects of gender, body mass index (BMI), physical activity status, and maximal oxygen uptake were examined. Mean predicted HR\textsubscript{max} by three former prediction formulas were compared with measured HR\textsubscript{max} within 10-year age groups. HR\textsubscript{max} was univariately explained by the formula \(211 - 0.64 \times \text{age} \) (SEE, 10.8), and we found no evidence of interaction with gender, physical activity, VO\textsubscript{2max} level, or BMI groups. There were only minor age-adjusted differences in HR\textsubscript{max} between these groups. Previously suggested prediction equations underestimated measured HR\textsubscript{max} in subjects older than 50 years. HR\textsubscript{max} predicted by age alone may be practically convenient for various groups, although a standard error of 10.8 beats/min must be taken into account. HR\textsubscript{max} in healthy, older subjects and women were higher than previously reported.

Maximal heart rate (HR\textsubscript{max}) is commonly used in clinical exercise testing and to prescribe exercise intensity in training and rehabilitation programs. HR\textsubscript{max} describes the highest heart rate achieved by a subject exercising to exhaustion and is verified by a plateau of heart rate despite increasing workload. In the literature, HR\textsubscript{max} commonly refers to the peak heart rate at termination of a graded maximal exercise test (Tanaka et al., 2001; Gulati et al., 2010). However, in clinical settings, a maximal exercise test is not always feasible and there is a need to predict HR\textsubscript{max} from age prior to testing to be able to adequately assess heart rate response and relative intensity of effort at submaximal levels. During diagnostic exercise testing, the test is commonly terminated and termed nondiagnostic if the subject reach a predetermined percentage of age-predicted HR\textsubscript{max} without electrocardiography (ECG) signs of ischemia (e.g., 85% of predicted HR\textsubscript{max}; Balady et al., 2004; Amsterdam et al., 2010). Moreover, sensitivity is reduced in tests not reaching the target heart rate, which seems to be true both in exercise ECG as well as in exercise in combination with imaging modalities (Cumming, 1972; Gian-rossi et al., 1989; Iskandrian et al., 1989). While in exercise testing the predicted HR may be substituted with rate of perceived exertion (RPE) which may better ensure an adequate stress level, this is not the case in pharmacological stress (Pinkstaff et al., 2010). Despite great individual variability, the ability to reach a given percentage of age-predicted HR\textsubscript{max}, an indication of impaired chronotropic competence, has a strong inverse association with coronary disease and mortality (Lauer et al., 1999; Dresing et al., 2000). Accordingly, establishing normal values for HR\textsubscript{max} at certain age groups may be of great clinical importance.

HR\textsubscript{max} at a given age is frequently estimated by the "220 – age" formula. This is usually implemented in nearly all commercial equipment for cardiac stress testing. However, the validity of this formula has often been questioned (Tanaka et al., 2001; Robergs & Landwehr, 2002; Brubaker & Kitzman, 2011). Another formula for age prediction of HR\textsubscript{max} based on a combined meta-analysis and a cross-validation in a sample of 514 healthy subjects, was proposed by Tanaka et al. in 2001. The formula \(208 - 0.7 \times \text{age}\) yield more precise esti-
mates of HR_max over a wide age range. More recently, Gulati et al. reported an overestimation of HR_max by the 220 – age formula in females referred for exercise testing and called for gender-specificity when incorporating parameters of HR response to exercise in clinical practice (Gulati et al., 2010). Others have proposed that factors such as body mass index (BMI), smoking, and physical activity status may also influence achievable HR_max (Miller et al., 1993; Zavorsky, 2000). However, most studies are limited by small or selected samples and lack of documentation of achieved exhaustion.

The aim of the present study was to develop a new prediction formula for HR_max through analysis of HR_max measured at VO2peak in a diverse population of 4635 healthy subjects and compare this formula with three commonly used prediction formulas. Furthermore, we wanted to investigate the relationship between HR_max and gender, physical activity status, BMI, and objectively measured aerobic fitness.

Materials and methods

Study population

The participants of the present study were derived from the HUNT Fitness Study, a sub-study of a large, population-based health study in Nord-Trøndelag county, in the middle of Norway. The HUNT Fitness Study was designed to obtain normal values of maximal oxygen uptake (VO2max) in a healthy, adult population. Inhabitants free from self-reported cardiovascular diseases, pulmonary diseases, cancer, hypertension, and physical disability, in three communities within the main HUNT study, were eligible for VO2max testing (n = 12 609). A brief medical interview was conducted prior to testing with a medical doctor evaluating if the subjects were eligible for maximal testing. None of the participants were on any medication considered to potentially affecting heart rate, including beta-blockers. The population is therefore considered apparently healthy. Between June 2007 and June 2008, 4635 participants (age range 19–89) accepted the invitation and completed the maximal exercise test. The HUNT Fitness Study participants were, on average, more physically active than the total HUNT population, but not different from the total healthy population in HUNT regarding age, blood pressure (systolic and diastolic), waist circumference, and blood glucose levels (Aspenes et al., 2011).

The study was approved by the Regional Ethical Committee for medical research and the Norwegian Data Inspectorate. All participants signed a document of informed consent.

Maximal exercise testing

Prior to the maximal testing, all participants carried out a warm-up period of approximately 10 min at an individualized treadmill speed. The warm-up included a brief introduction to treadmill walking or running and detailed instruction about the test procedure. Participants were then equipped with a facemask and heart rate monitor before entering the test treadmill. Oxygen uptake and heart rate were measured during an incremental, individualized treadmill protocol until exhaustion. All participants were encouraged to avoid hand-rail support. Oxygen uptake kinetics were measured directly by a portable mixing chamber gas analyzer (MetaMax II, Cortex, Leipzig, Germany) and heart rate was monitored continuously by radio telemetry (Polar S610, Polar Electro Oy, Kempele, Finland). Speed and/or inclination were increased gradually from the warm-up pace whenever the oxygen uptake flattened. An advantage of the individualized protocol with different initial workload levels is that, even in this heterogeneous population, all subjects could be brought to exhaustion within 8–12 min as recommended (Balady et al., 2010). A test was regarded maximal if the oxygen uptake did not increase more than 2 mL/kg/min despite increased workload, in combination with a respiratory exchange ratio above 1.05 and subjective rating of perceived exertion of 17 or above on the Borg 6–20 scale (Borg, 1974). Maximal heart rate was defined as the highest heart rate achieved at termination of a maximal test and consecutively noted in an individual test log. The test–retest reliability of maximal heart rate after maximal treadmill testing are provided by earlier studies and generally considered to be high (Froelicher et al., 1974; Bosquet et al., 2008). All tests were carried out by trained personnel and test equipment were routinely recalibrated. Volume ventilation was calibrated every third test and gas every fifth. Ambient air measurement was automatically checked before each test.

Covariates

BMI was calculated as body weight in kilograms divided by the squared value of height in meters and classified according to the definition suggested by the World Health Organization (“Normal”: <25; “Overweight”: 25–29.9; “Obese”: ≥30; World Health Organization, 2000). In total, 42.0%, 44.9%, and 13% of the participants were classified as normal, overweight, and obese, respectively. More men than women were considered overweight (56% vs 34% for men and women), while the percentage of obese participants were similar for both genders. Self-reported physical activity was classified according to the updated recommendations from the American College of Sports Medicine/American Heart Association as “Inactive” for less than once a week of self-reported activity, “Less than recommended” for less than 150 min/week of self-reported activity, and “Recommended activity” for 150 min or more per week of self-reported activity at moderate or high intensity (Haskell et al., 2007). Smoking status was self-reported and categorized as “Never smoked or quit smoking” and “Daily or occasional smoker”. Peak oxygen uptake was categorized as gender-specific tertiles (cut-off values, <32.0, 32.0–38.9, and ≥39.0 mL/kg/min and <40.0, 40.0–47.9, and ≥48.0 mL/kg/min for women and men, respectively).

Statistical procedures

Only subjects that fulfilled the criteria of a maximal test, with registered maximal heart rate (HR_max), were included in the analysis (n = 3320). General linear modeling was used to determine the effect of age on HR_max. HR_max was entered as the dependent variable and age as the independent variable. Nonlinearity of the relationship between age and HR_max was investigated by including polynomial terms to the regression model. In a subsequent analysis, the effects of gender, BMI, physical activity status, and maximal oxygen uptake were examined by entering these factors as independent variables in addition to age. In further subsequent models, interaction terms were included as well to assess effect modification. The continuous variables were checked for normality, homogeneity of variances, and heteroscedasticity of the residuals.

Validation of prior formulas was done by comparing mean predicted HR_max by the former formulas with measured HR_max within age groups. Age was categorized into 10-year age groups (i.e., 19–29 years, 30–39 years, . . . , 60–69 years, >70 years). Prediction error and total error by applying the different formulas to the present population were calculated for the total population and within subgroups of age. Prediction error was calculated as the
Table 1. Descriptive data for the total, male, and female participants

<table>
<thead>
<tr>
<th></th>
<th>Total</th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>3320</td>
<td>1726</td>
<td>1594</td>
</tr>
<tr>
<td>Age (years)</td>
<td>46.1 ± 12.8</td>
<td>46.9 ± 12.8</td>
<td>45.3 ± 12.7</td>
</tr>
<tr>
<td>Anthropometrical data</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height (cm)</td>
<td>173.2 ± 9.0</td>
<td>179.6 ± 6.3</td>
<td>166.2 ± 5.8</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>77.6 ± 13.6</td>
<td>85.3 ± 11.2</td>
<td>69.1 ± 10.8</td>
</tr>
<tr>
<td>BMI (kg·m⁻²)</td>
<td>25.8 ± 3.4</td>
<td>26.4 ± 3.1</td>
<td>25.0 ± 3.7</td>
</tr>
<tr>
<td>Smoking status (% yes/no)</td>
<td>22.5/77.5</td>
<td>22.7/77.3</td>
<td>22.4/77.6</td>
</tr>
<tr>
<td>Resting heart rate (beat/min)</td>
<td>59 ± 9.5</td>
<td>57 ± 9.1</td>
<td>60 ± 9.7</td>
</tr>
<tr>
<td>Treadmill data</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VO₂max (mL/kg/min)</td>
<td>41.8 ± 9.3</td>
<td>45.9 ± 8.9</td>
<td>37.3 ± 7.5</td>
</tr>
<tr>
<td>VO₂peak (L/min)</td>
<td>3.24 ± 0.90</td>
<td>3.88 ± 0.71</td>
<td>2.55 ± 0.48</td>
</tr>
<tr>
<td>Maximal heart rate (beat/min)</td>
<td>182 ± 13.6</td>
<td>182 ± 14.1</td>
<td>182 ± 13.0</td>
</tr>
<tr>
<td>Heart rate difference (beat/min)</td>
<td>123 ± 15.3</td>
<td>125 ± 15.5</td>
<td>121 ± 14.8</td>
</tr>
<tr>
<td>Ventilation (L/min)</td>
<td>108.6 ± 9.6</td>
<td>129.2 ± 23.7</td>
<td>86.4 ± 16.3</td>
</tr>
<tr>
<td>RER</td>
<td>1.14 ± 0.05</td>
<td>1.14 ± 0.05</td>
<td>1.14 ± 0.05</td>
</tr>
<tr>
<td>Peak RPE</td>
<td>18 ± 0.96</td>
<td>18 ± 0.95</td>
<td>18 ± 0.96</td>
</tr>
<tr>
<td>Physical activity data (N)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inactive (%)</td>
<td>501 (15.1)</td>
<td>339 (19.6)</td>
<td>162 (10.2)</td>
</tr>
<tr>
<td>Less than recommended (%)</td>
<td>1999 (60.2)</td>
<td>958 (55.5)</td>
<td>1041 (65.3)</td>
</tr>
<tr>
<td>Recommended activity (%)</td>
<td>800 (24.1)</td>
<td>418 (24.2)</td>
<td>382 (24.0)</td>
</tr>
</tbody>
</table>

Abbreviations: N, number of subjects; SD, standard deviation; BMI, body mass index; VO₂max, maximal oxygen uptake, heart rate difference, maximal heart rate – resting heart rate; RER, respiratory exchange ratio; RPE, rate of perceived exertion on Borg 6–20 scale. “Recommended” and “less than recommended” activity were categorized according to the updated recommendations from American College of Sports Medicine/American Heart Association (2011). Treadmill data variables refer to maximal values during the test.

Results

In the present study, 3320 subjects (1594 women and 1726 men, age range 19–89 years) were included based on HRmax during a graded maximal treadmill test. Descriptive statistics of the population is presented in Table 1. HRmax was inversely and linearly related to age in the total sample expressed by the following regression equation:

\[ \text{HR}_{\text{max}} = 211 - 0.64 \cdot \text{age} \]

Inclusion of polynomials did not improve on the fitness of the model. A standard error of the estimate of 10.8 beats/min demonstrated a substantial variation in HRmax, which was evident across the full age range.

Individual HRmax values with age for the total sample of men and women are presented in Fig. 1. Women had a statistically significant, although negligibly, lower HRmax adjusted for age (difference in women vs men, −1.4 beats/min, \( P < 0.001 \)). Subjects reporting physical activity habits in accordance with the ACSM/AHA recommendations showed a slightly lower HRmax adjusted for age than the “Inactive” and “Less than recommended” activity groups (difference in “Recommended” vs “Inactive”, −3.4 beats/min, \( P < 0.001 \)). When we divided subjects into gender-specific tertiles of peak oxygen uptake, we found no age-adjusted differences in women (\( P = 0.18 \)), while low-fit men (first tertile) showed a slightly lower HRmax than the most fit (third tertile, difference in low vs high fit, −2.4 beats/min, \( P = 0.003 \)). Obese subjects (BMI ≥ 30) showed a modestly decreased HRmax compared with the overweight and normal weight groups (difference in “Obese” vs “Normal weight”, −2.3 beats/min, \( P < 0.001 \)). There was no statistical evidence for a difference in age-adjusted HRmax between smokers and nonsmokers (\( P = 0.43 \)). A multivariate blockwise regression analysis revealed that age alone accounted for 36% of the explained variance (\( R^2 \), 0.36), while the inclusion of gender, physical activity, smoking, and BMI categories added virtually no contribution to the explained variance in the total population (\( R^2 \) change, 0.007). Inclusion of VO₂peak categories in gender-specific models or VO₂peak as a continuous variable in the full model did neither increase \( R^2 \) considerably.

Inclusion of interaction terms indicated that the rate of decline in HRmax by age was not significantly influenced by gender (\( P = 0.16 \)), physical activity status (\( P = 0.08 \)), smoking status (\( P = 0.62 \)), or BMI (\( P = 0.27 \)). The interaction between age and tertiles of VO₂peak was not significant among men (\( P = 0.19 \)) or women (\( P = 0.19 \)).

Validation of the previously suggested HRmax formulas showed that both the widely used equation initially proposed by Fox et al. (220 – age; 1971), the more recent equation by Tanaka et al. (2001), and the female-based
equation by Gulati et al. (2010) underestimated measured HR_{max} in the present population (Table 2, Figs 2 and 3). A tendency toward more substantial underestimation at older ages, particularly from the 220–age equation and the Gulati equation, was indicated by the slopes of the regression lines and increasing prediction error within older age groups (Table 3). In our sample, 76.6% (2543) of subjects had a HR_{max} above the value calculated from the 220-age formula and 23.4% (777) did not reach the predicted value. Among those under 40 years of age, however, 60.9% had values above predicted HR_{max} from 220–age, while the corresponding percentages for 40–60 years and above 60 years were 81.8% and 88.8%.

For the Tanaka formula (208–0.7·age), 74.3% of the subjects had HR_{max} above the predicted heart rate for

\[
\begin{align*}
\text{HUNT-formula (211-0.64 age)} & \quad (y=211-0.64 \times x) \\
\text{Tanaka-formula (208-0.7 age)} & \quad (y=208-0.7 \times x) \\
\text{220-age} & \quad (y=220)
\end{align*}
\]

Fig. 1. Individual values and regression lines depicting the relation between maximal heart rate and age for men and women.

Fig. 2. Distribution of HR_{max} predicted by established formulas using HUNT Fitness Study data.

Fig. 3. Distribution of HR_{max} in the female sample predicted by the Gulati formula and the HUNT formula using HUNT Fitness Study data.

**Table 2. Measured and predicted HR_{max} stratified by age in total sample**

<table>
<thead>
<tr>
<th>Age groups</th>
<th>HR_{max} (achieved)</th>
<th>HR_{max} (220-age)</th>
<th>HR_{max} (Tanaka)</th>
<th>HR_{max} (Gulati)*</th>
<th>Peak RPE</th>
<th>Peak RER</th>
</tr>
</thead>
<tbody>
<tr>
<td>19–29 (n = 399)</td>
<td>195 ± 9.9</td>
<td>195</td>
<td>191</td>
<td>184</td>
<td>19</td>
<td>1.16</td>
</tr>
<tr>
<td>30–39 (n = 687)</td>
<td>189 ± 10.1</td>
<td>184</td>
<td>183</td>
<td>175</td>
<td>18</td>
<td>1.15</td>
</tr>
<tr>
<td>40–49 (n = 923)</td>
<td>183 ± 10.9</td>
<td>175</td>
<td>177</td>
<td>167</td>
<td>18</td>
<td>1.14</td>
</tr>
<tr>
<td>50–59 (n = 795)</td>
<td>176 ± 11.6</td>
<td>165</td>
<td>170</td>
<td>158</td>
<td>18</td>
<td>1.14</td>
</tr>
<tr>
<td>60–69 (n = 440)</td>
<td>171 ± 12.3</td>
<td>156</td>
<td>163</td>
<td>150</td>
<td>18</td>
<td>1.13</td>
</tr>
<tr>
<td>70+ (n = 76)</td>
<td>164 ± 12.4</td>
<td>146</td>
<td>156</td>
<td>140</td>
<td>18</td>
<td>1.12</td>
</tr>
</tbody>
</table>

*Predicted scores from the female sample. ±, standard deviation from the mean.

HR_{max}, mean maximal heart rate; 220-age, predicted HR_{max} from the formula 220-age; Tanaka, predicted HR_{max} from 208-0.7 (age); Gulati, predicted HR_{max} from 206-0.88-age; RPE, rate of perceived exertion from the Borg 6–20 scale; RER, peak respiratory exchange ratio.
their age. However, the percentage was quite stable across age groups as expected from the slopes of the regression lines ($β = -0.64$ in the present study and $β = -0.7$ in the study by Tanaka et al.) and the mean differences in 10-year categories were less than for the 220–age equation, as shown in Table 3 (prediction error range 0–17 and 4–7 for the 220–age and Tanaka equation, respectively).

Applying the female-based equation proposed by Gulati et al. to our female population showed the most substantial underprediction. As indicated in Table 3, the mean underprediction increased with age from −10 beats/min in the 20- to 29-year-old group to −23 beats/min among those above 70 years old.

**Discussion**

The present study presents normal values of maximal heart rate ($HR_{\text{max}}$) for 3320 healthy subjects across a wide age range with uniform maximal testing. $HR_{\text{max}}$ was linearly and inversely related to age explained by the formula; 211 – 0.64-age (SEE = 10.8, $r = 0.60$). The standard error of the estimate is in accordance with numerous studies investigating the relationship between $HR_{\text{max}}$ and age (Sheffield et al., 1978; Tanaka et al., 2001; Robergs & Landwehr, 2002; Wohlfart & Farazdaghi, 2003; Gulati et al., 2010). Moreover, our data suggest that $HR_{\text{max}}$ at certain age groups may be higher than suggested by previous studies (Tanaka et al., 2001; Brawner et al., 2004; Gellish et al., 2007; Gulati et al., 2010; Zhu et al., 2010).

$HR_{\text{max}}$ was adequately explained by age alone and we could not find evidence of interaction with gender, self-reported physical activity, smoking status, $VO_{2\text{peak}}$ categories, or BMI categories. This finding is in line with many previous population-based studies (Fitzgerald et al., 1997; Tanaka et al., 2001; Gellish et al., 2007), but contrasts with others (Wohlfart & Farazdaghi, 2003; Whyte et al., 2008; Zhu et al., 2010). We found only small differences in age-adjusted $HR_{\text{max}}$ across categories of $VO_{2\text{peak}}$ and physical activity with all mean differences being within a few beats. However, that physically active subjects showed a slightly lower $HR_{\text{max}}$ than the inactive counterparts is in accordance with previous studies (Zavorsky, 2000). Our finding that smoking status was not associated with mean $HR_{\text{max}}$ was somewhat surprising as cigarette smoking is reported to be strongly associated with an attenuated HR response to maximal exercise in previous epidemiological studies (Lauer et al., 1997). A possible explanation could be that the present population was rather healthy and smoking may not have substantially affected the chronotropic ability of the subjects. The rate of decline of $HR_{\text{max}}$ with age was similar also for normal weight, overweight, and obese subjects. Although obese subjects showed a slightly lower mean $HR_{\text{max}}$ the difference was not enough to propose separate equations for normal weight and obese subjects. While the percentage of obese participants was quite low, it still contained 578 subjects, which are considerably more than previous studies including obese participants (Miller et al., 1993; Franckowiak et al., 2011).

**Validity of previously proposed equations**

Our study confirms the findings of several large studies claiming that the long-lived 220-age prediction equation, originally derived by Fox et al. (1971), substantially underestimates $HR_{\text{max}}$ with increasing age (Sheffield et al., 1978; Tanaka et al., 2001; Gellish et al., 2007).
Previous studies suggest that the 220-age formula overestimates $HR_{max}$ in young individuals, corresponds to actual $HR_{max}$ around 40 years of age, and then increasingly underestimates objectively measured values (Tanaka et al., 2001; Gellish et al., 2007). In our study, however, the underestimation by applying the 220-age formula starts already in the 30- to 39-year-old groups, while it seems to be rather accurate in the 20s. Among 60–69 year olds, the 220-age formula yields a mean underprediction of 15 beats/min, which given a total error of the estimate of 20.2 may lead to a predicted value $\geq$35 beats/min below the actual attainable $HR_{max}$ in certain subjects.

The findings in the present study are in close accordance with a study by Tanaka et al. which reported the association between $HR_{max}$ and age to be 208 – 0.7-age (Tanaka et al., 2001). Their equation was based on a large meta-analysis and cross-validated in a laboratory-based study including 514 voluntary subjects and was approved by a longitudinal follow-up study (Gellish et al., 2007). However, a mean underprediction of 4–7 beats/min is evident also by applying their formula to the present data.

We could not confirm the findings of Gulati et al. (2010), who reported that women had lower $HR_{max}$ than predicted from the 220-age equation, which they inaccurately interpreted as a male-based standard. In their large-scale study of asymptomatic women, only 25% of the participants achieved 100% or more of their age-predicted $HR_{max}$ from 220 – age. In our study, however, 75% of the female participants achieved 100% or more of their predicted value. In men, 78% achieved $HR_{max}$ above this threshold, also indicating that the gender differences were minor. The study by Gulati et al. did not report indicative measures of maximal effort (e.g., rating of perceived exertion, respiratory exchange ratio or flattening of HR, or oxygen uptake kinetics) and it may be speculated that the use of a symptom-limited protocol resulted in the termination of the test before maximal effort was attained.

**Clinical implications**

A reasonable accuracy of age-predicted maximal heart rate is of major importance in a number of clinical settings. First, inability to increase HR to “normal” age-specific values, commonly termed chronotropic incompetence (CI), is increasingly appreciated as a risk factor for cardiovascular disease and mortality (Lauer et al., 1996, 1999; Nishime et al., 2000; Myers et al., 2007; Brubaker & Kitzman, 2011). However, the widespread use of the 220-age formula in predicting $HR_{max}$ in clinical evaluation of CI may be bothersome. Given that multiple large-scale studies fail to validate the 220-age formula in different populations, using this formula as a reference to “normal” response seems quite arbitrary. Accordingly, Gulati et al. (2010) found that CI defined as being $\geq$1 standard deviation below the population-specific mean $HR_{max}$ was a stronger predictor of premature mortality than applying the 220-age equation. Furthermore, clinical exercise tests are commonly termed “nondiagnostic” if the subject reaches a target heart rate, typically 85% of their age-predicted $HR_{max}$ without signs of ischemia (Amsterdam et al., 2010). Consequently, underprediction of $HR_{max}$ (i.e., by applying the 220-age formula to older subjects) yields a great risk of a false negative result as a relatively high workload may sometimes be necessary to achieve an ischemic state of the heart (Cuming, 1972; Gianrossi et al., 1989; Iskandrian et al., 1989; Balady et al., 2004). Using 85% of 220 – age in our study would result in only 23.6% of the population reaching a target of 85% of their actual $HR_{max}$. Even using 100% of 220 – age would result in a substantial number of subjects not reaching 85% of their actual $HR_{max}$. As the individual variation is high, using 85% of our predicted value would still result in only about half of our study group reaching 85% of their real $HR_{max}$. Only using 100% of the predicted values as a target will result in nearly all subjects reaching at least 85% of their individual $HR_{max}$. Finally, in training and rehabilitation programs, recommended intensity of exercise is commonly prescribed to specific HR target zones, based on the linear association between HR and oxygen consumption. Prediction of HR initial to exercise may therefore result in a workload above, or more likely, below the intended exercise intensity, particularly if making use of some of the former formulas. Moreover, directly measured $HR_{max}$ is clearly beneficial to age-predicted $HR_{max}$ in most of the aforementioned settings and is recommended when practically possible.

**Strengths and limitations**

The main strengths of the present study are a population-based design including both genders across a wide age range. The treadmill protocol was designed to ensure a true maximal effort of the subjects by individual adjustment of workload (i.e., speed and inclination of the treadmill) in response to the oxygen uptake and heart rate kinetics. Nevertheless, the VO$_{2max}$ criteria in the present study were not very strict and the test protocol was not designed to evaluate $HR_{max}$ specifically, possibly resulting in some subjects not reaching a true $HR_{max}$. However, we tried different cut-off values for the peak Borg scale rating and RER, and found no improvement in the accuracy of prediction by increasing the cut-off values to Borg scale $\geq$18 and RER $\geq$1.10. Moreover, as the human heart rate response to exercise is assumed to plateau at a fixed maximum, and no other variables seemed to influence the relationship substantially, we believe that the high heart rate reported is an indication of a valid test procedure. We further speculate that the ability of the subjects to give a maximal voluntary effort, which may be influenced by exercise test procedure,
subject motivation and physical ability, is the main reason for the differences in mean \( \text{HR}_{\text{max}} \) across population samples. It may also be a strength of the present study that the participants in this study were very fit, as indicated by high mean \( \text{VO}_{\text{max}} \) values, as fit individuals may be more able and motivated to put forth a strenuous effort.

The cross-sectional design does not allow for examination of individual changes in \( \text{HR}_{\text{max}} \) over time. A longitudinal design may be superior to a cross-sectional design when aging effects are the main concern. However, for prediction of \( \text{HR}_{\text{max}} \) by age, individual changes with aging may be of less importance as long as the prediction is satisfactory. Two recent prospective studies have longitudinally examined the relationship between \( \text{HR}_{\text{max}} \) and age, both claiming that the rate of decline in \( \text{HR}_{\text{max}} \) with increasing age is best described as curvilinear rather than linear (Gellish et al., 2007; Zhu et al., 2010). The curvilinear relationship of \( \text{HR}_{\text{max}} \) to age is rarely confirmed in population-based cross-sectional studies, including this study (Inbar et al., 1994; Tanaka et al., 2001; Gulati et al., 2010). Nevertheless, Gellish et al. (2007) concluded that a linear model would be preferable to a less practically interpretable nonlinear model as they found only minor differences in model fit. The proposed regression equation was developed in the present material. Thus, it is (per definition) the best fit to the present data, compared with all other formulas. However, to statistically compare it with, i.e., the Tanaka formula, the material has to be validated in a different sample.

The population in the present study was free from cardiovascular disease, hypertension, and cancer and is thereby considered apparently healthy. The proposed regression equation may therefore not be suitable for some patients groups and previously suggested equations specifically determined for these groups may yield more accurate estimates (Fernhall et al., 2001; Brawner et al., 2004). More large-scale studies are also needed to confirm the HR-age relationship in obese subjects. However, our population is fairly comparable to the total healthy population in the HUNT study and may thereby be a reasonable reference to other predominantly healthy free-living populations.

**Perspectives**

Our results support several studies in demonstrating that the traditional 220-age formula is inappropriate in predicting \( \text{HR}_{\text{max}} \), especially in older subjects. Furthermore, the rate of decline in \( \text{HR}_{\text{max}} \) with age was not influenced by gender substantially, physical activity status, maximal oxygen uptake, smoking, or body mass index, indicating that \( \text{HR}_{\text{max}} \) predicted by age alone may be practically convenient for various groups. However, a standard error of the estimate of 10.8 beats/min must be accounted for when applying the formula 211 – 0.64-age to clinical settings, and a maximal test may be preferable when possible.

**Key words:** maximum heart rate, HUNT, population sample, clinical testing.

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