Heart rate prescriptions from performance and anthropometrical characteristics

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ABSTRACT

ROECKER, K., A. M. NIESS, T. HORSTMANN, H. STRIEGEL, F. MAYER, and H.-H. DICKHUTH. Heart rate prescriptions from performance and anthropometrical characteristics. Med. Sci. Sports Exerc., Vol. 34, No. 5, pp. 881–887, 2002. Purpose: Heart rate (HR) is widely used to adjust exercise intensity in aerobic training. Training HR recommendations are calculated often from simple equations. Because at lactate steady state (LASS) may be an intensity of exercise effecting similar objective measures of intensity and similar subjective measures of metabolism, it is an appropriate intensity upon which to base aerobic-training prescription. The purpose of this research was to develop regression equations using age and other easily accessible characteristics to estimate the HR associated with LASS (HR_LASS). Methods: The data of 7397 healthy subjects (age ≥ 10 yr, 5044 male, 2353 female) with different training habits were analyzed. All participants were tested in an incremental exercise test on the treadmill until subjective exhaustion. The LASS was determined by the concept of blood lactate at the “lactate threshold” plus a net increase of 1.5 mmol·L⁻¹. The interdependence of further characteristics was tested by stepwise multiple regression. Results: Age alone did not allow a precise prediction of HR_LASS (r = 0.645 for all participants), regardless of adjustment by sex, training state, body mass, or performance characteristics using ANCOVA. Resting HR (HRrest) decreased steeply within the second life decade but not with further advancing age. The best discrete lactate-independent predictor for HR_LASS was HR_max (r = 0.798). Inclusion of age and weight in the model resulted in only a small improvement of the prediction (r = 0.826). Other anthropometrical characteristics could not improve the model further. Conclusions: The use of age alone seems too imprecise for exactly driven aerobic training prescriptions. A minor improvement can be achieved in this objective by use of HR_max supplemented by age using a multiple regression model. Key Words: AGING, EXERCISE, CARDIOVASCULAR, ADOLESCENCE, AEROBIOSIS, EXERCISE TEST, TRAINING, HEART RATE-PHYSIOLOGY

Heart rate (HR) is proportional to the work rate in physical activities with aerobic energy supply. The relationship between HR and workload is highly reproducible for any individual (3). The simple way of registering HR has made it the most widely used estimate of metabolic strain in training or competition for many kinds of sports (2,19,33,38).

Standardizing exercise intensity based on HR measurements is a prerequisite for using HR measurements in sports. Absolute HR values show high differences at objectively identical exercise intensities among individuals. In other words, the relationship between absolute HR values and the actual metabolic strain is not the same for each person. Several efforts have been made using secondary characteristics to derive the most relevant rule for calculating a target HR. The American College of Sports Medicine (ACSM) recommends the use of a percentage of the maximum HR (%HR_max) as a guideline. An exercise level of 60–90% HR_max is described as moderate, whereby 90% HR_max is set as an upper limit for aerobic training. To improve the accuracy of HR prescriptions, Karvonen and Vuorimaa (24) suggested the use of the difference between the actual HR and the resting HR (HRrest). Other equations that allow for an ongoing increase of metabolic acidosis up to a time duration of 1 h and more (5,37). This enables the HR at LASS (HR_LASS) to be used as a preferred marker for training load to minimize ineffectively high training intensities. Many

Target Heart Rate = 200 – (Age × 0.7)  

This equation assumes a decline of 4 beats-min⁻¹ for each 5 yr of age. To further increase precision, other authors used the HR at the so-called ventilatory anaerobic threshold (VT) (19,20), the moment of the first blood lactate increase (LT), the individual anaerobic threshold (IAT) (7), or the onset of blood lactate accumulation (OBLA) (12,34) as reference points to calculate HR prescriptions. Coplan et al. (11) recommended the HR at VT as an upper intensity limit for patients suffering from coronary heart disease. On the other hand, running velocity at IAT corresponds closely to the marathon performance of competitive runners (17,32,34). By definition, the IAT or “lactate steady state” (LASS) determines the highest possible exercise intensity without ongoing increase of metabolic acidosis up to a time duration of 1 h and more (5,37). This enables the HR at LASS (HR_LASS) to be used as a preferred marker for training load to minimize ineffectively high training intensities. Many
studies reported that metabolic measures at the LASS, LT, or VT are much more stable than using calculations based on VO\textsubscript{2max} values (9,35).

Unfortunately, it is not possible to test each subject who is active in sports in a laboratory. Instead, the mentioned equations, including age or HR\textsubscript{max}, are used as substitutes. On average, the range from 75% to 90% HR\textsubscript{max} (19,20,22,33) has been reported for HR\textsubscript{LASS} prediction in the past. The corresponding percentages did not differ with respect to gender (19,20). Patients and sedentary subjects showed a clearly lower ratio of HR\textsubscript{LASS} to HR\textsubscript{max} than trained athletes in these studies. Both relationships, between HR\textsubscript{max} to age or HR\textsubscript{max} to HR\textsubscript{LASS}, are very variable for different individuals (38,39).

Thus, simple rules for HR prescriptions may be imprecise. Although this scattering was reported many years ago (25), only few uses of this finding have found their way into everyday training practice.

Earlier publications about the age dependence of HR included smaller subject populations than this study, which analyzes a much larger sample to achieve more exact predictability. We tried to evaluate the relationships between HR\textsubscript{LASS}, HR at rest and at maximum exhaustion, age, and the type of training in large groups of active and sedentary people. The use of age or HR\textsubscript{max} in HR prediction equations for aerobic cardiovascular training are examined compared with HR\textsubscript{LASS} as reference point.

**MATERIALS AND METHODS**

**Subjects.** A total of 7397 Caucasians (5044 men, 2353 women) in the age span between 10 and 70 yr underwent routine exercise testing in a sports-medical outpatient clinic. None of the included subjects received cardiovascular active medication before the exercise test, and none suffered from metabolic or cardiovascular disease. Body weight, height, and total lung capacity were measured before the exercise test. Total body fat percentage was measured by the skinfold caliper technique of Brozek et al. (6) at three measuring sites. The anthropometric characteristics for the subjects are shown in Table 1. The procedures were in accordance with the ethical standards of the Ethics Committee at the University Hospital Tuebingen and the Helsinki Declaration of 1975. All subjects gave their written informed consent to the use of their data for participation in the study.

The subjects were divided in three groups according to their training habits. Group ET (N = 4272) performed ≈2 h of endurance training per week and/or participated in endurance sports competitions. Group ST (N = 2169) were predominantly power trained. They performed ≥2 h/wk in team, racket, or power sports. The members of group UT (N = 956) were predominantly sedentary.

**Exercise test.** All subjects performed an exercise test on a treadmill (Saturn HP Cosmos, Traunstein, Germany), where velocity was increased incrementally until subjective physical exhaustion. The initial workload was 4, 6, or 8 km·h\textsuperscript{-1}, depending on the capacity of the subject. Running velocity was increased by 2 km·h\textsuperscript{-1} at 3-min intervals. The room temperature was maintained at 20°C and 50% humidity by an air-conditioning system. Most tests (about 95%) were performed in the morning hours with the subject in a postprandial state.

**Blood lactate measurements.** Capillary blood samples were drawn from the earlobe to measure lactate concentration at rest and at the end of each exercise level. Measurement of the lactate concentration was performed enzyme-chemically from hemolyzed whole blood (ESAT, Eppendorff, Germany). LASS was calculated in a software routine from the interpolated course of the blood lactate curve as described previously (13,32). A special software (Ergonizer, Freiburg, Germany) was used for investigator-independent calculation based on an equalizing SPLINE interpolation procedure (32). The lactate threshold (LT) was taken at the start of the increase in blood lactate concentration. LASS was defined as running velocity at a net lactate increase of 1.5 mmol·L\textsuperscript{-1} above the blood lactate concentration at LT.

**Heart rate measurements.** HR\textsubscript{rest} was recorded by surface ECG. The subjects were in an upright sitting position for about 3 min and were asked to hold their breath for 10 s. HR\textsubscript{rest} was registered as average value within this time span. There was only one other person than the subject in the exercise laboratory with closed doors. Talking was not allowed during the measuring phase. During the exercise test, HR was registered at the end of each stage. Maximum HR (HR\textsubscript{max}) was measured at the moment when maximum exhaustion was achieved. The range from HR\textsubscript{rest} to HR\textsubscript{max} was used as HR reserve (HR\textsubscript{r}) as mentioned by Karvonen et al. (24) (Eq. 2):

\[
HR_r = HR_{\text{max}} - HR_{\text{rest}}
\]  

HR at LASS (HR\textsubscript{LASS}) was taken from the interpolated course of exercise HR. This course was fitted with a SPLINE interpolation procedure as previously described for the lactate curve.
Statistics. Administration, selection and calculation of data were made using a relational database (ORACLE, Redwood Shores, CA). Statistical calculations were performed using the software JMP (SAS Institute, Cary, NC) and KaleidaGraph (Abelbeck, Reading, PA) on a personal computer (Apple Macintosh, Cupertino, CA). Mean values are presented as means ± standard deviation (SD). To test the distributions for normality, we used the Kolmogorov-Smirnov-Lilliefors test. With a resulting probability of \( P > 0.05 \), we considered a normal distribution. For comparative statistics, we applied simple linear regressions. The precision of the correlation coefficients was presented as 95% confidence interval (CI). To calculate confidence limits from correlation coefficients, Fisher’s Z-transformation was used. To test differences between the groups for significance, we applied a one-way ANOVA with a Tukey-Kramer HSD test for all pairs with an alpha-level of 0.05. The data of the UT, ET, and ST were adjusted against independent variables like weight, height, or age by way of a multiple ANCOVA.

The influence of additional variables was tested using a so-called forwarding multiple stepwise regression (I). A probability of \( P = 0.250 \) was the limit for entering additional parameters into the model.

RESULTS

Among all tested subjects (\( N = 7397 \)), \( HR_{\text{max}} \) was found to be significantly higher for women (195.2 ± 11.8 beats-min\(^{-1}\)) than for men (191.2 ± 13.0 beats-min\(^{-1}\)). Admittedly, after adjusting according to age, no significant difference in \( HR_{\text{rest}} \), \( HR_{\text{LASS}} \), or \( HR_{\text{max}} \) remained. Due to this finding, we performed no further gender differentiation with the data.

Mean lactate at LASS was 3.21 ± 0.85 mmol-L\(^{-1}\) and 8.52 ± 2.35 mmol-L\(^{-1}\) at maximum exhaustion, whereby 245 subjects did not reach 5.0 mmol·h\(^{-1}\).

The HR and other exercise test results are listed in Table 2. The clear age difference between ST and both UT and ET was considered in the analyses of any differences in the HR values using adjustments by ANCOVA (see Table 1). As expected, the mean velocities for the ET group were the highest in comparison with ST and UT. The other age-related differences are explained in the further sections.

The mean values for \( HR_{\text{rest}} \) were significantly lower for ET than for ST and UT (Table 2). \( HR_{\text{rest}} \) decreased steeply and significantly between the age of 10–30 yr but did not change with advanced age (Fig. 1). Beyond the age of 30 yr, \( HR_{\text{rest}} \) levelled out with no further significant changes in this age span. No significant differences were found in the age groups beyond the age of 25 yr (Fig. 1). This finding was independent from the gender or training habits of the subjects (Fig. 2).

The mean \( HR_{\text{LASS}} \) was lowest for UT, slightly higher for ET, and remarkably higher for ST, whereby all of these differences were statistically significant after adjustment by age and anthropometric data (Table 2). The mean \( HR_{\text{max}} \) decreased between the ages of 10–20 yr and levelled out significantly between the ages of 20–30 yr before further decreasing (Fig. 1). This levelling was observed particularly in the UT and ET groups but not in the ST group. \( HR_{\text{max}} \) was higher in ET than in UT and ST beyond age 25 and showed no difference with an age of less than 25 (Fig. 3). This resulted in significantly different ratios of \( HR_{\text{LASS}} \) to \( HR_{\text{max}} \) for ET (90.2 ± 3.83% versus ST (91.5 ± 4.04%) and UT (86.6 ± 6.74%).

The results of linear regressions between the various HR values and \( v_{\text{max}} \) are displayed in Table 3. \( HR_{\text{rest}} \) showed a higher correlation (\( r = 0.398; \text{CI} 0.379–0.417 \)) versus the maximum running velocity than \( HR_{\text{max}} \) (\( |r| = 0.083; \text{CI} 0.06–0.11 \)) or \( HR_{\text{LASS}} \) (\( |r| = -0.153; \text{CI} 0.09–0.19 \)).

![FIGURE 1—Mean heart rate values with ±SD for age groups in 5-yr intervals for all tested subjects (\( N = 7397 \)). \( HR_{\text{max}} \), maximum heart rate in the exercise test; \( HR_{\text{LASS}} \), heart rate at the lactate steady state; \( HR_{\text{rest}} \), heart rate at rest (upright sitting position); * indicates a significant difference of the marked group to all subsequent groups using a Tukey-Kramer HSD (comparison of all groups).](image-url)
any fixed percentage of this value) provides no better prediction for HR_{LASS} than HR_{max}. As displayed, HR_{max} was the best single predictive factor for HR_{LASS}. HR_{max} decreased linearly with no deviation during a specific age span (Fig. 1). With a maximum blood lactate concentration less than 5 mmol·L^{-1}, more subjects may not have reached their maximum exhaustion. Nevertheless, the quality of the predictions remained unchanged after exclusion of these subjects.

For the prediction of HR_{LASS} derived from HR_{max}, the age course of the ratio between HR_{LASS} and HR_{max} becomes relevant (Fig. 4). Hereby, a decrease of the ratio up to the age of 20 in all groups is evident. For the group older than 20, the ET remains at a stable value. The UT show an increase and the ST an explicit decrease beyond the age of 20. This age course due to the difference in total mean between the groups and it is adequate to calculate distinct predictions for HR_{LASS} from HR_{max} for each single group (Eq. 3–5):

\begin{align}
UT: HF_{LASS} &= 19.9 + 0.765 \times HF_{max} \quad (R = 0.62, CI 0.593–0.639) \\
ST: HF_{LASS} &= -14.7 + 0.99 \times HF_{max} \quad (R = 0.79, CI 0.782–0.804) \\
ET: HF_{LASS} &= -1.2 + 0.911 \times HF_{max} \quad (R = 0.84, CI 0.830–0.844)
\end{align}

Hereby, the prediction for the active subjects was considerably better than for the sedentary ones. As can be seen in Figure 4, other values like age may influence HR_{LASS} systematically. To improve the predictability of HR_{LASS} or HR_{max} by including such additional characteristics, we applied a so-called stepwise multiple regression (1). Table 4 and Table 5 show the stepwise inclusion of additional measures and the particular influence on predictability expressed by the correlation coefficient. In both cases, the inclusion of additional characteristics brought significant but small enhancements of the predictions.

**DISCUSSION**

HR is widely used as an estimate of metabolic stress during aerobic exercise (2,19,33,38). Easy measurement and the linear relationship to cardiac output are main arguments for this application. Target heart rates are a tool for exercise prescription. The most commonly used references for this graduation are HR_{max} or HR_{LASS}. The LASS has proven to be a reliable reference for the actual workload expressed as specific racing velocity in runners (17,32,34). Others have shown good correlations between ventilatory thresholds and lactate increase (13,29) or the use of the LASS in several types of aerobic training (4,7,30,32,36). There is no specific recommendation to perform aerobic training at the LASS.

**TABLE 3. Correlation coefficient r for a selection of factors with regard to the heart rate for all tested subjects (N = 7397).**

<table>
<thead>
<tr>
<th>r</th>
<th>HR_{LASS}</th>
<th>Age</th>
<th>V_{max}</th>
<th>HR_{rest}</th>
<th>HR_{max}</th>
<th>HR_{r}</th>
</tr>
</thead>
<tbody>
<tr>
<td>HR_{LASS}</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>-0.634</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V_{max}</td>
<td>-0.076</td>
<td>0.019</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HR_{rest}</td>
<td>0.430</td>
<td>-0.368</td>
<td>-0.398</td>
<td>1.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HR_{max}</td>
<td>0.800</td>
<td>-0.645</td>
<td>-0.084</td>
<td>0.430</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>HR_{r}</td>
<td>0.229</td>
<td>-0.163</td>
<td>-0.153</td>
<td>0.059</td>
<td>0.396</td>
<td>1.000</td>
</tr>
</tbody>
</table>

HR_{LASS}, heart rate at the lactate steady state; V_{max}, maximum running velocity in the treadmill test; HR_{rest}, resting heart rate before the exercise test; HR_{max}, maximum heart rate; HR_{r}, heart rate reserve.
The parameters include Age, HR rest, fat-free body mass, maximum running speed in the exercise test (V max), total lung capacity, body fat percent, weight, height, gender, body mass index, and type of training. Only the four shown parameters had a significant influence to the prediction of maximum heart rate. 0.283–0.581 × age + 0.173HRrest results as best prediction equation ($r = 0.677$). The average 95% confidence interval for this prediction is 2.24 beats-min⁻¹.

The better statistical predictability of HR LASS by HR max than by age is caused partly by the fact of the limitation of the HR LASS values by the HR max itself. The condition $HR_{max}$ > $HR_{LASS}$ is absolute and narrows the distribution of the $HR_{LASS}$ values, whereby the spreading of the heart rate versus age is symmetrical.

The exercise tests in our study were performed on a treadmill. Treadmill exercise results in higher maximal and submaximal HR values than bicycle ergometry. This is due to the greater amount of muscle mass involved (14,16). Exercise test results are specific with regard to the performed type of exercise (23), but the treadmill data should be more applicable for routine conditions. Running is less limited by local muscular endurance and strength, especially for older and untrained participants. Data from maximal exercise tests on a bicycle are more influenced by leg-specific strength and than in treadmill running.

The values for HR rest did not change beyond the age of 30 in the tested population. This is in agreement with another study (27). Also, Wilmore et al. (40) found only a slight lowering of HR rest from a prospective endurance training study. By taking the decrease of HR max with age into account, a diminished chronotropic regulation potency with apparent in the ET and UT group. This nonlinear behavior makes predictions of HR LASS by any linear model with age as predicting factor less exact. Despite this levelling off, the ratio HR LASS to HR max is remarkably stable beyond the age of 20 especially for the UT and ET. The glycolytic anaerobic capacity determines a larger part of exercise above LASS especially for the ST. This could be one reason for the lower HR LASS to HR max ratio in these subjects. A possible age dependent decrease of the anaerobic capacity beyond the third life decade (8,28), and sustained aerobic power due to specific training adaptions in the ET group may be responsible for their higher HR LASS compared with HR max.

HR LASS can be predicted by HR max whereby the individual spreading of the values is quite high. HR max is the best predictor for HR LASS, not the age of the participants. Apparently, it is not possible to predict HR LASS based on age with the exactness that is needed in athletic training, rehabilitation, or preventive sports. The better alternative would be to perform an all-out exercise test to measure HR max where applicable. To test whether the real peak HR has been achieved, metabolic values, such as the blood lactate concentration or subjective factors, should be used. By taking the residuals from the simple regressions, about 20% of the subjects was approximated with a failure of 12 beats·L⁻¹ or more to the true HR LASS value by the HR max.

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TABLE 5. Results for the stepwise multiple regression of several parameters versus heart rate at the lactate steady state (HR_{LASS}, N = 7397).

<table>
<thead>
<tr>
<th>Step</th>
<th>Parameter</th>
<th>Probability</th>
<th></th>
<th>95% CI for $r$</th>
<th>Estimate</th>
<th>95% CI for Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Intercept</td>
<td>$&lt;0.0001$</td>
<td></td>
<td>0.798</td>
<td>0.789-0.807</td>
<td>0.777-0.798</td>
</tr>
<tr>
<td>2</td>
<td>HR_{max}</td>
<td>$&lt;0.0001$</td>
<td></td>
<td>0.815-0.830</td>
<td>-0.180</td>
<td>-0.197-0.164</td>
</tr>
<tr>
<td>3</td>
<td>Age</td>
<td>$&lt;0.0001$</td>
<td></td>
<td>0.826</td>
<td>0.817-0.833</td>
<td>-0.168</td>
</tr>
</tbody>
</table>

The parameters include Age, HR_{rest}, fat-free body mass, maximum running speed in the exercise test, total lung capacity, body fat percent, weight, height, gender, body mass index, type of training, and maximum heart rate. Only the three shown parameters lead to a significant improvement of the prediction of heart rate at the LASS. Taking these parameters into account, the equation $0.38 - 0.16 \times age + 0.168 \times weight + 0.777 \times HR_{max}$ results in the best prediction ($|r| = 0.826$). The average 95% confidence interval for this prediction is $2.20 \text{ beats-min}^{-1}$.

advancing age becomes apparent. Furthermore, calculation of HR_{r} did not deliver more exact predictions for HR_{LASS} than HR_{max}. This is confirmed by the multiple regression for HR_{LASS} (Table 5), where HR_{rest} (which is a determinant for HR_{r}) resulted in little improvement of the regression.

Cooper et al. (10) showed a significantly steeper age-related decrease of HR_{max} for less fit compared with trained people. In contrast, HR_{max} decreased for all training groups equivalently in our study. Consequently, our results confirm indirectly several other investigations which stated that training may not have influence on the chronotropic response to maximal exercise with advancing age (3,31). The applied exercise test protocol or selection criteria for the fitness factor may be due to this difference. Cooper et al. defined fitness as the ability to climb. This probably favored peripheral performance determining factors, such as leg muscle strength more than cardiovascular factors like the maximal cardiac output.

Indeed, the age-related lowering of HR_{max} and subsequently of the cardiac output has been described as major contributor for the decrease of $\dot{V}O_2_{max}$ with aging (18,21). In contrast, in a group free of coronary heart disease, Fleg (15) shows that cardiac output does not decrease with advancing age, although HR_{max} and systolic emptying are lowered. He interpreted that age-related changes to HR may be offset by an increased utilization of the Frank-Starling mechanism. Furthermore, Fleg hypothesizes an age-associated, diminished end-organ responsiveness similar to beta-adrenergic blockade for the decreased HR_{max}, increased preload, and decrease in ejection fraction at maximal effort. Endurance athletes have larger left ventricular end-diastolic volumes and have larger exercise-induced increases in ejection fraction than sedentary subjects or strength-trained athletes (16,26). Thus, endurance athletes at each age level produce a higher stroke volume index at their virtually identical HR levels in exhausting exercise (26). This effect may additionally compensate for the age-related decrease of heart rate regulation potency in endurance trained. On the other hand, it is likely that there are other factors that influence the limits of HR response for the younger age groups as compared with the older participants. A growth-related limitation of the left ventricular volume in relation to increasing body mass could be the dominant factor for the higher HR_{max} of the adolescents. Probably higher sensitivity to sympathetic beta-adrenergic stimulation is decisive in this age span, but the HR_{LASS} for the ET group decreased less with age than in the other groups.

HR_{max} or other test results depending on a maximal effort are supposedly subject to mental motivation. The spreading of HR_{max} versus age may be partly due to this influence. Admittedly, the exclusion of all participants with a maximum blood lactate concentration less than 5 mmol.L$^{-1}$ did not change the predictability of HR_{max} by age, indicating that motivational influences are low for the HR_{max} in this study.

In summary our results lead us to the following conclusions:

1. The spreading of HR values is too high for an exact age derived prediction of target HR in aerobic exercise. However, the HR_{max} values show a linear decrease of about 3–4 beats-min$^{-1}$ for each 5 yr of age.
2. Other than HR_{max}, the age related decrease of HR_{LASS} was not linear. This impedes the prediction of HR_{LASS} by linear models based on age.
3. A calculation of the difference between HR_{rest} and HR_{max} (known as heart rate reserve) does not result in better predictions for HR_{LASS} than from HR_{max}.
4. Only minor improvements for the prediction of HR_{max} and HR_{LASS} can be derived by including additional characteristics via stepwise multiple regressions.
5. HR_{LASS} as base to scale aerobic training intensity can be predicted by HR_{max} with a certain reliability depending on the type of sport performed. Whether someone should execute a more valid laboratory test has to be decided individually.
6. HR_{max} but not HR_{rest} decreases with advancing age. This leads to a diminished chronotropic regulation potency. The training habits have no special effect in the age-related decrease of HR_{max} in the tested population. Greater cardiovascular fitness in older adults may be due to other factors than HR regulation.

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