Resting Heart Rate Percentiles and Associated Factors in Children and Adolescents

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Objectives To present population-based resting heart rate (RHR) percentiles and associated factors in children and adolescents.

Study design Standardized RHR measurements with an oscillometric device were obtained from 3- to 17-year-olds who participated in the German Health Interview and Examination Survey for Children and Adolescents (n = 11 986). Age- and sex-specific RHR percentiles were derived using flexible age-dependent modeling. Linear regression was used to test associations of RHR and associated factors.

Results RHR decreased with age and mean RHR was on average 3.0 beats per minute (bpm) higher in girls than in boys ($P < .01$). The 95th RHR-KiGGS-percentile (P95) in boys and girls are up to 10 bpm lower than P95 based on pooled heterogeneous international studies and more similar to percentiles based on population data from NHANES (higher or lower by ≤5 bpm, depending on age). Factors independently associated with RHR in both sexes were age, SBP and height in children aged 3-10 years; and age, systolic blood pressure, and high aerobic fitness in adolescents aged 11-17 years. In girls, we further found an association between RHR and underweight (OR 3.3 and 4.7 for underweight girls aged 3-10 and 11-17, respectively, compared with normal weight girls). Associations between RHR and aerobic fitness, physical activity, and media use were stronger in boys than in girls.

Conclusion This study provides population-based RHR percentiles and evidence for sex-dependent associations of cardiovascular risk factors with RHR in children and adolescents, many of which are lifestyle related. *(J Pediatr 2017;187:174-81).*

The heart rate (HR) is, in addition to the respiratory rate, blood pressure (BP), and temperature, an important vital sign.[1,2] It is regulated and therefore strongly determined by the autonomic nervous system.[3] Through its sympathetic stimulation, for instance during exercise or emotional excitement, the HR increases and, in contrast, through parasympathetic activation, for instance during rest or emotional tranquility, decreases the HR.[3] In adults, the resting HR (RHR) is a predictor of cardiovascular morbidity and mortality.[4-9] In pediatric populations, a higher RHR is associated with cardiovascular risk factors such as elevated BP,[10,11] dyslipidemia,[12] weight gain,[13] high blood glucose,[12] and less physical exercise.[11,14] Because the RHR in children and adolescents decreases with age and is sex dependent,[14-17] percentile-based references are needed. However, different reference ranges for the normal RHR are published in pediatric textbooks and guidelines and often lack sources of references.[18-21] For instance, the upper RHR limit for a 12-year-old varies between 100 and 130 beats per minute (bpm),[21-23] generating clinical uncertainty. The underlying reason may be that there are few population-based studies with standardized RHR measurements. As an exception, RHR percentiles have been derived in the US with National Health and Nutrition Examination Survey (NHANES 1999-2008).[17] In addition, RHR percentiles have been derived by Fleming et al[24] from aggregated results of 69 rather heterogeneous international studies; however, these are not sex specific, despite known sex differences in the RHR.[14-17]

Therefore, the purpose of this study is to present RHR percentiles by age and sex based on a nationally representative sample of 11 986 participants of the German Health Interview and Examination Survey on Children and Adolescents (KiGGS) 2003-2006 aged 3 to 17 years and to compare these RHR percentiles with the NHANES references[17] and the percentiles from the meta-analysis done by Fleming et al.[24] The second aim of this study is to explore which cardiovascular risk factors and sociodemographic characteristics are associated with RHR in childhood and adolescence.

BMI	Body mass index
BP	Blood pressure
bpm	Beats per minute
DBP	Diastolic BP
HR	Heart rate
KiGGS	German Health Interview and Examination Survey on Children and Adolescents
NHANES	National Health and Nutrition Examination Survey
RHR	Resting HR
SBP	Systolic BP
TC	Total cholesterol
WC	Waist circumference
WtHR	Waist to height ratio

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Methods

The KiGGS 2003-2006 study is a population-based, cross-sectional, national examination survey in children and adolescents aged 0 to 17 years living in Germany. The 2-stage sampling procedure involved the selection of 167 study locations from strata according to federal state, community type, and population size.[25] Subsequently, an equal number of children per birth year from each location were identified through local population registries and invited to participate in the study. There were 17 640 children and adolescents aged 0 to 17 years who participated in the study (8654 girls and 8986 boys; response rate of 66.6%). The study was approved by the ethical committee of Charité–University Medicine, Berlin, and by the Federal Commissioner for Data Protection and Freedom of Information. Informed written consent and assent were obtained from all parents and from adolescents aged 14 years of age or older, respectively. KiGGS included 17% of children and adolescents with a 2-sided migration background; migrants from Turkey and the former Soviet Union were the 2 largest groups.[25] A computer-assisted personal interview by a study physician covered current and past medical conditions and medication within the 7 days preceding the interview. All medications were coded in accordance with the World Health Organization's Anatomic Therapeutic Chemical Classification System.

In children and adolescents aged 3 to 17 years, a reading of RHR and 2 readings of systolic BP (SBP) and diastolic BP (DBP) were obtained with an automated upper arm oscillometric device (Datascope Accutorr Plus, Mahwah, New Jersey) after a nonstrenuous part of the examination and an additional 5-minute rest in the sitting position with a height-adjustable chair with a backrest and the right forearm resting on a table at the level of the heart, the elbow slightly bent, legs not crossed, and the feet placed firmly on the floor.[26] Using 1 of 4 cuff sizes (6×12, 9×18, 12×23, or 17×38.6 cm), which had to cover at least two-thirds of the upper arm length (from the axilla to the antecubital fossa), the measurement was performed.

Measurement methods and BP reference percentiles by sex, age, and height based on KiGGS data from nonoverweight children have been reported previously.[27] For the present analysis, the mean of the 2 systolic and diastolic measurements was used and hypertension was defined at or above the 95th age-, sex-, and height-specific percentile (90th percentile for prehypertension).[27] Height was measured without shoes to the nearest 0.1 cm by using portable devices (Harpenden Stadiometer; Holtain Ltd, Crymych, United Kingdom) and weight in underwear to the nearest 0.1 kg with a calibrated scale (Seca, Birmingham, United Kingdom), both according to a standardized protocol.[25] Body mass index (BMI) was calculated as the ratio of weight (in kilograms) by height (in meters squared) and rounded to 3 digits. According to the current German reference system, BMI was categorized as underweight (<P10), normal weight (P10-P90), overweight (>P90-P97) and obese (>P97).[28,29] A non-elastic tape was used to measure waist circumference (WC) at the narrowest part of the torso, to the nearest 0.1 cm.[30] Waist to height ratio (WtHR) was calculated as WC divided by height and abdominal obesity was WtHR ≥90th percentile for age and sex.[31] Total cholesterol (TC) was measured using the enzymatic cholesterol oxidase peroxidase–antiperoxidase method (Roche, Mannheim, Germany) and elevated TC was defined as >200 mg/dL.[32] A media use index was calculated by cumulating the amount of time spent daily with television, video games, computer/Internet, listening to music, or cell phone.[33] Information on physical activity in children aged 3-10 years was parent-reported sports activities per week (≥3, 1-2, <1),[34] in adolescents aged 11-17 years it was self-reported leisure time physical activity that makes them sweat or get out of breath (0-2, 3-4, and 5 hours per week).[33] Aerobic fitness was measured in 11- to 17-year-olds with a standardized submaximal cycle ergometer test (Ergosana CE 0124, Ergosana, Beograd, Serbia).[33] The Physical Work Capacity at an HR threshold of 170 bpm (PWC170) was calculated using interpolation. PWC170 values were then divided by the body weight of the test person. The upper limits of the one-third of quintiles (boys 2.4 and girls 1.9 watt/kg) were used as cutoff points for high aerobic fitness.[33]

Of 14 835 KiGGS participants aged 3 to 17 years of age, exclusion criteria were missing or invalid RHR (<30 or ≥200 bpm) (n = 173); cardiovascular diseases, arrhythmias, or pacemakers (n = 137); abnormal thyroid function based on thyroid-stimulating hormone values[35] (n = 629); medications that could affect RHR which are listed in the **Appendix** (available at www.jpeds.com) (n = 2069); pregnancy (n = 3); and anxiety at measurement (n = 52), leaving 11 986 children and adolescents (5935 girls and 6051 boys) for the analysis (**Table I**).

RHR percentiles as a flexible function of age were modeled for boys and girls separately using the LMS method[36] with the package gamlss[37] (version 4.3-8, 2016) under R version 3.2.3 (R Foundation for Statistical Computing, Vienna, Austria). The LMS method assumes that the observed distribution of RHR values can, for a given age, be transformed to a standard normal distribution via the Box-Cox transformation based on 3 measures: the skewness (L), the median (M), and the coefficient of variation of the original data (S). From the measures L, M, and S, any desired percentile can be calculated.[36] In girls, 8 outlying values were winsorized, that is, 8 extreme values were set to the age-specific maximum of the rest of the values. For the present data, it turned out that RHR values were log-normally distributed (L = 0) with M modeled as a cubic spline and S as a linear function of age.

We explored correlations of RHR with age, height, BMI, WC, WtHR, SBP, DBP, media use, TC, physical activity, and aerobic fitness. Factors associated with RHR were further analyzed in linear regression models using SAS 9.2 (SAS Institute, Cary, North Carolina) and STATA SE14.1 (StataCorp, College Station, Texas. In a multivariable linear regression model, interactions between sex and all other independent variables were tested one at a time and $P < .10$ was considered significant. Models were run separately for the age groups 3-10 and 11-17 owing to the availability of fitness data only from age 11. Sampling weights were used to account for unequal sampling probabilities and to reflect the distribution of the population in Germany as of December 31, 2004, with respect