Reference Values for Exercise Systolic Blood Pressure in 12- to 17-Year-Old Adolescents

Claudia Hacke1,2 and Burkhard Weisser1

OBJECTIVE
In adults, blood pressure (BP) during exercise has prognostic advantages compared to resting BP, whereas its relevance for children has not been revealed as clearly. Because exercise BP among young subjects might be of clinical importance, we sought to determine reference values in adolescents.

METHODS
BP recordings at rest and during a cycle ergometer test (1.5 W/kg) were assessed in 492 teenagers (12–17 years) in the Kiel EX.PRESS Study (Exercise and PRESSure). The resting systolic BP (SBP) values at the 90th and 95th percentile of the German reference population were applied on our resting SBP distribution. The resulting resting SBP percentiles were then used to propose exercise SBP limits.

RESULTS
Of our group, 12.4% exhibited a resting SBP ≥ 90th reference percentile, with 7.9% ≥ 95th percentile. The corresponding age-group- and sex-specific percentiles were assigned to the exercise SBP distribution resulting in reference values for high normal and elevated SBP (upper limit, girls/boys, mm Hg): 172/172 for 12–13 years, 174.7/177.3 for 14–15 years, 178.5/181.3 for 16–17 years). Using these limits, exercise SBP values were elevated in 8.1%, 5.5% were within the high normal range. Normal resting SBP but at least high normal exercise SBP was found in 7.7%. In contrast, 7.4% were high normal or hypertensive at rest but normotensive during exercise.

CONCLUSIONS
Exercise BP is expected to be of additional use for the evaluation of BP in younger age groups. As long as prognostic data for exercise BP in adolescents are not available, the limits proposed might be considered in clinical practice.

Keywords: adolescents; blood pressure; blood pressure measurement; exercise; hypertension; reference values.

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The determination of exercise blood pressure (BP) has been established in the evaluation of hypertension and cardiovascular prognosis in adults,1–11 but has previously not been accounted for in children and adolescents.

BP measurement during exercise testing provides valuable information on a potentially inadequate hemodynamic response to acute exercise12 and increases the reproducibility and precision of BP recordings.4,8,11–13 However, only resting casual/office BP values are generally used to define high BP in both children and adults.14,15 Especially in younger age groups, various influences limit the reliability of resting BP measurements.16,17 On the contrary, exercise BP might be a more reliable parameter than casual BP, as it is influenced to a lesser extent by psychological factors than at rest.21 Given that the predictive power for cardiovascular disease of an exaggerated BP response during exercise appears to be superior to resting BP in adult populations, special emphasis should be laid on the exercise BP even in adolescents as well. We recently demonstrated similar or even stronger associations between classical familial risk factors and systolic BP (SBP) during submaximal exercise in adolescents.22

To date, the knowledge of BP reactions during exercise in youth is still limited, although it was assumed that an excessive increase of exercise BP precedes the onset of hypertension,23–25 and permits an early diagnosis.26–29 Therefore, exercise BP responses might be of additional clinical and prognostic value for a more detailed risk stratification in adolescents.23,24,30–32 However, agreed-upon exercise BP reference values (as often recommended for adults) do not exist for children and adolescents. Available data offer cutoff values mostly at 1.0 W/kg and 50–100 W, respectively or have been calculated using mean exercise BP ± 1 SD at 100 W, as in the case of adults.33,34

The goal of the present cross-sectional study is to propose SBP reference values during aerobic submaximal exercise in 12- to 17-year-old adolescents, which can serve as a basis for clinical evaluation. The common classification defines resting casual BP above the 95th percentile as high, and below the 90th percentile as the limit between normal and high

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normal BP in children and adolescents. Currently there are no studies investigating, which exercise BP values are in accordance to the accepted reference percentiles of resting BP in young subjects.

**METHODS**

**Study population**

All of the subjects in this study were participants enrolled in the cross-sectional Kiel EX.PRESS. Study. The aim of this study was to investigate the association between SBP response during acute exercise and several lifestyle and familial risk factors, and examinations were carried out between March 2011 and October 2012. For this purpose all public schools in Kiel, Northern Germany, were invited in a written request to the school administration. Among the initially 645 young subjects from 6 participating schools, a total of 531 healthy adolescents aged 12–17 years (271 boys and 260 girls, 14.6 ± 1.5 years) were enrolled, resulting in a response rate of 82.3%. None of the subjects had previously been diagnosed with hypertension or other cardiovascular diseases.

Due to illness or reduced performance caused by injuries, 7.5% of the children were measured the resting BP, but could not perform the cycle exercise test. Thus, the exercise BP was assessed in 492 adolescents (251 boys and 241 girls). The mean body mass index was 21.0 ± 3.4 kg/m² (range: 13.2–35.5 kg/m²). Overweight (body mass index between the 90th and 97th percentile according to German reference data) was found in 42 (7.9%) participants (24 boys and 18 girls) and obesity (≥97th percentile) was observed in a total of 29 (5.5%) examined adolescents (14 boys and 15 girls). Both parents and children were informed about the study by oral and written information and signed the consent form. The study fulfilled the criteria of the Declaration of Helsinki and was approved by the local scientific ethics committee of the Medical Faculty at Kiel University.

**BP measurement**

BP measurements at rest and during exercise were obtained on 2 separate days by the same trained examiner using a standard stethoscope and sphygmomanometer. Resting BP was measured 3 times in a sitting position after a resting time of 5 minutes at a 2-minute interval.

SBP and diastolic BP (DBP) were determined by auscultation of the 1st and 5th Korotkoff sounds. The cuff sizes were selected according to the child’s upper right arm circumference by referring to standardized procedural guidelines. Only the lowest value of these measurements was analyzed. Resting BP was defined as hypertensive if above the 95th age-, height- and sex-specific percentile as hypertensive, and as high normal above the 90th percentile, following German reference data of normal weight individuals.

Exercise BP was studied during a graded cycle ergometer submaximal exercise test (Physical Working Capacity 170) and measured at 1.5 W/kg body weight, which corresponds approximately to the recommendation for adults. In addition, it has also been reported that the effect of psychological factors on BP is negligible at a workload above 1.0 W/kg. Heart rate was monitored throughout the test (Polar X30; Polar Electro, Buettelborn, Germany). After an initial workload of 1.0 W/kg body weight the workload was gradually increased every 3 minutes by 0.5 W/kg. Because physical performance is not proportional to body weight the weight-related test protocol was modified in overweight and obese adolescents, using their age- and sex-specific normal weight in accordance to the 50th percentile to determine the initial and incremental workload. Exercise SBP was taken at the end of each 3-minute workload while subjects were still exercising. Because exercise DBP cannot be measured reliably, only SBP (at 1.5 W/kg) was taken for statistical comparison in this study.

**Determination of reference values**

In this analysis, data from our school-based Kiel EX.PRESS. Study were evaluated to determine the exercise SBP values corresponding to the well-accepted reference percentiles of resting SBP by using percentiles of the distribution of both resting and exercise SBP. This procedure proved to be an appropriate method to determine informative and less arbitrary normal values as generated in previous studies.

In order to consider maturational differences, the study population was divided into 3 subgroups within the sexes involving participants aged 12–13 years, 14–15 years, and 16–17 years.

At first, the prevalence of high normal (≥90th percentile) and hypertensive resting SBP (≥95th percentile) in our study were derived from German age-, height- and sex-based reference data of only normal weight subjects, which are very similar to international data. As a consequence, the corresponding SBP percentiles within age group and sex strata for the present study were available. Subsequently, the calculated percentiles of our distribution of resting SBP were used to identify the respective percentiles for exercise SBP. The exercise SBP values at these percentiles in our sample are proposed as reference values for high normal and elevated exercise SBP (Figure 1).

**Statistics**

For descriptive purposes, data are reported as means ± SD, 95% confidence interval (CI), or as a percentage as appropriate. Partial Pearson correlation coefficient (adjusted for age, sex, height) was calculated to evaluate the association between resting and exercise SBP. Independent samples t-test were carried out to assess SBP differences by sex. Comparisons among age groups for resting and exercise SBP were analyzed by 1-way analysis of variance. Significant analysis of variance tests were followed by Scheffe post hoc tests. A P-value <0.05 was considered to indicate statistical significance. All statistical analyses were performed with IBM SPSS Statistics 22.0 (SPSS, Chicago, IL).

**RESULTS**

Mean resting SBP (according to the lowest measured SBP) was 113.1 ± 12.8 mm Hg (95% CI: 112.0–114.2; range: 82.0–158.0). A significant difference in SBP was found between
Prevalence of resting SBP values above 90th & 95th percentile derived from German reference data

Calculation of percentiles for our distribution of resting SBP

Corresponding percentiles in our population of exercise SBP

Exercise SBP values at these percentiles

Figure 1. Determination strategy for exercise systolic blood pressure (SBP) reference values.

Table 1. Systolic blood pressure at rest (n = 531) and during exercise at 1.5 W/kg body weight (n = 492), by age group and sex

<table>
<thead>
<tr>
<th></th>
<th>Boys</th>
<th>Girls</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resting SBP, mm Hg (n = 531)</td>
<td>115.5 ± 13.2 (113.4–116.6)</td>
<td>110.6 ± 11.9 (109.0–112.0)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>12–13 yr (n = 158)</td>
<td>110.4 ± 11.9 (107.7–113.1)</td>
<td>109.2 ± 10.4 (107.0–111.7)</td>
<td>0.519</td>
</tr>
<tr>
<td>14–15 yr (n = 196)</td>
<td>114.9 ± 13.2 (111.2–116.3)</td>
<td>111.1 ± 12.1 (108.3–113.6)</td>
<td>0.038</td>
</tr>
<tr>
<td>16–17 yr (n = 177)</td>
<td>120.9 ± 12.3 (118.5–123.7)</td>
<td>111.4 ± 13.0 (108.2–113.9)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Exercise SBP, mm Hg (n = 492)</td>
<td>153.6 ± 20.6 (151.0–156.1)</td>
<td>146.1 ± 18.2 (143.8–148.4)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>12–13 yr (n = 154)</td>
<td>144.3 ± 16.5 (140.6–148.1)</td>
<td>140.2 ± 15.1 (136.7–143.6)</td>
<td>0.103</td>
</tr>
<tr>
<td>14–15 yr (n = 180)</td>
<td>153.5 ± 18.4 (149.7–157.2)</td>
<td>148.0 ± 18.6 (143.9–152.0)</td>
<td>0.049</td>
</tr>
<tr>
<td>16–17 yr (n = 158)</td>
<td>162.6 ± 22.9 (157.5–167.7)</td>
<td>150.0 ± 19.4 (145.6–154.3)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Abbreviations: SBP, systolic blood pressure; CI, confidence interval.

Means (SD) are shown. P-value based on 2 sample t-tests for the difference between the sexes of same age group.

boys and girls (P < 0.001; Table 1). SBP at rest decreased between single recordings from 120.0 ± 15.0 mm Hg (95% CI: 119.6–122.2) at the beginning to 113.1 ± 12.9 mm Hg (95% CI: 112.5–114.6) at the third measurement.

As expected, mean SBP during exercise increased almost linearly with workload and age (Figures 2 and 3). At each workload, boys had a higher exercise SBP than girls (P < 0.01). The mean exercise SBP (at 1.5 W/kg body weight) was 149.9 ± 19.8 mm Hg (95% CI: 148.2–151.7; range: 108.0–240.0), and the average heart rate was 150.4 ± 17.1 beats per minute (95% CI: 148.9–151.9). The SBP response to exercise was also higher in boys than in girls (P < 0.001; Table 1). Moderate correlations were observed between resting and exercise SBP (r = 0.564, P < 0.001) after adjusting for age, sex, and height.

Furthermore, there were lower mean resting SBP values in 12- to 13-year-olds compared to 14- to 15-year-olds (3.4 mm Hg, 95% CI: 0.4–6.7, P = 0.045) and 16- to 17-year-olds (6.2 mm Hg, 95% CI: 2.8–9.6, P < 0.001). This age-dependent increase in BP was significant even during exercise testing between all age groups (8.7 mm Hg, 95% CI: 3.6–13.8, P < 0.001 for 12- to 13-year-olds vs. 14- to 15-year-olds; 14.1 mm Hg, 95% CI: 8.8–19.4, P < 0.001 for 12- to 13-year-olds vs. 16- to 17-year-olds; 5.4 mm Hg, 95% CI: 0.3–10.5, P = 0.037 for 14- to 15-year-olds vs. 16- to 17-year-olds). Significant differences between boys and girls of same age groups are shown in Table 1.

Prevalence of high normal and hypertensive resting SBP

Applying the German BP reference percentiles,36 7.9% (n = 42) had a resting SBP greater than the 95th percentile and 4.5% (n = 24) of the participants showed resting SBP values within the high normal BP range. The number of boys and girls in these subgroups were identical, therefore, 8.1% of the girls (n = 21) and 7.7% of the boys (n = 21) had an elevated resting SBP. The age group and sex-specific prevalence of higher than optimal and hypertensive resting SBP in the present study is shown in Table 2.

Notably, approximately one third (n = 162) of the adolescents exhibited a resting SBP greater than the adult threshold for optimal SBP (120 mm Hg). Additionally, in this subgroup hypertensive resting SBP could be identified even in 12.3% (n = 20) according to the definition for adults (≥140 mm Hg).16

With regard to the prevalence of elevated SBP (12.4%), it can be stated that the age- and sex-specific SBP level in our sample seems to be slightly above the level of the KiGGS Study reference population even though the lowest SBP value was analyzed. Furthermore, using the mean value of 3 individual measurements, resting SBP would be 4.1 mm Hg higher (117.2 mm Hg). Finally, even more participants could be identified showing resting SBP values exceeding adult thresholds.

Moreover, an exercise SBP (at 1.5 W/kg) above the commonly used systolic upper limit of 200 mm Hg for exercise hypertension in adults16 was present in 11 subjects (2.2%).

Exercise SBP reference values

Based on our distribution of high normal and hypertensive resting SBP values the corresponding percentiles in our study were determined and the exercise SBP values (1.5 W/kg) at these percentiles were calculated. The exercise SBP...
that correlates to the defined limit of hypertensive (≥95th percentile) and high normal resting SBP (≥90th percentile) referring to German reference percentiles were derived for boys and girls across age groups. The results are presented in Table 2.

The detected reference values were related to a prevalence of 8.8% (n = 21) and 7.5% (n = 19) of hypertensive exercise SBP values in the female and male subgroup, 5.8% (n = 14) and 5.2% (n = 13) were within the high normal range, respectively. Therefore, a proportion of 8.1% of the investigated adolescents showed an exaggerated SBP response during exercise testing (measured at 1.5 W/kg) in the present study.

That also implies, 79.1% of our participants had normal resting and exercise SBP values, whereas normal resting SBP but at least high normal SBP values during exercise testing were studied in 7.7%. In this subgroup, several predictive risk factors, e.g., a higher body mass index and waist circumference as well as poorer physical fitness and a lower amount of physical activity could be identified compared to subjects with both normal resting and exercise SBP. In contrast, a higher than optimal or hypertensive resting SBP was not confirmed during exercise in 7.3% of the subjects. Though, additional 5.9% had both at least high normal resting and exercise SBP values.

**DISCUSSION**

In the present study, comprising approximately 500 adolescents, the SBP during submaximal aerobic exercise at 1.5 W/kg body weight was measured to propose reference values that previously existed only for adults.

Generally, the reason for identifying reference values is the definition of the BP level associated with an increased risk of morbidity and mortality. In adults, the predictive power of the exercise BP is deemed superior to the resting BP. However, for young individuals, risk-stratified normal values are currently not even available for the resting BP. We suggest reference values to have at least a first orientation for exercise SBP (assessed at 1.5 W/kg) in the examined age group, which offer a differentiated evaluation of susceptible resting casual BP measurements.

The study findings offer an opportunity for the classification of adolescents into risk groups with respect to future hypertension. This especially concerns the proportion of 13.6% of the adolescents, who displayed at least high normal exercise SBP values and those participants with both at least high normal resting and exercise SBP values (5.9%), respectively.

Additionally, the results point to the need for routine BP measurements as a large number of resting SBP values exceeded the nonoptimal range of adults. The study indicates
that the common practice of using statistical thresholds does not necessarily reflect medically desired BP ranges. Furthermore, their use accompanies the risk of non-detection of nonoptimal BP values in adolescents.39

A major strength of our study is its use of a standardized weight-related exercise test protocol, adapted in overweight/obese participants by determining the relative capacity based on their age- and sex-specific normal weight. As a result, this study did not suffer from the common issue that overweight subjects had higher starting and/or absolute workloads.

Another strength of the investigation at hand is the comparability of resting SBP data to the reference population of the German KiGGS Study, despite minor differences in methodology and study design. The defined resting SBP limits in our study indicate that SBP criteria for adults would be applicable to boys aged–17 years, which is similar to the present study finding for high normal SBP during exercise testing in our study. Compared to other common methods (e.g., mean ± 1 SD) our calculated exercise SBP values are less arbitrary due to relying on a representative reference population.

A common issue associated with the use of percentiles is the decision of inclusion or exclusion of overweight/obese subjects for normal values calculations, because elevated BP in overweight children could distort the definition of reference BP values in normal weight children. Our study addresses this issue by using resting SBP percentiles as reference, which were calculated data based only from nonoverweight children and adolescents. As a result, resting SBP values of overweight and obese adolescents were classified into higher BP reference percentiles, which simultaneously reflect the higher risk in the presence of obesity.

In our study, the exercise BP was assessed at a single level of workload, 1.5 W/kg body weight. We acknowledge that this might be considered an arbitrary cutoff, but this procedure is more adapted to the individual than the common clinical practice in adults. At this age, exercise BP measurements are commonly carried out at a fixed (independent of body weight) definition of workload (e.g., 100 W).1,5,10,11

Our study has aimed at identifying exaggerated SBP response to activity intensity levels similar to everyday stress, such as climbing stairs.13 In addition, this level of exercise

### Table 2. Percentiles of the resting systolic blood pressure distribution in the present study according to the blood pressure level at the 90th and 95th German reference percentiles35 and the corresponding exercise systolic blood pressure limits

<table>
<thead>
<tr>
<th>Age group, yr</th>
<th>%</th>
<th>n</th>
<th>Resulting percentile</th>
<th>SBP at rest, mm Hg</th>
<th>SBP during exercise, mm Hg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Girls (n = 260)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12–13</td>
<td>5.0</td>
<td>4/80</td>
<td>95.0</td>
<td>127.8</td>
<td>172.0</td>
</tr>
<tr>
<td>≥95th percentilea</td>
<td>“hypertensive”</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14–15</td>
<td>9.1</td>
<td>8/88</td>
<td>90.9</td>
<td>127.8</td>
<td>174.7</td>
</tr>
<tr>
<td>16–17</td>
<td>9.7</td>
<td>9/92</td>
<td>90.3</td>
<td>128.0</td>
<td>178.5</td>
</tr>
<tr>
<td>Total</td>
<td>8.1</td>
<td>21/260</td>
<td>91.9</td>
<td>128.0</td>
<td>174.0</td>
</tr>
<tr>
<td>≥90th percentilea</td>
<td>“high normal”</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12–13</td>
<td>12.5</td>
<td>10/80</td>
<td>87.5</td>
<td>122.0</td>
<td>158.0</td>
</tr>
<tr>
<td>Boys (n = 271)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12–13</td>
<td>7.7</td>
<td>6/78</td>
<td>92.3</td>
<td>128.0</td>
<td>172.0</td>
</tr>
<tr>
<td>≥95th percentilea</td>
<td>“hypertensive”</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14–15</td>
<td>8.3</td>
<td>9/108</td>
<td>91.7</td>
<td>134.0</td>
<td>177.3</td>
</tr>
<tr>
<td>16–17</td>
<td>7.1</td>
<td>6/85</td>
<td>92.9</td>
<td>141.8</td>
<td>201.3</td>
</tr>
<tr>
<td>Total</td>
<td>7.7</td>
<td>21/271</td>
<td>92.3</td>
<td>134.0</td>
<td>184.0</td>
</tr>
<tr>
<td>≥90th percentilea</td>
<td>“high normal”</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12–13</td>
<td>11.5</td>
<td>9/78</td>
<td>88.5</td>
<td>125.8</td>
<td>166.3</td>
</tr>
<tr>
<td>14–15</td>
<td>13.9</td>
<td>15/108</td>
<td>86.1</td>
<td>131.7</td>
<td>172.0</td>
</tr>
<tr>
<td>16–17</td>
<td>10.6</td>
<td>9/85</td>
<td>89.4</td>
<td>136.0</td>
<td>193.0</td>
</tr>
<tr>
<td>Total</td>
<td>12.1</td>
<td>33/271</td>
<td>87.9</td>
<td>132.0</td>
<td>176.8</td>
</tr>
</tbody>
</table>

Abbreviation: SBP, systolic blood pressure.
aReferring to the age-, sex- and height-specific reference values of the German KiGGS Study.35.
was performed by most participants, whereas more subjects (18.5%) did not achieve the next higher level of workload due to limited endurance capacity. Moreover, Mocellin et al.\textsuperscript{21} showed that BP values above a workload of 1.0 W/kg are no longer affected by psychological components, which justifies our approach of determining exercise BP using sub-maximal workload.

Two important conclusions can be drawn from our study. First, we proposed reference values that enable not only a general evaluation of adolescents’ SBP during exercise, but also a better assignment to risk groups when additionally considering their resting SBP. Second, the use of BP at rest alone does not necessarily predict whether adolescents are going to show an excessive increase in SBP during exercise testing. The stronger association of exercise BP compared to resting BP with lifestyle or familial risk factors additionally emphasizes the importance of this parameter in adolescents.\textsuperscript{22,24} Generally, longitudinal studies of many years duration including measures of target organ damage or events are needed to have prognostic data regarding development of hypertension later in life.

Although the exercise BP test is certainly less convenient than recording only the resting BP for routine diagnostics, the measurement of BP during exercise could lead to an improved assessment of individual cardiovascular risk as it is well known for adults.\textsuperscript{8,10}

ACKNOWLEDGMENTS

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DISCLOSURE

The authors declared no conflict of interest.

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