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Reference values for maximum work capacity in relation to body composition in healthy Dutch children

V.A.M. Gulmans*, K. de Meer**, R.A. Binkhorst+, P.J.M. Helders*, W.H.M Saris++

Reference values for maximum work capacity in relation to body composition in healthy Dutch children. V.A.M. Gulmans, K. de Meer, R.A. Binkhorst, P.J.M. Helders, W.H.M Saris. ©ERS Journals Ltd 1997.

ABSTRACT: Exercise performance is associated with physical development. For sick children, there is a need for parameters reflecting exercise performance, which should be easy to measure and should take their nutritional state into account. The aim of this study was to investigate the relationship between maximum workload (W_{max}) and body weight (BW) as well as fat-free mass (FFM) in healthy children performing an incremental maximum exercise test on a bicycle ergometer, and to develop reference values for W_{max} corrected for nutritional state.

A random sample of 158 children (77 boys and 81 girls), aged 12–18 yrs, underwent an incremental maximum exercise test on a bicycle ergometer. BW and FFM were also measured.

Correlation analysis showed a significant association ($p<0.001$) between BW and W_{max} (boys: $r=0.82$; girls: $r=0.73$), and between FFM and W_{max} (boys: $r=0.89$; girls: $r=0.79$). Two-way analysis of variance showed a significant effect of gender on variance of W_{max}/BW ratio as well as W_{max}/FFM ratio. The influence of age was significant for W_{max}/FFM ($p=0.003$), but not for W_{max}/BW.

The maximum workload/body weight ratio and the maximum workload/fat-free mass ratio are useful parameters of work capacity in bicycle exercise testing in children. The reference values (mean, SD, median, and percentiles) for boys and girls aged 12–18 years can be used to predict workload corrected for body composition in healthy and sick children.

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Depts of *Pediatric Physiotherapy and **Gastroenterology of the University Hospital for Children and Youth "Wilhelmina Kinderziekenhuis", Utrecht, The Netherlands. +Dept of Physiology, University of Nijmegen, The Netherlands. ++Dept of Human Biology, University of Maastricht, The Netherlands.

Correspondence: V.A.M. Gulmans
Dept of Pediatric Physiotherapy
University Hospital for Children and Youth
Wilhelmina Kinderziekenhuis
P.O. Box 18009
3501 CA Utrecht
The Netherlands

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Maximum exercise tolerance is an important parameter for diagnosis and evaluation in children and adults with cardiopulmonary and metabolic diseases [1]. In younger children, up to 10 yrs of age, performance on treadmills is used to assess exercise tolerance. In older children and adults, testing on a bicycle ergometer can be performed, with the advantage of more precise dosage of workload [1, 2]. Incremental exercise protocols using bicycle ergometers have been advocated to assess maximum exercise tolerance [2–4]. Reference values for parameters such as maximum oxygen consumption ($V'O_{2,max}$), maximum workload (W_{max}) and maximum heart rate (HR_{max}) have been developed for adults [1, 5, 6] and children [4, 7, 8]. A linear correlation has been described between $V'O_{2,max}$ and W_{max} during steady state in adults [1], as well as in children [2].

In the reference values for healthy children, $V'O_{2,max}$ is described as a function of gender, age and body weight. In general, a greater body weight (BW) and, in particular, a higher fat-free mass (FFM), are associated with an increased $V'O_{2,max}$ [9]. The larger proportion of FFM in boys as compared to girls explains the difference in $V'O_{2,max}$ between the sexes. Although GODFREY [2] has already described the relationship between W_{max} and body weight. W_{max} is mostly presented as a function of gender and age [10]. However, it can be hypothesized that BW, and more specifically FFM, is an important predictor of W_{max}. This may be relevant in clinical studies in children with cardiopulmonary or metabolic diseases, in particular in children with a diminished nutritional state (*e.g.* children with cystic fibrosis). In settings where exercise tests are performed without gas analysis, $V'O_{2,max}$ per kg of body mass cannot be used to correct for diminished body weight and FFM. Reference values for W_{max} with correction for body composition would, thus, be of practical value.

We therefore reanalysed data collected in an earlier study [11] to investigate the relationship between W_{max} and BW as well as FFM, in healthy children who performed a maximum incremental exercise test on a bicycle ergometer. If strong correlations were found, we aimed to develop reference values for these parameters.

Materials and methods

Subjects

A random sample of children from a Dutch urban and suburban community (Nijmegen) took part in the study [11]. They were divided into cohorts aged 12, 14, 16 and 18 yrs, with a standard deviation for each cohort <2 weeks. On the basis of medical history and physical examination, 6% of the initial sample was excluded because of cardiopulmonary disease, including asthma, and physical handicap or mental retardation. The present sample, thus, consisted of 158 children (77 boys and 81 girls). Data on smoking behaviour were not collected. The study was approved by the Medical Ethics Committee of the University of Nijmegen. Parents and children were informed about the procedures, and consent was obtained.

Methods

The recorded anthropometric data consisted of height, body weight, and thickness in duplo of left-sided triceps, biceps, subscapular and crista skinfolds (Holtain calliper, accuracy 0.1 mm). The fraction of fat mass (FM) was calculated from the sum of the four skinfolds, according to DURNIN and RAHAMAN [12]. Fat-free mass (FFM) was calculated as FFM=(1-fraction of FM)×BW.

Maximum incremental exercise tests were performed on an electronically-braked bicycle ergometer (RH400; Lode, Groningen, The Netherlands) with stepwise rectangular loads of 20 $W \cdot min^{-1}$ at 60 rotations per minute. Calibration of the ergometer was performed by the manufacturer twice a year, with an accuracy of 1%. Oxygen consumption (V'_{O_2}) was measured, either by means of Douglas bags, or by an automated system (Oxycon IV; Jaeger, Breda, The Netherlands), which was calibrated with the Douglas bag method. For the Douglas bags, the volume of expired air was measured with a Tissot-spirometer, and gas analyses were performed with a paramagnetic oxygen cell (Servomax A0272, UK) and an infrared CO_2-analyser (Uras; Hartman and Brown, Germany). Calibration was performed twice daily with two gas mixtures in the expected range, which were standardized with chemical analyses (Scholander method). In the automatized system, oxygen and carbon dioxide concentrations were measured with a paramagnetic O_2 analyser (Datex, Helsinki; accuracy 0.02% O_2) and an infra-red CO_2 analyser (Datex, Helsinki; accuracy 0.01% CO_2), respectively. Internal gas and volume calibration was performed each day according to the instructions of the manufacturer, as described by ZOLADZ *et al.* [13]. Continuous electrocardiographic (ECG) recordings were registered (Cardiostat; Siemens, Germany). The subjects were encouraged to perform until exhaustion. Maximum workload (W_{max}) was defined as the workload that could be maintained during the last 30 s of the test.

The tests were considered to be adequate if at least two out of the following three criteria were met: 1) levelling off of the heart rate, despite further increments of the workload; 2) during the measurements with the Oxycon, increase of the respiratory exchange ratio (carbon dioxide elimination (V'_{CO_2}/V'_{O_2}) above 1.0; and, finally, 3) a capillary blood sample was taken from the middle finger 3 min after reaching the maximum level, while the subject was still cycling at low intensity (50 W) to recover. Lactate concentration was determined using an enzymatic method (Boehringer, Germany). The test was considered to be adequate if the concentration exceeded the threshold levels, as described in the literature. These levels are age-related and were defined as 4.9, 5.2, 5.7 and 6.0 $mmol \cdot L^{-1}$ in children aged 12, 14, 16 and 18 yrs, respectively [7]. All subjects fulfilled at least two criteria for maximum performance.

Data analysis

Concerning the normality assumption of distribution of the data, Kolmogorov-Smirnov goodness-of-fit test showed no significant deviations. Correlation analyses of BW, FFM and age with W_{max} and $V'_{O_2,max}$ were performed for both sexes. Regression analyses were performed for age on the dependent variables W_{max}, W_{max}/BW ratio and W_{max}/FFM ratio, in both sexes. The influence of age and gender on W_{max}/BW and on W_{max}/FFM was also investigated by two-way analysis of variance (ANOVA), taking into account nonlinear effects with polynomials. Means and standard deviations as well as the 10th, 50th and the 90th percentiles were calculated for W_{max}/BW and W_{max}/FFM in relation to gender and age. For statistical analysis the Statistical Package for the Social Sciences (SPSS) PC+ package was used. A p-value of less than 0.05 was considered significant.

Results

Anthropometric data and W_{max} in relation to age and gender are presented in table 1. The larger FFM and W_{max} in boys as compared to girls is evident. Both parameters levelled-off towards the age of 18 yrs in both sexes. The results of the correlation analyses (table 2) showed a highly significant association between W_{max} and $V'_{O_2,max}$. Highly significant associations were also found between W_{max} and BW, between W_{max} and FFM, and between W_{max} and age (all $p<0.001$). Similar analyses with substitution of $V'_{O_2,max}$ for W_{max} led to significant associations between $V'_{O_2,max}$ and BW, between $V'_{O_2,max}$ and FFM, and between $V'_{O_2,max}$ and age (all $p<0.001$).

Table 1. – Anthropometric data, W_{max} and $V'_{O_2,max}$ in relation to age and gender

Age yrs	Ss n	Height cm	Weight kg	FFM kg	W_{max} W	$V'_{O_2,max}$ $L \cdot min^{-1}$
Boys						
12	13	154±6	42±11	36±6	178±31	2.04±0.34
14	22	165±8	52±9	45±6	234±31	2.64±0.46
16	24	179±5	63±7	55±6	300±37	3.51±0.60
18	18	180±6	66±5	58±4	304±24	3.56±0.35
Girls						
12	22	154±8	43±9	38±5	158±20	171±0.29
14	22	163±6	51±7	39±5	199±34	2.12±0.39
16	18	167±6	57±8	42±4	216±31	2.39±0.41
18	19	166±7	55±8	41±4	211±30	2.29±0.43

Values are expressed as mean±SD. Gas volume are in STPD. Ss: subjects; W_{max}: maximum workload; $V'_{O_2,max}$: maximum oxygen consumption; FFM: fat-free mass; STPD: standard temperature and pressure, dry.

Table 2. – Correlation coefficients of W_{max} and $V'_{O_2,max}$ with BW, FFM and age for girls and boys

	W_{max}		$V'_{O_2,max}$	
	Boys	Girls	Boys	Girls
BW	0.82	0.73	0.81	0.77
FFM	0.89	0.79	0.87	0.82
Age	0.78	0.52	0.74	0.50
W_{max}	-	-	0.95	0.95

W_{max}: maximum workload; $V'_{O_2,max}$: maximum oxygen consumption; BW: body weight; FFM: fat-free mass. All p-values <0.001.

Table 3. – Regression-analyses for age on *W*max parameters for boys and girls*

Y	r	a	b	p-value (for b)
Boys				
*W*max W	0.78	-77.5 (23.0)	22.1 (1.5)	<0.001
*W*max/BW W·kg^{-1}	0.25	3.74 (0.37)	0.06 (0.02)	0.02
*W*max/FFM W·kg^{-1}	0.31	4.24 (0.34)	0.07 (0.02)	0.005
Girls				
*W*max W	0.52	59.8 (20.4)	8.9 (1.4)	<0.001
*W*max/BW W·kg^{-1}	0.07	3.63 (0.33)	0.01 (0.02)	NS
*W*max/FFM W·kg^{-1}	0.23	4.24 (0.37)	0.05 (0.02)	0.04

Data are presented as mean, and SD in parenthesis. *: linear regression equation: Y=a+(b×X), where Y is the *W*max parameter (see left column), a and b are the intercept and slope, respectively, and X is the age of boys or girls in years. r: Pearson's correlation coefficient; NS: not significant. For further definitions see legend to table 2.

In table 3 the equations are presented for regression of age on *W*max, *W*max/BW and *W*max/FFM.

The results of the polynomial ANOVA showed a significant influence of gender on *W*max/BW ratio (F-ratio= 72.4; p<0.001) as well as *W*max/FFM ratio (F=5.4; p= 0.02); whereas the influence of age was only significant in the *W*max/FFM ratio (F=4.9; p=0.003) and not in *W*max/BW ratio (F=1.8; NS). The F-values for the effects of age by sex were not significant for either ratio (*W*max/ BW: F=0.8; and *W*max/FFM: F=0.3).

In table 4, mean, SD and percentile values (P10, P50 and P90) for *W*max/BW ratio and *W*max/FFM ratio in boys and girls are given for the age cohorts.

Table 4. – Values for *W*max/BW and *W*max/FFM in boys and girls

	Age	Mean±SD	P10	P50	P90
***W*max/BW**					
Boys	12	4.31±0.69	3.24	4.48	5.38
	14	4.60±0.55	3.94	4.71	5.26
	16	4.75±0.47	4.05	4.71	5.36
	18	4.62±0.49	3.77	4.66	5.27
	12–18	4.60±0.55	3.91	4.64	5.27
Girls	12	3.75±0.59	2.93	3.66	4.49
	14	3.93±0.50	3.30	4.00	4.74
	16	3.84±0.56	3.16	3.92	4.78
	18	3.85±0.39	3.21	3.87	4.40
	12–18	3.85±0.51	3.20	2.87	4.58
***W*max/FFM**					
Boys	12	4.91±0.60	3.93	4.96	5.73
	14	5.27±0.46	4.61	5.32	5.88
	16	5.42±0.51	4.78	5.36	6.12
	18	5.28±0.49	4.39	5.33	5.98
	12–18	5.26±0.52	4.49	5.31	5.97
Girls	12	4.74±0.57	4.05	4.63	5.54
	14	5.15±0.60	4.43	5.23	6.01
	16	5.09±0.59	4.32	5.04	5.87
	18	5.11±0.44	4.40	5.04	5.69
	12–18	5.01±0.57	4.29	5.03	5.77

Mean±SD and percentile (P10, P50 and P90) values are presented. *W*max/BW: ratio of maximum workload and body weight; *W*max/FFM: ratio of maximum workload and fat-free mass.

Discussion

The correlation analyses (table 2) indicate that FFM had the strongest correlation with *W*max out of the variables FFM, BW and age. Likewise, FFM had the strongest correlation with $V'o_{2,max}$. These correlations are not surprising, as $V'o_{2,max}$ and *W*max are known to be strongly associated in children [1, 2, 5], as shown by our data. The present results with the incremental bicycle test are in agreement with earlier publications by BINKHORST *et al.* [14] on the same study sample, showing that FFM explained the highest proportion of variance in $V'o_{2,max}$ when exercise testing was performed with the Bruce-protocol during treadmill-walking. BOILEAU and LOHMAN [15] and MALINA and LITTLE [9] also described the significant effect of FFM on physical performance.

It is difficult to define criteria for maximal exercise testing in childhood. All participating children met the criteria concerning heart rate, lactate concentration and respiratory quotient (RQ). According to present standards, maximal performance was, thus, reached in all children in the present study. Moreover, the results for $V'o_{2,max}$ from this random sample of children were very similar to those from other published studies [16–18]. This suggests that our results for *W*max can be used to calculate reference values for *W*max/BW and *W*max/FFM.

The results of the polynomial ANOVA showed that gender differences have to be taken into account when interpreting *W*max/FFM or *W*max/BW ratios, whereas it is not necessary to correct for age with respect to *W*max/ BW ratio. This is also shown by the low proportion of explained variance in *W*max/FFM and *W*max/BW when age is taken into account (table 3).

Although measurement of $V'o_2$ has been claimed as the most valid reflection of metabolic demand during exercise testing [1], *W*max/BW and *W*max/FFM ratios may also be useful parameters in exercise testing for several reasons. From a practical point of view, the measurement of *W*max is not limited to specialized centres and it provides an easy method for screening or follow-up purposes. Moreover, in malnourished children or children with growth disturbances it will probably lead to a more realistic estimation of their performance level compared to reference values of absolute *W*max in healthy children in the same age group. This is of special interest in the clinical use of exercise testing in children whose exercise tolerance is limited by cardiopulmonary as well as nutritional factors (*e.g.* cystic fibrosis or cardial cachexia).

In conclusion, maximum workload/body weight ratio and maximum workload/fat-free mass ratio are good indicators of exercise capacity as measured on a bicycle ergometer in healthy children aged 12–18 yrs. Reference values for these parameters have to be gender-specific, but age is not a strong predictor when correction of maximum workload for body weight and fat-free mass is carried out in healthy children. These parameters are easy to measure and could be of value for clinical judgements. Further studies on their practical use are needed, particularly in malnourished children.

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