The Steep Ramp Test in Healthy Children and Adolescents: Reliability and Validity

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ABSTRACT

BONGERS, B. C., S. I. DE VRIES, P. J. M. HELDERS, and T. TAKKEN. The Steep Ramp Test in Healthy Children and Adolescents: Reliability and Validity. *Med. Sci. Sports Exerc.*, Vol. 45, No. 2, pp. 366–371, 2013. **Purpose**: This study aimed to examine the reliability and validity of the steep ramp test (SRT), a feasible, maximal exercise test on a cycle ergometer that does not require the use of respiratory gas analysis, in healthy children and adolescents. **Methods**: Seventy-five children were randomly divided in a reliability group (n = 37, 17 boys and 20 girls; mean ± SD age = 13.86 ± 3.22 yr), which performed two SRTs within 2 wk, and a validity group (n = 38, 17 boys and 21 girls; mean ± SD age = 13.85 ± 3.20 yr), which performed both an SRT and a regular cardiopulmonary exercise test (CPET) with respiratory gas analysis within 2 wk. Peak work rate (WR_{peak}) was the main outcome of the SRT. Peak oxygen uptake ($\dot{V}O_{2peak}$) was the main outcome of the CPET. Reliability was examined with the intraclass correlation coefficient and a Bland and Altman plot, whereas validity was assessed using Pearson correlation coefficients and stepwise linear regression analysis. **Results**: Reliability statistics for the WR_{peak} values attained at the two SRTs showed an intraclass correlation coefficient of 0.986 ($P < 0.001$). The average difference between the two SRTs was −6.4 W, with limits of agreement between +24.5 and −37.5 W. A high correlation between WR_{peak} attained at the SRT and the $\dot{V}O_{2peak}$ achieved during the CPET was found ($r = 0.958$; $P < 0.001$). Stepwise linear regression analysis provided the following prediction equation: $\dot{V}O_{2peak}$ (mL·min^{-1}) = (8.262WR_{peak} SRT) + 177.096 ($R^2 = 0.917$, SEE = 237.4). **Conclusion**: The results suggest that the SRT is a reliable and valid exercise test in healthy children and adolescents, which can be used to predict $\dot{V}O_{2peak}$. **Key Words:** EXERCISE TESTING, PHYSICAL FITNESS, REPRODUCIBILITY, CHILD.

Aerobic capacity is an important determinant of overall health, in which a higher aerobic capacity has been related to a lower morbidity and mortality (5,25). Direct measurement of aerobic capacity during a symptom-limited maximal cardiopulmonary exercise test (CPET) facilitates an accurate and objective assessment of the integrative response of the metabolic, cardiovascular, and pulmonary system to exercise. The results of a CPET represent the profiles and adequacy of the physiological responses to exercise, which provide clinically diagnostic and prognostic information (32). Measuring maximal oxygen uptake ($\dot{V}O_{2max}$) using respiratory gas analysis during incremental exercise is considered the gold standard for aerobic capacity by the World Health Organization (30) and others (1,34). The physiological $\dot{V}O_{2max}$ requires the oxygen uptake ($\dot{V}O_2$) to attain a plateau despite a further increase in work rate (WR) (3). This plateau rarely occurs in pediatric populations (4,28). Therefore, the highest $\dot{V}O_2$ measured during a symptom-limited maximal CPET ($\dot{V}O_{2peak}$) is often considered the best measurable indicator of aerobic capacity (9,33). Nevertheless, the direct measurement of $\dot{V}O_{2peak}$ in clinical settings is sometimes not feasible because of the expense, the need for special equipment for respiratory gas analysis, and the trained staff required (11,12,26).

As exercise testing is sometimes underused in daily clinical practice (15,31), there is a need for less demanding alternatives not requiring respiratory gas analysis. This might help to increase the use of clinical exercise testing. Maximal exercise testing with peak work rate (WR_{peak}) as primary outcome parameter is a much less demanding procedure (12). WR_{peak} has been indicated as an appropriate alternative measure of $\dot{V}O_{2peak}$ in healthy children (12) as well as in children and adolescents with juvenile idiopathic arthritis (11). The steep ramp test (SRT) is a feasible, short-time maximal exercise test with the achieved WR_{peak} as the main outcome, entitled maximum short-time exercise capacity. The SRT originates from determination and optimization of training WR in adult patients with chronic heart failure (20–22) and does not require the use of respiratory gas analysis. Hence, the SRT might contribute to an increase of the use of exercise testing in clinical settings. Despite its potential clinical applicability, the reliability and validity of the SRT in healthy children and adolescents are currently unknown.

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Information concerning its reliability and validity is required for clinicians and researchers willing to use the SRT to evaluate (changes in) exercise capacity. Therefore, the purpose of the current study was to investigate the reliability and validity of the SRT in healthy children and adolescents. Reliability was studied examining the test–retest reliability of the SRT, whereas validity was determined investigating the ability of the SRT to predict $\dot{V}O_{2peak}$ attained during a regular CPET.

METHODS

Participants. Healthy children and adolescents were recruited from primary and secondary schools in the Netherlands. The safety and the possible risk of maximal exercise for an individual were assessed before inclusion using a modified Physical Activity Readiness Questionnaire, leading to the exclusion of willing participants who answered yes to one or more questions. Three children were excluded because of musculoskeletal disease: one had cardiovascular disease, and two children reported chest pain in the month before exercise testing when performing physical activity. Eventually, the study population consisted of 75 healthy participants who were randomly divided in a reliability (n = 37) or a validity group (n = 38), in which randomization was stratified by gender and age. Children between 8 and 19 yr who were free from cardiovascular, pulmonary, neurological, or musculoskeletal disease were eligible. The study protocol was approved by the institutional review board of the University Medical Center Utrecht, the Netherlands, and written informed consent was obtained from the legal guardians and/or from the children themselves if they were 12 yr and older. Characteristics of both groups are presented in Table 1.

Study design. To assess the reliability of the SRT, the reliability group performed two SRTs within 2 wk (mean ± SD between-visit time = 8.03 ± 5.29 d). The WR_{peak} attained at the first SRT was compared with the WR_{peak} achieved at the second SRT. To assess the validity of the SRT, the validity group performed an SRT at the first visit and a symptom-limited maximal CPET including respiratory gas analysis at the second visit (mean ± SD between-visit time = 8.26 ± 4.71 d). Both maximal exercise tests were performed at the same time of the day for a given participant. The reached WR_{peak} at the SRT was compared with the $\dot{V}O_{2peak}$ attained at the CPET.

Anthropometry. Anthropometric measurements were conducted before exercise testing. Body mass was measured using an electronic scale (Seca 803; Seca, Hamburg, Germany), and body height was measured using a wall-mounted stadiometer (Seca 206; Seca). Biological maturity was assessed by measuring sitting height to predict the age from peak height velocity (24). Body mass index was calculated as the body mass divided by the square of the body height. SD scores were calculated for body height for age, body mass for age, and body mass index for age, using Dutch normative values (16). Body surface area (BSA) was calculated using the equation of Haycock et al. (18), which has been validated in infants, children, and adults. Percent body fat and subsequent fat-free mass (FFM) were determined by measuring subcutaneous fat of the biceps, triceps, subscapular, and supra-iliac regions with a Harpenden skinfold caliper (13). After estimating body density using the equations proposed by Deurenberg et al. (13), a modification of the Siri equation was used to estimate percent body fat (35).

Exercise testing. Exercise tests were performed on an electronically braked cycle ergometer (Lode Corival; Lode BV, Groningen, the Netherlands). Seat height was adjusted to the participant's leg length. During the tests, HR was monitored by using an elastic belt with an HR sensor (Polar T31™ transmitter; Polar, Kempele, Finland). To examine validity, the participants in the validity group breathed through a facemask (Hans Rudolph, Kansas City, MO) during the SRT and the CPET, which was connected to a mobile respiratory gas analysis system (Cortex Metamax B^3; Cortex Medical GmbH, Leipzig, Germany). The metabolic test system was calibrated for respiratory gas analysis measurements (ambient air and a gas mixture of 17% oxygen and 5% carbon dioxide) and volume measurements (3-L syringe) twice a day: in the morning and at noon. The metabolic test system consisted of the facemask and a transmitting unit with oxygen and carbon dioxide analyzers carried on the participant's chest (total weight = 0.57 kg). The mobile respiratory gas analysis system had a wireless connection with a computer, so real-time physical strain of the children during the SRT and the CPET could be measured, as indicated by the minute ventilation ($\dot{V}_E$), $\dot{V}O_2$, carbon dioxide production ($\dot{V}CO_2$), and HR averaged at 10-s

TABLE 1. Group characteristics.

	Reliability Group (n = 37)		Validity Group (n = 38)		P
Gender (boys/girls)	17/20		17/21		
Age (yr)	13.9 ± 3.2	[8.1 to 18.9]	13.9 ± 3.2	[8.1 to 18.9]	0.991
Body mass (kg)	52.8 ± 15.0	[30.0 to 97.8]	51.1 ± 15.3	[23.6 to 94.2]	0.630
Body height (m)	1.62 ± 0.16	[1.29 to 1.87]	1.61 ± 0.14	[1.26 to 1.85]	0.809
Age from peak height velocity (yr)	0.8 ± 2.5	[−4.0 to 4.0]	0.8 ± 2.4	[−4.0 to 4.0]	0.978
BMI ($kg \cdot m^{-2}$)	19.9 ± 3.2	[15.3 to 28.8]	19.3 ± 3.3	[13.2 to 31.5]	0.463
BSA (m^2)	1.53 ± 0.28	[1.07 to 2.27]	1.50 ± 0.29	[0.90 to 2.16]	0.630
Body fat (%)	21.0 ± 6.1	[10.7 to 35.5]	19.7 ± 4.7	[10.3 to 30.0]	0.288
FFM (kg)	41.5 ± 11.0	[23.7 to 63.1]	40.8 ± 11.3	[21.2 to 68.5]	0.790

Values are presented as means ± SD [range].
BMI, body mass index; BSA, body surface area; FFM, fat-free mass.

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intervals. This metabolic test system was found to be a reliable and valid system for measuring ventilatory parameters during exercise (8,19,23). WR_{peak} was defined as the highest achieved WR, whereas peak $\dot{V}_E$ ($\dot{V}_{E\mathrm{peak}}$), $\dot{V}O_{2\mathrm{peak}}$, and peak HR ($HR_{peak}$) were defined as the highest value achieved during the last 30 s before peak exercise. Before and directly after the exercise tests, participants completed a 10-point visual analog scale (VAS) indicating their level of fatigue. By doing this, the exhaustiveness of the SRT and the CPET (ΔVAS; posttest VAS score minus pretest VAS score) was assessed.

Steep ramp test. To make the test suitable for pediatric populations, the original SRT protocol (WR increments of 25 W·10 s^{-1} [20]) was modified. After a 3-min warm-up at 25 W, the test started by applying resistance to the ergometer with increments of 10, 15, or 20 W·10 s^{-1}, depending on the participant's body height (<120 cm, between 120 and 150 cm, and >150 cm, respectively). The participant was instructed to maintain a pedaling frequency between 60 and 80 rpm, and the protocol continued until there was a sustained drop in the participant's pedaling frequency from 60 rpm despite strong verbal encouragement. Peak exercise was defined as the point at which the participant's pedaling frequency definitely dropped less than 60 rpm. Efforts were considered to be maximal when participants showed subjective signs of intense effort (e.g., unsteady biking, sweating, facial flushing, and clear unwillingness to continue despite encouragement).

Cardiopulmonary exercise test. During the CPET, participants started with a 3-min warm-up at 25 W where after the WR was increased by 10, 15, or 20 W·min^{-1} depending on the participant's body height (<120 cm, between 120 and 150 cm, and >150 cm respectively) (17). Participants had to maintain a pedaling frequency between 60 and 80 rpm. Peak exercise was defined as the point at which there was a sustained drop in the participant's pedaling frequency from 60 rpm despite strong verbal encouragement. A test was considered to be at or near the maximal level if at least one of the following criteria was met: an HR_{peak} >180 beats·min^{-1} or an RER at peak exercise (RER_{peak}) >1.0 (2).

Statistical analysis. Data analysis was performed using the Statistical Package for the Social Sciences (version 15.0; SPSS Inc., Chicago, IL). All data were expressed as mean ± SD and [range] and were verified for normality with Shapiro–Wilk tests. Because all variables were normally distributed, paired samples *t*-tests were completed to determine whether there were significant differences for test duration, exercise variables, and exhaustiveness between the two SRTs performed by the reliability group and between the SRT and the regular CPET executed by the validity group. The two-way mixed intraclass correlation coefficient (ICC) for WR_{peak} and WR_{peak} normalized for body mass were computed to assess reliability of the SRT. ICC values higher than 0.75 were considered acceptable (27). To analyze agreement, limits of agreement were calculated for WR_{peak} according to the procedure described by Bland and Altman (6) using the two WR_{peak} values attained at the two SRTs. To examine the validity of the SRT, the Pearson correlation coefficient was calculated between the attained WR_{peak} at the SRT and the $\dot{V}O_{2\mathrm{peak}}$ achieved during the CPET. Stepwise linear regression analysis was used to develop an equation to predict $\dot{V}O_{2\mathrm{peak}}$ reached at the regular CPET with the SRT performance (WR_{peak}). First, univariate regression analyses were completed to determine which demographic and anthropometric variables were the best candidate predictors of $\dot{V}O_{2\mathrm{peak}}$ achieved at the CPET. On the basis of their goodness of fit, variables were selected to be included into the stepwise linear regression analysis. Statistically significant differences were inferred from $P < 0.05$.

RESULTS

The SRTs were well tolerated by all participants of the reliability group, and they all performed the two SRTs at a maximal effort without any complications or adverse effects. They all met signs of the subjective criteria of maximal effort during the two SRTs, and most the participants also showed objective signs of maximal effort at the SRT, as indicated by an HR_{peak} > 180 beats·min^{-1} (53%). The participants of the validity group met the subjective criteria of maximal effort at the SRT and the CPET as well, and they all attained an HR_{peak} > 180 beats·min^{-1} and/or an RER_{peak} > 1.0 during the CPET. A plateau in $\dot{V}O_2$ during maximal exercise (29) was observed in 13 children (34%).

Reliability. The results of the two SRTs performed by the reliability group are shown in Table 2. Although the differences in test duration (3.24 s), WR_{peak} (6.41 W), and WR_{peak} normalized for body mass (0.11 W·kg^{-1}) between the two SRTs were small and therefore not clinically relevant, significantly higher values were observed during the second SRT. HR_{peak} and exhaustiveness (ΔVAS) were not significantly different between the two SRTs.

Reliability statistics for the SRT showed an ICC of 0.986 (95% confidence interval [CI] = 0.973–0.993; $P < 0.001$) for WR_{peak} and an ICC of 0.935 (95% CI = 0.878–0.966; $P < 0.001$) for WR_{peak} normalized for body mass. The ICC for the attained HR_{peak} at the SRT was 0.676 (95% CI = 0.451–0.821; $P < 0.001$). To analyze agreement between the two SRTs, a Bland and Altman plot is depicted in Figure 1. The mean bias ±1.96 SD between the two SRTs was −6.4 ± 30.9 W. Hence, the limits of agreement for WR_{peak} were +24.5 and −37.3 W.

Validity. Table 3 presents the results of the SRT and the CPET completed by the validity group. Although significantly higher values were found for the WR_{peak} attained at the SRT compared with the achieved WR_{peak} at the CPET, significantly lower values at the SRT compared with the CPET were observed for test duration, HR_{peak} and $\dot{V}_{E\mathrm{peak}}$. All participants of the validity group indicated that they favored the SRT over the CPET when they were asked about their preferential maximal exercise test. This is confirmed by the fact that the CPET received significantly higher values for

TABLE 2. SRT results of the reliability group.

	First SRT		Second SRT		P
Duration (s)[a]	131 ± 42	[63–220]	135 ± 44	[70–223]	0.020
WR_{peak} (W)	277 ± 93	[131–456]	284 ± 97	[133–468]	0.018
WR_{peak} per kilogram ($W \cdot kg^{-1}$)	5.2 ± 0.8	[3.6–6.5]	5.3 ± 0.9	[3.7–6.7]	0.038
HR_{peak} (beats·min^{-1})	182 ± 10	[163–203]	183 ± 10[b]	[166–201]	0.659
ΔVAS	5.5 ± 1.9	[0.7–9.3]	6.1 ± 1.8	[1.6–9.6]	0.053

Values are presented as means ± SD [range].
[a] Duration of the load phase, excluding warm-up and cooldown.
[b] HR_{peak} was not determinable in 1 boy, so in this case n = 16 for boys.
HR_{peak}, peak heart rate; ΔVAS, visual analog scale difference addressing the participant's level of fatigue (post-SRT minus pre-SRT); WR_{peak}, peak work rate (maximal short-time exercise capacity).

exhaustiveness (ΔVAS) than the SRT. Figure 2 shows the strong linear relationship between the WR_{peak} attained at the SRT and the $\dot{V}O_{2peak}$ achieved during the CPET. Both variables correlated highly with each other (r = 0.958; P < 0.001). On the basis of univariate regression analysis, FFM and BSA were also included in the stepwise linear regression analysis. However, the results indicated that WR_{peak} attained at the SRT (P < 0.001) remained the only significant predictor of $\dot{V}O_{2peak}$, whereas FFM (P = 0.377) and BSA (P = 0.391) were removed from the model. The following equation was developed to predict $\dot{V}O_{2peak}$ achieved during a CPET from the attained WR_{peak} at the SRT: $\dot{V}O_{2peak}$ ($mL \cdot min^{-1}$) = (8.262WR_{peak} SRT) + 177.096 (R^2 = 0.917, SEE = 237.4).

DISCUSSION

The aim of this study was to investigate the reliability and the validity of the SRT in healthy children and adolescents. The main results indicate that the SRT comprises good test–retest reliability and is a valid maximal exercise test that can predict $\dot{V}O_{2peak}$ as reached during a regular symptom-limited CPET. In addition, the SRT seems to put a smaller burden on the cardiopulmonary system compared with a regular CPET, as shown by the significantly lower values for HR_{peak} and $\dot{V}_{E}$peak attained during the SRT. The latter is caused by the short duration of the SRT because of the fast increase in WR compared with the regular CPET. Hence, peripheral muscle strength predominates in limiting SRT performance, with consequential higher WR_{peak} values and lower HR_{peak} and $\dot{V}_{E}$peak values during the SRT.

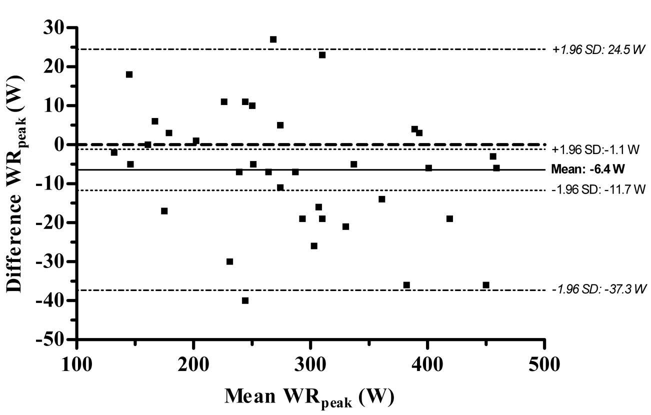

FIGURE 1—Bland and Altman plot of the WR_{peak} as attained at the first SRT versus the second SRT.

Especially in pediatric clinical populations, it is important that an exercise test can be easily performed by the participant. The SRT is a simple, short-time maximal exercise test, which was well tolerated by all participants. The current study in healthy children and adolescents demonstrates that the SRT seems to be appropriate for pediatric clinical populations because of the fact that it does not require respiratory gas analysis, it has a short duration (approximately between 2 and 3 min, excluding warm-up and cooldown), its good reliability, and the valid equation to predict an individual's $\dot{V}O_{2peak}$.

Regarding its reliability, the average difference between the absolute WR_{peak} values attained at the two SRTs was −6.4 W, indicating that the reliability group on average attained slightly higher WR_{peak} values at the second SRT. Because the differences are scattered symmetrically around the zero-bias line up to 400 W, there is no evidence for a significant learning effect. Very high ICCs (>0.9) (27) were found for both WR_{peak} and WR_{peak} normalized for body mass attained at the SRT. This indicates that the SRT is appropriate to use for discriminative purposes in cross-sectional samples. For clinicians, however, agreement of the measurements is more of interest, as they intend to determine meaningful improvements in a single individual (14). Concerning agreement, or individual variation between the test and the retest, the average absolute WR_{peak} achieved at the two SRTs showed acceptable limits of agreement (24.5 to −37.3 W), which means that the agreement as indicated by the smallest detectable change at the SRT equals 30.9 W. Expressed as a percentage, the limits of agreement were 9% to −13% (smallest detectable change = 11%) and appropriate to use in support of evaluative purposes after exercise testing of individual subjects.

It is difficult to compare the current study outcomes with existing literature because this is, to our knowledge, the first reliability study of the SRT in pediatric participants. De Backer et al. (10) investigated the test–retest reliability of the WR_{peak} in adult oncology patients who performed an SRT during cancer rehabilitation and reported an ICC of 0.996 (95% CI = 0.989–0.998). This is comparable with the ICCs observed in the current study in healthy children and adolescents. Overall, it seems that the SRT performance can be reproducibly performed by healthy children and adolescents.

TABLE 3. SRT and CPET results of the validity group.

	SRT		CPET		*P*
Duration (s)[a]	139 ± 41	[73–232]	558 ± 183	[278–949]	<0.001
WR_{peak} (W)	290 ± 94	[138–484]	203 ± 69	[94–348]	<0.001
WR_{peak} per kilogram ($W \cdot kg^{-1}$)	5.7 ± 0.7	[4.5–7.9]	4.0 ± 0.6	[2.7–5.8]	<0.001
HR_{peak} ($beats \cdot min^{-1}$)	181 ± 10[b]	[157–201]	193 ± 9[b]	[170–209]	<0.001
$\dot{V}_{Epeak}$ ($L \cdot min^{-1}$)	80.7 ± 30.2	[27.4–170.3]	93.3 ± 30.7	[44.8–166.0]	<0.001
$\dot{V}O_{2peak}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	NA	NA	50.7 ± 7.8	[36.9–71.2]	NA
ΔVAS	5.9 ± 1.7	[2.2–9.1]	7.2 ± 1.8	[2.3–9.9]	<0.001

Values are presented as means ± SD [range].

[a] Duration of the load phase, excluding warm-up and cooldown.

[b] HR_{peak} was not determinable in 1 girl during both exercise tests, so in this case n = 20 for girls.

HR_{peak}, peak heart rate; NA, not available; RER_{peak}, peak respiratory exchange ratio; ΔVAS, visual analog scale difference addressing the participant's level of fatigue (post-SRT minus pre-SRT); $\dot{V}_{Epeak}$, peak minute ventilation; $\dot{V}O_{2peak}$, peak oxygen uptake; WR_{peak}, peak work rate (maximal short-time exercise capacity).

The WR_{peak} attained at the SRT was highly associated with the $\dot{V}O_{2peak}$ achieved during the CPET, showing its validity as a measure of aerobic capacity. Our results are comparable with those of De Backer et al. (10) in adult oncology patients who also observed a significant correlation between the SRT's WR_{peak} and the CPET's $\dot{V}O_{2peak}$ (r = 0.82; P < 0.01). With the attained WR_{peak} at the SRT, it was therefore possible to predict a child's aerobic capacity. Several other studies predicted aerobic capacity in pediatric populations during exercise testing, including the regular CPET (11,12) and a submaximal treadmill test (26). $\dot{V}O_{2peak}$ ($mL \cdot min^{-1}$) could be estimated from the WR_{peak} accomplished at a CPET in healthy children (R^2 = 0.83, SEE = 114) (12) as well as in children with juvenile idiopathic arthritis (R^2 = 0.91, SEE = 180) (11). Using a submaximal treadmill test, it was found that $\dot{V}O_{2peak}$ ($mL \cdot min^{-1}$) could be predicted (based on HR and walking speed among others) in overweight children (R^2 = 0.75, SEE = 271) (26). De Backer et al. (10) developed a prediction equation to predict $\dot{V}O_{2peak}$ ($mL \cdot min^{-1}$) from WR_{peak} attained at the SRT in adult oncology patients and reported an SEE of 308 (R^2 = 0.67). The current study observed an SEE of 237 when predicting $\dot{V}O_{2peak}$ ($mL \cdot min^{-1}$), which is comparable with those reported earlier. One can argue that this SEE is larger than those observed by Dencker et al. (12) and De Backer et al. (11); however, in these studies, WR_{peak} and $\dot{V}O_{2peak}$ were obtained during the same test. In the current study, the SRT and the CPET were performed approximately 8 d apart, which includes also some day-to-day variance in performance (see Reliability section). The same test approach was used by De Backer et al. (10), and the comparison of the results revealed that our SEE and R^2 values were more favorable than observed in their study. A Bland–Altman plot for the predicted versus the measured $\dot{V}O_{2peak}$ in the current study showed a mean difference between the predicted and the measured $\dot{V}O_{2peak}$ of 0.3 $mL \cdot min^{-1}$, with all values scattered symmetrically around the zero-bias line. The limits of agreement were +459.4 and −458.9 $mL \cdot min^{-1}$. Nevertheless, the conversion to $\dot{V}O_{2peak}$ might be unnecessary because gender- and age-related reference values for the SRT performance (WR_{peak}) have recently been developed in healthy children and adolescents (7), which facilitates interpretation of SRT results for clinicians and researchers.

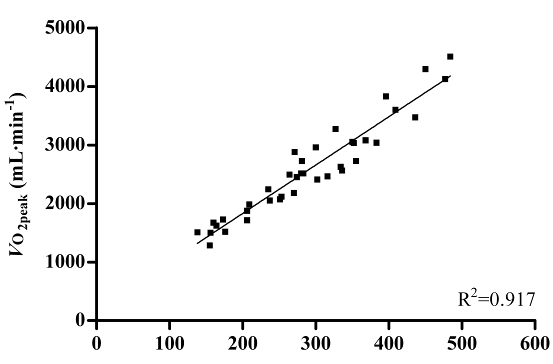

FIGURE 2—The linear relationship between the $\dot{V}O_{2peak}$ attained at the CPET and the WR_{peak} attained at the SRT.

Compared with a regular CPET, the significantly lower values for HR_{peak} and $\dot{V}_{Epeak}$ indicate that the SRT puts a smaller burden on the cardiopulmonary system as has previously been described in heart failure patients (21). In relation with this finding, all participants in the validity group indicated that they preferred performing an SRT over a CPET. Because exercise testing strongly depends on motivational factors, a more positive affective response during exercise will result in better adherence to the exercise protocol. Hence, the results of the exercise test will be more reliable and valid.

Study limitations. One of the limitations of this study is that only healthy participants were tested. In future studies, the reliability and validity of the SRT in clinical populations should be investigated. Although the participant's anthropometry differed not significantly from the general Dutch population norms, the currently developed regression equation for the prediction of aerobic capacity by SRT performance should be cross validated in a healthy population as well as in clinical populations. The lack of habitual physical activity data of the participants and the lack of a randomized testing order within the validity group are additional limitations of the current study.

CONCLUSIONS

The SRT seems to be a reliable and valid exercise test, which can predict $\dot{V}O_{2peak}$ in healthy children and adolescents. As the SRT seems to be cardiopulmonary less demanding than a regular CPET, it might be of interest for use in clinical populations as well as in less motivated participants.

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The authors declare no conflict of interest.

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