Reliability of treadmill measures and criteria to determine $\dot{V}O_{2max}$ in prepubertal girls

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ABSTRACT

REINALDO FIGUEROA-COLON, GARY R. HUNTER, MATTHEW S. MAYO, RUBY A. ALDRIDGE, MICHAEL I. GORAN, and ROLAND L. WEINSIER. Reliability of treadmill measures and criteria to determine $\dot{V}O_{2max}$ in prepubertal girls. *Med. Sci. Sports Exerc.*, Vol. 32, No. 4, pp. 865–869, 2000. **Purpose:** The main objective of this study was to determine the reliability of measuring treadmill exercise economy ($\dot{V}O_{2submax}$) and the maximal oxygen uptake ($\dot{V}O_{2max}$) in prepubertal girls tested twice, 6 wk apart. We also wanted to examine the percentage of young girls who were able to reach the criteria for achieving $\dot{V}O_{2max}$ and to describe methods that would allow a high proportion of young children to achieve criteria for reaching a true $\dot{V}O_{2max}$. **Methods:** We studied 61 normal-weight, prepubertal girls with a mean (± SD) age 7.3 ± 1.3 yr (range 4.8 to 10.3 yr). $\dot{V}O_{2submax}$ was determined while walking for 4 min at 2.5 mph with 0% grade. $\dot{V}O_{2max}$ was measured during a progressive, all-out, continuous treadmill test using standardized procedures and criteria. Heart rate (HR) was measured using a Polar monitor. Respiratory rate (RR), respiratory exchange ratio (RER), ventilation (V), and $\dot{V}O_2$ were measured using a Sensormedics metabolic monitor. **Results:** There were no significant differences between visits 1 and 2 in mean HR, RR, RER, V, $\dot{V}O_{2submax}$ (421 vs 422 mL·min^{-1}, respectively), and $\dot{V}O_{2max}$ (1036 vs 1049 mL·min^{-1}, respectively). Intra-individual coefficients of variation (CV) between visits 1 and 2 for submaximal tests were: HR = 5.1%, RR = 12.4%, RER = 7.2%, V = 12.5%, and $\dot{V}O_2$=12.4%. Intra-individual CVs for the maximum tests were: HR_{max} = 2.1%, RR_{max} = 10.8%, RER_{max} = 5.3%, V_{max} = 11.7%, and $\dot{V}O_{2max}$ = 7.5%. A high proportion of the girls reached criteria for $\dot{V}O_{2max}$ [RER>1.00, HR>85% of age predicted maximum, and plateauing of $\dot{V}O_{2max}$] in both visits: 99% reached one of three criteria, 92% reached two of three criteria, and 70% reached all three criteria. Twenty girls [mean age 7.2 ± 1.2 yr] reached at least two criteria in both visits, whereas 32 girls [mean (± SD) age 8.6 ± 1.0 yr] reached three criteria in both visits. **Conclusion:** Exercise measurements using treadmill testing were reliable in healthy, normal-weight, prepubertal girls. Older girls when compared to the younger girls were able to reach criteria for $\dot{V}O_{2max}$ more often. Thus, we recommend that one testing should give researchers an accurate measure of walking economy and aerobic capacity, and that two criteria are enough for determining $\dot{V}O_{2max}$. **Key Words:** CHILDREN, WALKING ECONOMY, AEROBIC FITNESS, PHYSICAL ACTIVITY

Maximal oxygen uptake or aerobic power ($\dot{V}O_{2max}$) is the gold standard for determining aerobic fitness (4). $\dot{V}O_{2max}$ is used to evaluate the change that occurs after training, to help assess functional capacity, and to compare with values in healthy individuals (1). Although $\dot{V}O_{2max}$ can be reliably measured in adults, there has been some discussion as to whether it is reliable in young children (2,5,16,17,19). One study (5) reported poorer coefficients of reliability in 10-yr-old boys who did not reach a plateau (increase in workload with no corresponding increase in $\dot{V}O_{2max}$) during $\dot{V}O_{2max}$ testing than in those boys who did reach a plateau. The boys in the plateauing group had greater variability in $\dot{V}O_{2max}$ than the boys in the nonplateauing group (5). Calculation of standard errors of prediction of the two groups from published data indicates that the nonplateauing group actually had lower standard errors of prediction than the plateauing group (5). Other studies (2,16–18) have shown that plateauing is not necessary for obtaining reliable measures of $\dot{V}O_{2max}$. However, none of the above studies have included subjects younger than 8 yr of age. To our knowledge no one has determined what test criteria are necessary for obtaining reliable measures in children younger than 8 yr.

Employing a treadmill, we used the following physiological criteria for reaching $\dot{V}O_{2max}$: a respiratory exchange ratio (RER) > 1.00, a heart rate (HR) > 85% of age predicted maximum, and a defined plateau of $\dot{V}O_2$ [i.e., a change with workload that is < 2 SD below that observed

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TABLE 1. Demographic and physical characteristics of 61 prepubertal girls at enrollment; data shown as Mean ± SD (range).

Age (yr)	7.3 ± 1.3 (4.8–10.3)
Race:	
White (*N*)	52
African-American (*N*)	8
Asian-American (*N*)	1
Weight (kg)	27.1 ± 5.3 (16.2–42.0)
Height (cm)	126.8 ± 8.8 (103.0–149.0)
Body mass index ($kg \cdot m^{-2}$)	16.7 ± 1.5 (14.0–20.0)

in the mean values between the submaximal workloads or < 150 $mL \cdot min^{-1}$ (16)]. The main objective of this study was to determine the reliability of measuring treadmill exercise economy ($\dot{V}O_{2submax}$) and the maximal oxygen uptake ($\dot{V}O_{2max}$) in 61 girls tested twice, 6 wk apart. We also wanted to examine what percentage of young girls were able to reach criteria for achievement of $\dot{V}O_{2max}$ and to describe methods that allow a high proportion of young children to achieve criteria for reaching a true $\dot{V}O_{2max}$.

METHODS

Subjects. Demographic and physical characteristics of the girls are shown in Table 1. We studied 61 healthy girls aged 4.8–10.3 yr. All girls weighed < 120% of ideal body weight-for-height using standards from the National Center for Health Statistics (8). All girls were prepubertal, Tanner Stage I (21). They were not consuming special diets, participating in extreme exercise programs, or taking any medications. The girls were recruited from surveys of several schools in the Birmingham area. Before enrollment, each child was familiarized with the procedures and equipment used in the treadmill test through a demonstrative interview. The purpose of the study was explained to the girls and parents before informed written consent/assent was obtained. The Institutional Review Board of the University of Alabama at Birmingham approved this study.

Treadmill testing. After 12 h fasting, on two mornings 6 wk apart, treadmill testing was measured for 10–15 min. The treadmill protocol involved a constant speed of 2.5 mph at an initial 0% grade for the first 4 min. The average of minutes 3 and 4 constituted the steady-state values. The grade was then increased to 10% for 2 min. Every 2 min thereafter, the grade was increased by 2.5% to a maximum of 22.5%, when speed was increased by 0.6 mph each minute until exhaustion. Exercise measures [oxygen consumption ($\dot{V}O_2$), ventilation (V), respiration exchange ratio (RER), and respiratory rate (RR)] were measured using a Sensormedics 2900 metabolic monitor (Loma Linda, CA). Heart rate (HR) was measured using a Polar monitor (Kempele, Finland). The HR was recorded at the end of every 2-min stage. Exercise economy was measured by the $\dot{V}O_2$ in steady state. The criteria for reaching $\dot{V}O_{2max}$ test were: RER > 1.00, HR > 85% percentile of age predicted maximum, and plateau of $\dot{V}O_2$ maximum [i.e., a change with workload that is < 2 SD below that observed in the mean values between the submaximal workloads or < 150 $mL \cdot min^{-1}$ (16)].

Procedures. Treadmill testing was measured twice 6 wk apart. Three individuals administered the test: one person operated the metabolic monitor and recorded the heart rate, a "catcher" stood behind the girls on the treadmill, another person was positioned in front of the treadmill to encourage and keep the girl's attention. Generally, the tests were administered without the parent present in the laboratory. Before the visit 1 exercise test, the girl was oriented with the equipment to be used during the test by walking on the treadmill, using the mouthpiece, and playing with the headgear and nose clip. She was already familiar with the Polar heart rate monitor. Before starting the test, a resting heart rate was obtained and the mouthpiece and headgear were positioned. As the test progressed and the workload became harder, the girls were verbally encouraged to continue as long as possible. However, the safety and well-being of the girls was of primary concern at all times. The test was terminated when they could no longer continue. This was evidenced by stumbling, refusal to continue, grasping the handrails, or a glazed look in the eyes.

Statistical analysis. The data were reported as percentages, means ± SD, and intra-individual coefficients of variation (CV). The CV was calculated as SD of the difference ÷ mean of the difference × 100. Paired *t*-tests were used to compare the data of visits 1 and 2. A multivariate analysis of variance (MANOVA) was used to compare the steady state and maximal variable in Table 2, between those girls who met all three criteria at both visits versus girls who met at least two criteria at both visits. Given a multivariate effect, univariate analysis of variance (ANOVA) was used to assess which variable(s) contributed to this effect. To maintain an overall Type I error rate of 5%, a Bonferroni adjustment was used; therefore, each ANOVA was performed with an individual Type I error rate of 5%. The two-sample *t*-test was used to compare the age of the girls in these two groups. The Pearson correlation coefficient (r) was used to assess the correlation of age with the variables in Table 2. The Wilcoxon signed rank test was used to compare the $\dot{V}O_{2max}$ values when girls reached two criteria in one of the visits and when the same girls reached three criteria in the other visit. All analyses were performed using the Statistical Analysis System, SAS Windows Version 4.0.950, on a Gateway P5–120 personal computer (SAS Institute, Inc. Cary, NC: SAS Institute, Inc., 1996).

RESULTS

In 3 of the 61 girls, one of the treadmill tests was not completed; therefore, data presented are of 58 girls. Using paired *t*-tests, there were no significant differences between visits 1 and 2 in mean heart rate, respiratory rate, respiratory exchange ratio, ventilation, $\dot{V}O_{2submax}$ (421 vs 422 $mL \cdot min^{-1}$), and $\dot{V}O_{2max}$ (1036 vs 1049 $mL \cdot min^{-1}$) (Table 2). The intra-individual coefficients of variation (CV) between visits 1 and 2 for submaximal tests were: HR = 5.1%, RR = 12.4%, RER = 7.2%, V = 12.5%, and $\dot{V}O_2$=12.4%. The intra-individual CVs for the $\dot{V}O_2$ maximum tests were: HR_{max} = 2.1%, RR_{max} = 10.8%, RER_{max} = 5.3%, V_{max} =

TABLE 2. Variability in treadmill testing in 58 prepubertal girls (mean ± SD).

	No. of Girls[a]	Visit 1[b]	Visit 2[b]	Intra-individual CV (%)
Steady-state				
Heart rate (bpm)[c]	58	122 ± 12	122 ± 10	5.1 ± 5
	20	126 ± 12	124 ± 9	4.1 ± 2
	32	121 ± 12	122 ± 10	5.7 ± 6
Respiratory rate	58	36 ± 9	34 ± 8	12.4 ± 10
	20	38 ± 10	34 ± 10	12.1 ± 10
	32	34 ± 7	35 ± 6	12.5 ± 10
Respiratory exchange ratio	58	0.93 ± 0.1	0.89 ± 0.1	7.2 ± 6
	20	0.92 ± 0.1	0.86 ± 0.1	7.2 ± 7
	32	0.93 ± 0.1	0.92 ± 0.1	6.7 ± 5
Ventilation ($L \cdot min^{-1}$)	58	12 ± 3	12 ± 2	12.5 ± 11
	20	13 ± 4	12 ± 2	13.9 ± 11
	32	12 ± 2	12 ± 3	11.4 ± 10
$\dot{V}O_2$ ($mL \cdot min^{-1}$)	58	421 ± 74	422 ± 77	12.4 ± 9
	20	426 ± 81	415 ± 69	15.5 ± 10
	32	424 ± 73	432 ± 83	10.3 ± 9
Maximum				
Heart rate (bpm)[c]	58	196 ± 9	196 ± 10	2.1 ± 3
	20	193 ± 9	193 ± 12	3.3 ± 4
	32	200 ± 7	198 ± 7	1.7 ± 1
Respiratory rate	58	62 ± 13	61 ± 11	10.8 ± 12
	20	62 ± 14	62 ± 13	14.1 ± 15
	32	62 ± 13	61 ± 10	8.8 ± 10
Respiratory exchange ratio	58	1.1 ± 0.1	1.1 ± 0.1	5.3 ± 5
	20	1.1 ± 0.2	1.0 ± 0.1	6.5 ± 7
	32	1.1 ± 0.1	1.1 ± 0.1	4.6 ± 4
Ventilation ($L \cdot min^{-1}$)	58	37 ± 9	37 ± 9	11.7 ± 9
	20	32 ± 7	32 ± 8	14.8 ± 11
	32	41 ± 9	41 ± 8	10.0 ± 7
$\dot{V}O_2$ ($mL \cdot min^{-1}$)	58	1036 ± 191	1049 ± 207	7.5 ± 7
	20	947 ± 178	989 ± 194	11.2 ± 10
	32	1115 ± 175	1115 ± 193	5.3 ± 4

[a] 58 girls = entire cohort; 20 reached at least two criteria for determining VO_{2max} in both visits; 32 reached three criteria for determining VO_{2max} in both visits.
[b] No significant differences between visits for any of the variables using paired t-tests.
[c] bpm, beat per minute.

11.7%, and $\dot{V}O_{2max}$ = 7.5%. As shown in Table 3, 70% of girls reached their physiologic limit as evidenced by meeting all criteria for $\dot{V}O_2$ maximum, on visits 1 and 2. During 77% of the treadmill tests, an RER > 1.00 (mean = 1.1) was observed, in 81% of the tests a HR > 85% of age predicted maximum (mean = 196 beat per minute) was obtained, and in 84% of the tests the plateau criterion was demonstrated. Twenty girls [mean age 7.2 ± 1.2 yr] reached at least two criteria in both visits, whereas 32 girls [mean (± SD) age 8.6 ± 1.0 yr] reached three criteria in both visits. The data were reanalyzed for the 20 and 32 girls separately (Table 2). Lower CVs were observed in the 32 girls who reached three criteria in both visits when compared with those reaching two criteria. When compared with the younger girls, the older girls were able to reach their $\dot{V}O_{2max}$ more often. Eleven girls reached two criteria in one of the visits and three criteria in the other visit. Using the Wilcoxon signed rank test, when 11 of the girls reached two of the criteria the median for $\dot{V}O_{2max}$ was 897 $mL \cdot min^{-1}$ (range 671-1135 $mL \cdot min^{-1}$); and when the same 11 girls reached all three criteria the median for $\dot{V}O_{2max}$ was 1002 $mL \cdot min^{-1}$ (range 703 $mL \cdot min^{-1}$ to 1346 $mL \cdot min^{-1}$). These median values were not statistically significant (P = 0.2783).

DISCUSSION

This is the first study in children that demonstrates the reliability of treadmill testing in healthy, normal weight, prepubertal girls. Even though the repeated treadmill measurements were performed 6 wk apart, our findings show that: a) the treadmill testings were reliable; b) in this group of prepubertal girls, all three criteria for $\dot{V}O_{2max}$ were achieved in 70% and at least two criteria were reached in 92%; and c) the older girls were able to reach more $\dot{V}O_{2max}$ criteria than the younger girls.

The 6-wk interval is a limitation of this study. This study was conducted as a subproject of a larger investigation of metabolic predictors of weight gain in normal-weight, prepubertal girls. Because of the timing and magnitude of other tests involved in the protocol, i.e., biochemical, body composition, and metabolic tests during a 4-d stay at the General Clinical Research Center, we could not ask the children and

TABLE 3. Criteria on aerobic power during $\dot{V}O_2$ maximum in 58 prepubertal girls.

No. of Criteria Achieved: [RER > 1.00, HR >85% of age predicted maximum, $\dot{V}O_2$ plateau]	Visit 1		Visit 2	
	N	%	*N*	%
1 of 3	58	100.0	57	98.3
2 of 3	56	96.6	50	86.2
all 3	39	67.2	42	72.4

their parents to repeat treadmill testing in a shorter interval of time. The 6-wk interval for retesting of the treadmill measurements introduces the confounding influence of growth and/or changes in fitness. It should be pointed out that this would only decrease the reliability of the treadmill tests making our estimates of reliability conservative, i.e., the tests are in all likelihood more reliable than those we report.

Previous studies have indicated that 21–59% of children will demonstrate a $\dot{V}O_2$ plateau during a progressive continuous treadmill exercise test (2,3,5–7,9,14–18,20). In contrast to earlier reports, our findings showed that 84% of the girls reached a plateau using a ramp protocol. We used techniques similar to Hester et al. (9) and feel that the reward system and familiarization with equipment, procedures, and personnel collectively contributed to the high percentage of the girls who reached a plateau. In addition, our subjects underwent biochemical, body composition, and metabolic tests in a 4-d hospitalization, twice 6 wk apart. Likely for them, the treadmill tests were not as challenging as the other tests. It should be noted that although the appearance of a $\dot{V}O_2$ plateau has been considered less common in children than adults, a similar wide range of observed plateaus (7% to 80%) has been reported in older subjects (13).

Another study gave similar results in a younger group of 19 boys and 6 girls (mean age 5.3 yr, range 3.7–6.4 yr) during progressive treadmill walking test (20). In 87% of the treadmill tests, an RER $>$ 1.00 was observed; in 86% of the tests, a HR $>$ 195 beat per min was obtained; but in only 59% of the tests was the plateau criterion observed (20). In terms of the criteria for $\dot{V}O_2$ maximum, one of the three criteria was met in 97% of the tests, two criteria were met in 86% of the tests, and all three criteria were met in only 52% of the tests (20). Fourteen boys and five girls of this cohort of children underwent similar treadmill testing 4 yr later (6). A high proportion of the children demonstrated criteria for reaching $\dot{V}O_{2max}$. All the children met at least one of the three criteria, 95% met two of the three criteria, and 86% met all three criteria during the follow-up study (6).

The nature of the exercise testing protocol affects the demonstration of a $\dot{V}O_2$ plateau. One study (19) evaluated the ability of a continuous walking, continuous running and intermittent running treadmill protocol to produce a plateau in the same group of 10- to 12-yr-old boys. A plateau (rise in $\dot{V}O_2 < 2$ SD of the mean between previous workloads) was observed in 31%, 56%, and 69% of subjects, respectively. In general, intermittent exercise protocols in children have yielded a higher percentage of $\dot{V}O_2$ plateaus than continuous protocols (4,10–12), a finding previously noted in adult studies (15).

Studies in children older than 8 yr of age have shown that plateauing is not necessary for obtaining reliable measures of $\dot{V}O_{2max}$ (2,5,16–18). These previous studies suggest that a plateau of $\dot{V}O_2$ during progressive treadmill testing should not be considered a requisite for determination of $\dot{V}O_{2max}$ in children older than 8 yr of age (2,5,16–18). Maximal exercise tests with children are normally terminated by voluntary exhaustion, and the investigators are left with the problem of deciding whether the children delivered a maximal effort. Subjective criteria and the pediatric exercise testing experience of the investigators are vital in making this decision because no single variable can confirm a maximal effort. However, our findings concur with others (2,17) that despite wide individual variability, maximal HR and RER are valuable subsidiary criteria when using a progressive, incremental exercise test. In the 11 girls who reached two of the criteria in one of the visits and all three criteria in the other visit, the median $\dot{V}O_{2max}$ values were not significantly different. This finding suggests that two criteria are enough for determining $\dot{V}O_{2max}$.

In summary, this study indicates that a $\dot{V}O_{2max}$ was achieved in two thirds of this group of prepubertal girls. The treadmill testings were reliable in both younger and older girls. Older girls were able to reach their $\dot{V}O_{2max}$ more often. We recommend that one testing should give researchers an accurate measure of walking economy and aerobic capacity, and that two criteria are enough for determining $\dot{V}O_{2max}$.

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