The Steep Ramp Test in Dutch White Children and Adolescents: Age- and Sex-Related Normative Values

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Background. The Steep Ramp Test (SRT), a feasible, reliable, and valid exercise test on a cycle ergometer, may be more appealing for use in children in daily clinical practice than the traditional cardiopulmonary exercise test because of its short duration, its resemblance to children's daily activity patterns, and the fact that it does not require respiratory gas analysis.

Objective. The aim of the present study was to provide sex- and age-related normative values for SRT performance in Dutch white children and adolescents who were healthy and 8 to 19 years old.

Design. This was a cross-sectional, observational study.

Methods. A total of 252 Dutch white children and adolescents, 118 boys (mean age=13.4 years, SD=3.0) and 134 girls (mean age=13.4 years, SD=2.9), performed the SRT (work rate increment of 10, 15, or 20 W·10 s^{-1}, depending on body height) to voluntary exhaustion to assess peak work rate (WRpeak). Normative values are presented as reference centiles developed by use of generalized additive models for location, scale, and shape.

Results. Peak work rate correlated highly with age (r=.915 and r=.811), body mass (r=.870 and r=.850), body height (r=.922 and r=.896), body surface area (r=.906 and r=.885), and fat free mass (r=.930 and r=.902) in boys and girls, respectively. The reference curves demonstrated an almost linear increase in WRpeak with age in boys, even when WRpeak was normalized for body mass. In contrast, absolute WRpeak in girls increased constantly until the age of approximately 13 years, when it started to level off. Peak work rate normalized for body mass in girls showed only a slight increase with age until 14 years of age, when a slight decrease in relative WRpeak was observed.

Limitations. The sample may not have been entirely representative of the Dutch population.

Conclusions. The present study provides sex- and age-related normative values for SRT performance in terms of both absolute WRpeak and relative WRpeak, thereby facilitating the interpretation of SRT results by clinicians and researchers.

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Physical fitness or aerobic capacity is an important determinant of overall health. Aerobic capacity is typically assessed by measuring peak oxygen uptake ($\dot{V}O_2$peak) as an approximation of maximal oxygen uptake[1] during maximal cardiopulmonary exercise testing (CPET), the gold standard for assessing $\dot{V}O_2$peak. However, standardized exercise testing remains underused in many health care centers.[2–4] Moreover, CPET is not feasible in clinical populations in whom maximal testing is contraindicated or when performance may be impaired by pain, shortness of breath, or fatigue rather than exertion.[5] Thus, a simple, short, inexpensive, reliable, valid, and less physically demanding alternative exercise test may increase the use of exercise testing in daily clinical practice.

The Steep Ramp Test (SRT) is a short maximal exercise test that does not require respiratory gas analysis measurements. The main outcome of the SRT is the achieved peak work rate (WRpeak), which partially reflects anaerobic power and leg muscle strength.[6] The fact that performance on the SRT depends more on anaerobic capacity than performance on CPET implies that the SRT reflects children's daily activity patterns (short bursts of intense exercise) more appropriately. Performing the SRT may be better tolerated by special populations with chronic disease than performing CPET, as the SRT seemingly places a smaller burden on the cardiopulmonary system because of its short duration, as evidenced by significantly lower values for peak heart rate (HRpeak) and peak minute ventilation ($\dot{V}E$peak).[7] An additional advantage of the SRT is the demonstrated strong association between the WRpeak attained in the SRT and the $\dot{V}O_2$peak obtained from traditional CPET, as reported in children who were healthy (r=.958)[7] and adults who survived cancer (r=.850).[8] Therefore, the SRT may be useful as a simple screening tool to provide a clinician with an indication about a child's aerobic capacity. A child with significantly reduced SRT performance (WRpeak) can be referred for extensive maximal CPET to evaluate precisely the integrated physiological response to exercise.

Although the SRT appears to be a promising alternative to CPET for evaluating aerobic capacity in daily clinical practice, the lack of normative values for the test limits a clinician's ability to interpret SRT performance. Therefore, the objective of this study was to provide sex- and age-related normative values for SRT performance in children and adolescents who were healthy and 8 to 19 years old.

Method

Participants

In this cross-sectional, observational study, children and adolescents who were healthy and 8 to 19 years old were recruited from primary and secondary schools throughout the Netherlands to perform a single SRT to volitional exhaustion. Written informed consent was obtained from the parents or guardians; potential participants who were more than 12 years old also were asked to provide written consent. Children and adolescents who had cardiovascular, pulmonary, neurological, or musculoskeletal disease were excluded. All potential participants completed a modified Physical Activity Readiness Questionnaire before participation to ensure safety. Children and adolescents who answered "yes" to 1 or more questions on the modified Physical Activity Readiness Questionnaire also were excluded.

Anthropometry

Before exercise testing, participant body mass (determined to the nearest 0.1 kg) and body height (determined to the nearest 0.5 cm) were measured with an electronic scale (Seca 803, Seca, Hamburg, Germany) and a metric measuring tape with a wall stop, respectively. Sitting height also was measured and was used to predict age from peak height velocity as a marker of biological maturity.[9] Body mass index (kg·m^{-2}) was calculated as the body mass divided by the body height squared. Standard deviations were calculated for body height for age, body mass for age, and body mass index for age by use of Dutch normative values.[10] The equation of Haycock et al[11] was used to estimate body surface area (meters squared). Subcutaneous fat distribution was measured with a Harpenden skinfold caliper (Baty International, West Sussex, United Kingdom) at triceps, biceps, subscapular, and suprailiacal sites on the right side of the body.[12] The sum of the 4 skinfolds (millimeters) was used to estimate the body density with standard equations.[12] The percentage of body fat and the fat-free mass (kilograms) were estimated with a modification of the Siri equation proposed by Weststrate and Deurenberg.[13]

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- eTable 1: Habitual Physical Activity of Participants
- eTable 2: Age- and Sex-Related Normative Values for Peak Work Rate and WRpeak Normalized for Body Mass in the Steep Ramp Test and Traditional Cardiopulmonary Exercise Testing
- eFigure: Relationship Between Body Mass Index and Age for Boys and Girls

Accelerometry

For the assessment of habitual physical activity, all participants were asked to wear an accelerometer on their right hip for 7 consecutive days during all waking hours, except when engaging in water activities. For practical purposes, 2 different types of accelerometers were used: the ActiGraph GT3X (Actigraph LLC, Pensacola, Florida) and the Actical (Minimitter/Respironics, Bend, Oregon). Activity was recorded in 15-second epochs on both devices. Participants who adhered to the instructions were defined as those who wore the accelerometer for at least 600 $\text{min}\cdot\text{d}^{-1}$ for a minimum of 4 days (including 1 weekend day). Average wear time ($\text{min}\cdot\text{d}^{-1}$), time spent sedentary ($\text{min}\cdot\text{d}^{-1}$), time spent in light physical activity ($\text{min}\cdot\text{d}^{-1}$), time spent in moderate physical activity ($\text{min}\cdot\text{d}^{-1}$), time spent in vigorous physical activity ($\text{min}\cdot\text{d}^{-1}$), time spent in moderate to vigorous physical activity ($\text{min}\cdot\text{d}^{-1}$), and time spent in total physical activity ($\text{min}\cdot\text{d}^{-1}$) were determined on the basis of the count cutpoints defined by Evenson et al.[14]

SRT

For reduced variability in testing, all SRTs were supervised by 1 experienced exercise physiologist (B.C.B.) and were performed on an electronically braked cycle ergometer (Lode Corival, Lode BV, Groningen, the Netherlands) with a standardized procedure validated in a previous study.[7] With this procedure, the SRT was found to be a reliable exercise test (intraclass correlation coefficient=.986, $P<.001$).[7] The average difference between 2 SRTs was −6.4 W (mean between-test time=8 days, SD=5), with limits of agreement of +24.5 and −37.5 W.[7] Hence, the minimal detectable change was 30.9 W (11%).

Seat height was adjusted to a comfortable leg length for each participant. A modified SRT protocol was used.[7] In brief, after a 3-minute warm-up at 25 W, the test began with the application of resistance of 10, 15, or 20 $\text{W}\cdot 10\ \text{s}^{-1}$ in a ramplike manner (2, 3, or 4 $\text{W}\cdot 2\ \text{s}^{-1}$), on the basis of the participant's body height (<120 cm, 120–150 cm, or >150 cm, respectively). The participant was instructed to maintain a pedaling rate of between 60 and 80 rpm. The test was terminated when the participant could no longer maintain the minimum required pedaling rate of 60 rpm, despite strong verbal encouragement (standardized) (Appendix). Heart rate (bpm) was monitored throughout the test (Polar T31 transmitter, Polar, Kempele, Finland). The WRpeak was defined as the work rate (watts) at peak exercise, the point at which the participant's pedaling frequency definitely dropped below 60 rpm. The HRpeak was defined as the highest value achieved during the last 30 seconds before test termination. Before and directly after the SRT, participants completed a 10-point visual analog scale indicating their level of fatigue, allowing us to gain a better understanding of the exhaustiveness of the SRT (by subtracting the visual analog scale score before the test from that after the test).

Data Analysis

Data analysis was performed with the Statistical Package for the Social Sciences (SPSS version 15.0, SPSS Inc, Chicago, Illinois). All data were expressed as mean, standard deviation, and range. Tests for normality were performed on the SRT data with Kolmogorov-Smirnov tests. Differences between boys and girls were examined with independent-sample *t* tests. A 2-way independent analysis of variance was used to identify significant differences in the WRpeak achieved during the SRT by boys and girls within the different age groups. Independent-sample *t* tests with the Holm-Bonferroni method to counteract the problem of multiple comparisons were then performed to locate the exact significant differences between boys and girls. Pearson correlation coefficients were calculated to examine associations between the WRpeak attained in the SRT and various anthropometric variables.

Reference curves were computed as follows: 8 models were fitted, including all combinations of the 2 main outcomes of the SRT (WRpeak and WRpeak normalized for body mass), 2 predictors (age and body mass), and sex. The outcome distributions were fitted as smooth functions of the predictors through the least-mean-square model with cubic splines.[15] The parameters were estimated by use of generalized additive models for location, scale, and shape (GAMLSS 4.1-2),[16] and the degree of smoothing needed was chosen by means of the worm plot with 9 panels.[17] Computations were performed with the open source statistical package R (version 2.14.2, R Foundation for Statistical Computing, Vienna, Austria). A P value of less than .05 was considered statistically significant.

Role of the Funding Source

This study was funded by an unconditional research grant from Scientific Committee Physiotherapy of the Royal Dutch Society for Physiotherapy.

Results

Of the initial 266 young people who were willing to participate and gave written informed consent, 252 were tested (118 boys and 134 girls; mean age=13.4 years, SD=3.0 [boys] or 2.9 [girls] years, range=8–19). Five children were excluded because of musculoskeletal disease, 2 had neurological disease, 2 had cardiovascular disease, 3 children felt pain in their chest when performing physical activity in the month before exer-

Table 1.
Characteristics of Participants[a]

Characteristic	Boys (n=118)			Girls (n=134)			P	95% CI
	X̄	SD	Range	X̄	SD	Range		
Age (y)	13.4	3.0	8.1–19.0	13.4	2.9	8.2–19.0	.879	−0.67 to 0.79
Body mass (kg)	51.6	15.6	23.6–104.2	50.6	13.8	21.5–97.8	.563	−2.57 to 4.71
Body height (m)	1.61	0.15	1.26–1.91	1.58	0.12	1.23–1.87	.099	−0.01 to 0.06
Age predicted from peak height velocity (y)[b]	−0.36	2.41	−4.00–4.00	1.11	2.14	−3.40–4.00	<.001	−2.04 to −0.91
BMI ($kg \cdot m^{-2}$)	19.4	3.1	13.4–31.5	19.8	3.3	13.2–29.4	.318	−1.20 to 0.39
BSA (m^2)[c]	1.51	0.29	0.90–2.32	1.48	0.26	0.85–2.27	.436	−0.04 to 0.10
Body fat (%)[d]	17.6	4.9	9.9–30.7	22.8	4.8	13.7–35.5	<.001	−6.40 to −3.98
FFM (kg)	42.3	11.9	21.2–74.0	38.7	9.3	17.3–63.1	.009	0.92 to 6.29

[a] CI=confidence interval, BMI=body mass index, BSA=body surface area, FFM=fat-free mass.
[b] Calculated with the equation of Mirwald et al.[9]
[c] Calculated with the equation of Haycock et al.[11]
[d] Calculated with the equations of Deurenberg et al[12] and Weststrate and Deurenberg.[13]

Table 2.
Steep Ramp Test Results[a]

Parameter	Boys (n=118)			Girls (n=134)			P	95% CI
	X̄	SD	Range	X̄	SD	Range		
Duration (s)	140	44	61–239	120	28	63–193	<.001[b]	11.0 to 29.5
WRpeak (W)	290	100	126–502	252	67	120–409	.001[c]	16.3 to 59.2
WRpeak ($W \cdot kg^{-1}$)	5.6	0.9	3.1–7.9	5.0	0.7	3.4–6.6	<.001[b]	0.35 to 0.75
HRpeak (bpm)[d]	185	9	162–203	186	9	165–210	.679	–2.75 to 1.79
ΔVAS	5.9	1.6	1.5–9.3	5.2	2.0	0.7–9.6	.003[c]	0.23 to 1.12

[a] CI=confidence interval, WRpeak=peak work rate (maximal short-time exercise capacity), HRpeak=peak heart rate, ΔVAS=difference in participants' level of fatigue as scored on a visual analog scale (score after test minus score before test).
[b] Significant at $P<.001$.
[c] Significant at $P<.01$.
[d] HRpeak could not be determined in 1 boy and 2 girls, so for this parameter, n=117 for boys and n=132 for girls.

cise testing, and 2 children were not tested because of scheduling issues.

The characteristics of the participants are shown in Table 1. Compared with girls, boys had significantly less biological maturity, lower percentage of body fat, and higher fat-free mass. eTable 1 (available at ptjournal.apta.org) shows the habitual physical activity of the participants. Boys had higher levels of total physical activity, perhaps because boys spent more time in moderate to vigorous physical activity and vigorous physical activity than girls.

All participants performed a maximal SRT without any complications or adverse events. They all showed subjective signs of maximal effort, including unsteady biking, sweating, facial flushing, and a clear unwillingness to continue despite strong verbal encouragement. The majority of the participants (n=191) also showed objective signs of maximal effort, as indicated by an HRpeak of greater than 180 bpm.

All exercise variables were normally distributed and are shown in Table 2. The mean duration of the SRT (excluding warm-up) was 129 seconds (SD=38). Compared with girls, boys cycled significantly longer, resulting in significantly higher values for WRpeak. Peak work rate normalized for body mass also was significantly higher in boys. Boys experienced the SRT as being more exhaustive, as indicated by the greater difference between the level of fatigue before the test and the level of fatigue after the test (change in visual analog scale score) in boys; however, HRpeak was not significantly different between boys and girls. An analysis of covariance with sex and age as covariates demonstrated that there was no significant difference in SRT performance between children living in a rural

Table 3.
Pearson Correlation Coefficients for Peak Work Rate and Anthropometric Variables[a]

Variable	Boys (n=118)		Girls (n=134)	
	r	*P*	*r*	*P*
Age (y)	.915	<.001	.811	<.001
Body mass (kg)	.870	<.001	.850	<.001
Body height (m)	.922	<.001	.896	<.001
Age predicted from peak height velocity (y)[b]	.949	<.001	.879	<.001
BMI (kg·m^{-2})	.564	<.001	.601	<.001
BSA (m^2)[c]	.906	<.001	.885	<.001
Body fat (%)[d]	−.019	NS	.211	.014
FFM (kg)	.930	<.001	.902	<.001

[a] BMI=body mass index, BSA=body surface area, NS=not significant, FFM=fat-free mass.
[b] Calculated with the equation of Mirwald et al.[9]
[c] Calculated with the equation of Haycock et al.[11]
[d] Calculated with the equations of Deurenberg et al[12] and Weststrate and Deurenberg.[13]

area (n=103) and children living in an urban area (n=149), as indicated by both WRpeak (276 W and 266 W, respectively; P=.136, 95% confidence interval=−3.02 to 22.15) and WRpeak normalized for body mass (5.4 W·kg^{-1} and 5.3 W·kg^{-1}, respectively; P=.304, 95% confidence interval=−0.10 to 0.32).

High correlations were observed between WRpeak and various anthropometric variables, as shown in Table 3 for boys and girls separately. As expected, WRpeak was positively associated with age, body mass, body height, biological maturity, body surface area, and fat-free mass (r=.811–.930, with P<.001 for all coefficients). Moderate positive correlations were found between WRpeak and body mass index; conversely, no correlation was found between WRpeak and percentage of body fat.

Figure 1 (top graphs) shows the age-related reference centile charts for absolute WRpeak in the SRT for boys and girls. The values demonstrate an almost linear increase in WRpeak with chronological age; however, commencing at an age of 13 or 14 years, WRpeak began to level off in girls but continued to increase linearly in boys. When normalized for body mass, WRpeak showed an almost linear increase with chronological age up to 19 years of age in boys, as indicated by the age-related centile charts in Figure 1 (bottom graphs). In girls, WRpeak normalized for body mass showed only a slight increase with chronological age until 14 years of age, when a slight decrease was observed.

When WRpeak and WRpeak normalized for body mass were modeled against body mass (Fig. 2), the same trends in the study outcomes were found. Of special interest were the distributions of WRpeak normalized for body mass as a function of body mass (Fig. 2, bottom graphs). For boys, peak performance occurred at a body mass of approximately 60 kg, whereas in girls, WRpeak normalized for body mass rapidly declined beyond a body mass of approximately 55 kg.

eTable 2 (available at ptjournal.apta.org) shows the age- and sex-related normative values for WRpeak and WRpeak normalized for body mass, including standard deviations, for the SRT as well as for traditional CPET according to the Godfrey protocol[18] (previously described for Dutch children[19]).

Boys attained significantly higher absolute WRpeak values than girls by the age of 15 years and beyond (Fig. 3, top graph). For WRpeak normalized for body mass (Fig. 3, bottom graph), there seemed to be a trend toward higher values being achieved by boys than by girls between 11 and 15 years of age. Beyond this age, the difference between boys and girls became significant. The eFigure (available at ptjournal.apta.org) shows the relationship between body mass index and age for the study sample.

Discussion

The objective of the present study was to provide sex- and age-related normative values for the WRpeak attained during the SRT by children and adolescents who were healthy and 8 to 19 years old. The SRT was originally developed and described as an alternative measure for determining and readjusting training workload for adult patients with chronic heart failure.[6,20] Since then, it has been applied in the rehabilitation setting, specifically for prescribing training load and monitoring training progress, for various groups of adult patients, including patients with cancer,[8] chronic obstructive pulmonary disease,[21] type 2 diabetes,[22] and chronic heart failure.[23]

The SRT has several advantages over traditional CPET in daily clinical practice. First, the test duration is relatively short, 2 to 3 minutes, excluding warm-up; the duration of CPET is 8 to 12 minutes (excluding warm-up). Second, the SRT does not require expensive respiratory gas analysis measurements. In most clinical practice settings, health care professionals do not have access to a metabolic cart. In addition, the use of a face mask or mouthpiece might

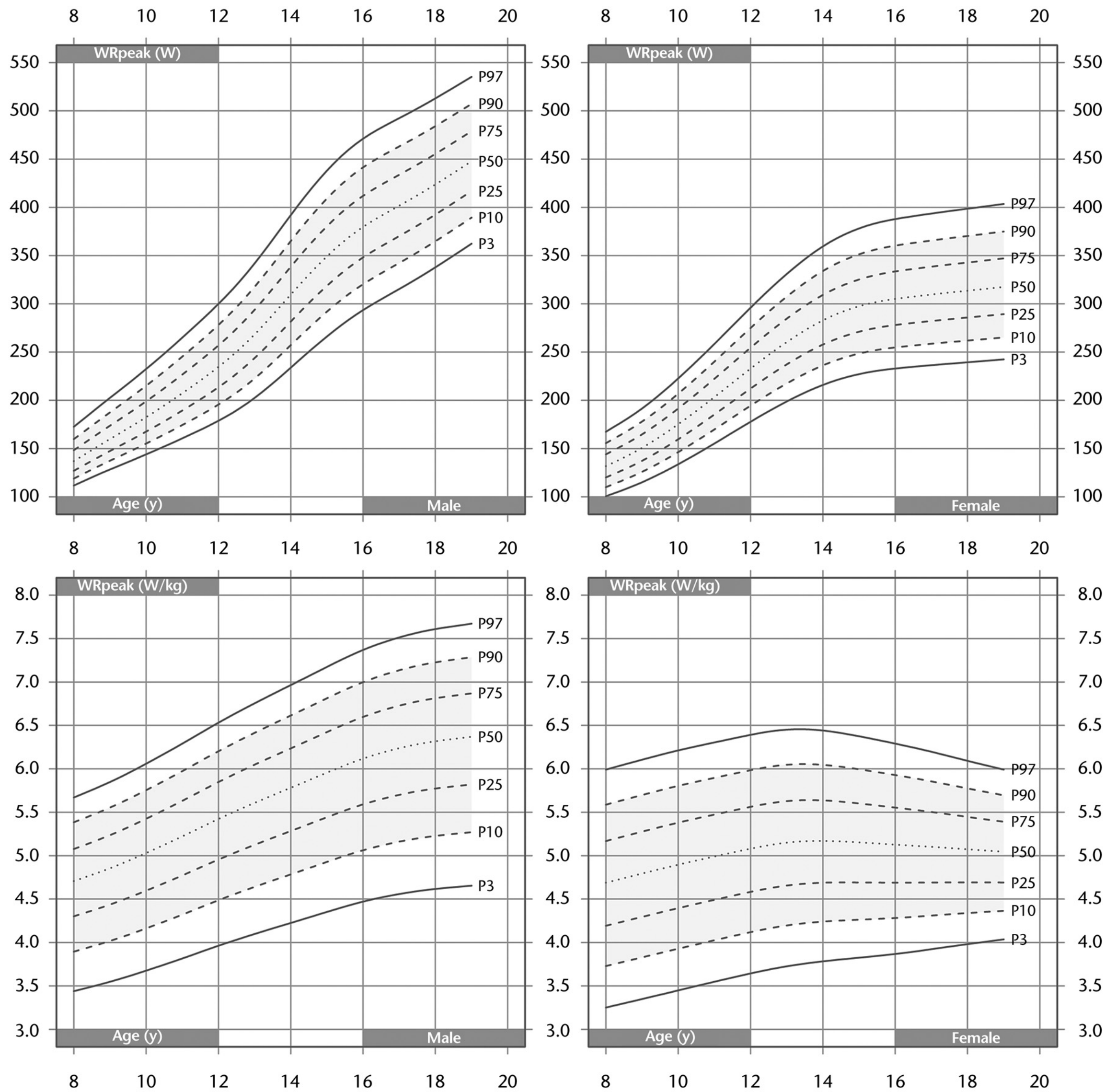

Figure 1.
Age-related centile charts for the absolute peak work rate (WRpeak) (top graphs) and peak work rate normalized for body mass (bottom graphs) in the Steep Ramp Test for boys and girls separately. Dotted lines represent the 50th centile (P50); dashed lines correspond to the 10th, 25th, 75th, and 90th centiles (P10, P25, P75, and P90, respectively); and solid lines indicate the 3rd and 97th centiles (P3 and P97, respectively).

frighten young children.[24] Third, the SRT is known to be a reliable maximal exercise test and seems to place a much smaller burden on the cardiopulmonary system than traditional CPET, despite the fact that the WRpeak attained in the SRT is about 1.5 times higher than that attained in CPET (eTab. 2).[7] This result is due to the faster work rate increments in the SRT than in CPET (the work rate increases 6 times faster in the SRT), resulting in higher WRpeak values and lower HRpeak and $\dot{V}_E$peak values being attained in the SRT. The significantly lower HRpeak and $\dot{V}_E$peak values attained in the SRT than in CPET suggest that local muscle fatigue limits performance in the SRT. Nevertheless, Bongers et al[7] reported high correlation coefficients between the WRpeak attained during the SRT and the $\dot{V}O_2$peak achieved during traditional CPET (r=.958, P<.001). They developed a prediction model that estimates the $\dot{V}O_2$peak from the WRpeak attained in the SRT. Perhaps most importantly, Bongers et al[7] also showed that the SRT is safe and easily performed by children. Through the construction of reference curves with age-related reference centiles

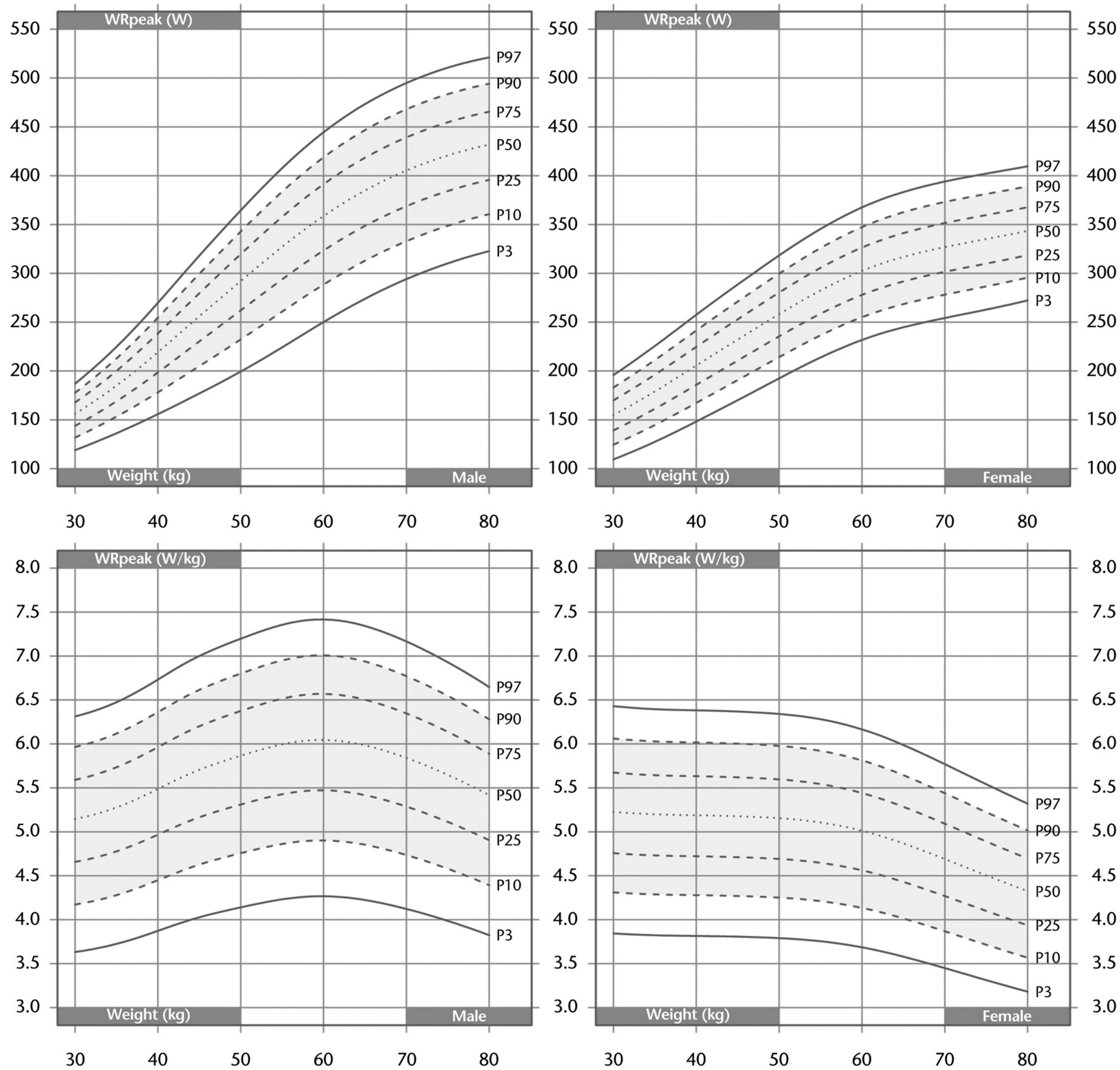

Figure 2.
Body mass–related centile charts for the absolute peak work rate (WRpeak) (top graphs) and peak work rate normalized for body mass (bottom graphs) in the Steep Ramp Test for boys and girls separately. Dotted lines represent the 50th centile (P50); dashed lines correspond to the 10th, 25th, 75th, and 90th centiles (P10, P25, P75, and P90, respectively); and solid lines indicate the 3rd and 97th centiles (P3 and P97, respectively).

for the absolute WRpeak and the relative WRpeak, the SRT results now have become easy for clinicians to interpret.

For daily clinical practice, the SRT may be valuable as a simple screening tool to indicate a child's aerobic capacity. A WRpeak in the SRT that is significantly below average indicates that the child may have a reduced aerobic capacity compared with peers who are healthy. Because the SRT should not be used as a substitute for traditional CPET, a child with reduced SRT performance should be referred for traditional CPET to assess the integrated physiological response of the cardiovascular, pulmonary, and musculoskeletal systems to progressive exercise up to voluntary exhaustion. As a cutoff point for indicating reduced SRT performance, an absolute WRpeak or a relative WRpeak (or both) that falls below the third percentile of the presented reference curves can be used.

The SRT examines aerobic power as well as anaerobic power. It is evident that with growth there are concomitant increases in aerobic power and anaerobic power. Our results indicated that boys attained significantly higher absolute WRpeak values than girls as of 15 years of age and beyond (Fig. 3, top graph). This finding is in line with those of several studies investigating aerobic power and anaerobic power in boys and girls. Bar-Or and Rowland[25] presented maximal aerobic power ($\dot{V}O_2$peak) data in relation to the chronological age of 3,910 boys and girls between 6 and 18 years old (originating from multiple cross-sectional studies). They reported that $\dot{V}O_2$peak values increased until the age of 17 or 18 years in boys, whereas $\dot{V}O_2$peak values hardly increased beyond 14 years of age in girls. These data were confirmed by $\dot{V}O_2$peak normative values based on cross-sectional data for a representative group of Dutch children who were 6 to 18 years old.[26] Regarding the development of anaerobic power with age, girls generally had lower values than boys, and the difference became more apparent at 14 years of age and beyond.[25] Van Praagh[27] used data from a study[28] investigating the absolute cycling peak anaerobic power in relation to age in boys and girls and found that girls began diverging from boys at the age of 13 or 14 years, with significantly lower values being reported for girls as of 14 or 15 years of age.

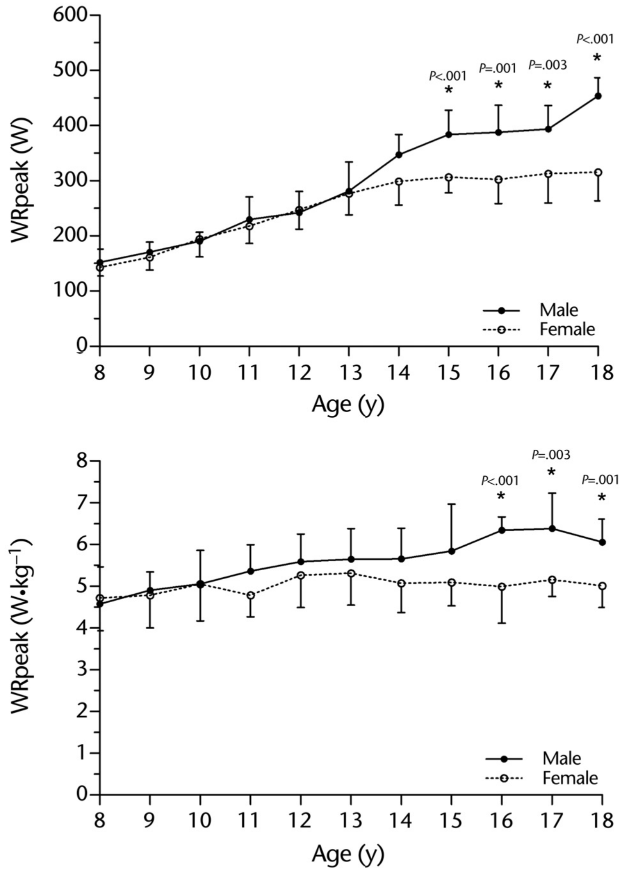

Figure 3.
Age-related sex differences for the absolute peak work rate (WRpeak) (top graph) and peak work rate normalized for body mass (bottom graph) in the Steep Ramp Test. Data are expressed as means and standard deviations.

The sex-associated variation in aerobic power and anaerobic power and therefore in SRT performance is most likely caused by a greater increase in muscle mass with age in boys as well as by a greater increase in body fat with age in girls. These increases are largely related to changes in endocrine function throughout puberty,[29] with testosterone playing an important role in the gain of muscle strength in boys.[30] Fiber type distribution and neural adaptation may be factors in age-associated differences in muscle strength.[31] Sex-associated differences, especially postpubertal, were also reported for grip strength (a predictor of overall muscle strength), with higher values being attained in boys.[32] In the present study, the prepubertal sex-associated differences (nonsignificant) in relative WRpeak values were likely associated with the higher proportion of body fat in girls.

Limitations

Almost all of the participants in the present study were white. Whether the normative values reported here are valid for other ethnic groups remains to be determined. Moreover, standard deviations for body mass for age were significantly different from Dutch population norms in girls (+0.19 SD [P=.031]), whereas standard deviations for body mass index for age were significantly different from general population norms in boys and girls (+0.29 SD [P=.002] and +0.24 SD [P=.006], respectively).[11] Despite the fact that these differences were small, the sample might not be entirely representative of the Dutch population. Standard deviations for body height for age did not differ significantly from Dutch normative values in boys and girls.[11]

Conclusion

The present study provides sex- and age-related normative values (presented as reference centiles) for SRT performance in terms of both absolute WRpeak and relative WRpeak. The reference curves demonstrated an almost linear increase in WRpeak with age in boys up to 19 years old, even when WRpeak was normalized for body mass. In contrast, WRpeak in girls increased constantly until the age of approximately 13 years, when WRpeak started to level off. Peak work rate normalized for body mass showed only a slight increase with age in girls, and a slight decrease in relative WRpeak commenced at 14 years of age. Given the expense and technical nature of measuring maximal oxygen uptake, the availability of reference curves for the SRT may simplify the interpretation of this clinically useful alternative to traditional CPET.

Dr de Vries, Dr Helders, and Dr Takken provided concept/idea/research design. Dr Bongers, Dr van Buuren, and Dr Helders provided writing. Dr Bongers and Dr Takken provided data collection. Dr Bongers, Ms Obeid, Dr van Buuren, and Dr Takken provided data analysis. Dr Bongers, Dr Helders, and Dr Takken provided project management. Dr Helders and Dr Takken provided fund procurement. Dr de Vries and Dr Takken provided facilities/equipment. Dr de Vries and Ms Obeid provided consultation (including review of manuscript before submission).

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Appendix.

Encouragement

Since the duration of the load phase of the Steep Ramp Test (SRT) differed among the participants, it was difficult to provide standardized encouragement throughout the test for each participant. During the first part of the SRT performed in the present study, encouragements such as “You are doing great, come on” and “Keep on going, great work” were used. When it became clear that a participant was struggling during the test, the exercise physiologist said, “OK, keep pushing hard on the pedals; the work rate increases fast, and you should try to maintain a pedaling frequency of about 80 rpm.” When the pedaling frequency at peak exercise started to drop toward 60 rpm (end of test criterion), the exercise physiologist said, “Come on, this is the most important part of the test; try to perform one last sprint, give everything you have got.”