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A new approach to assessing maximal aerobic power in children: the Odense School Child Study

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Summary. In two experiments maximal aerobic power ($\dot{V}_{O_{2\,max}}$) calculated from maximal mechanical power (W_{max}) was evaluated in 39 children aged 9-11 years. A maximal multi-stage cycle ergometer exercise test was used with an increase in work load every 3 min. In the first experiment oxygen consumption was measured in 18 children during each of the prescribed work loads and a correction factor was calculated to estimate $\dot{V}_{O_{2\,max}}$ using the equation $\dot{V}_{O_{2\,max}} = 12 \cdot W_{max} + 5 \cdot \text{weight}$. An appropriate increase in work rate based on height was determined for boys (0.16 $W \cdot cm^{-1}$) and girls (0.15 $W \cdot cm^{-1}$) respectively. In the second experiment 21 children performed a maximal cycle ergometer exercise test twice. In addition to the procedure in the first experiment a similar exercise test was performed, but without measurement of oxygen uptake. Calculated $\dot{V}_{O_{2\,max}}$ correlated significantly ($p<0.01$) with those values measured in both boys ($r=0.90$) and girls ($r=0.95$) respectively, and the standard error of estimation for $\dot{V}_{O_{2\,max}}$ (calculated) on $\dot{V}_{O_{2\,max}}$ (measured) wass less than 3.2%. Two expressions of relative work load (%$\dot{V}_{O_{2\,max}}$ and %W_{max}) were established and found to be closely correlated. The relative work load in %$\dot{V}_{O_{2\,max}}$ could be predicted from the relative work load in %W_{max} with an average standard error of 3.8%. The data demonstrate that calculated $\dot{V}_{O_{2\,max}}$ based on a maximal multi-stage exercise test provides an accurate and valid estimate of $\dot{V}_{O_{2\,max}}$.

Key words: Cycle ergometer — Maximal oxygen uptake — Calculated maximal oxygen uptake — Maximal power output

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Introduction

It is difficult to define overall physical performance, and even more difficult to measure it. The direct measurement of maximal oxygen uptake ($\dot{V}_{O_{2\,max}}$) is restricted to performance in a well-equipped laboratory with the help of trained and skilled personnel. Thus, it is not realistic to apply the direct measurement of $\dot{V}_{O_{2\,max}}$ to the screening of large populations or to locations apart from the laboratory.

Several methods of estimating $\dot{V}_{O_{2\,max}}$, using submaximal exercise testing, have been developed. The most widely accepted method is based on heart rate (HR) response to a corresponding work load (Åstrand and Ryhming 1954; Bengtsson 1956; Maritz et al. 1961; Margaria et al. 1965; Wyndham et al. 1966; Harrison et al. 1980). Evaluation by the measurement of the respiratory exchange ratio during submaximal exercise has also been used (Issekutz et al. 1962). The standard error of estimation for these methods of prediction of $\dot{V}_{O_{2\,max}}$ from submaximal exercise tests is of the order of 10%-15% (Åstrand et Rodahl 1986; Shephard 1984), and these methods are thus very limited in accuracy. Greater accuracy has been demonstrated by using a maximal predictive cycle ergometer test with a fixed increase in work load every minute for estimating $\dot{V}_{O_{2\,max}}$ (Patton et al. 1982; Myles and Toft 1982). Even this method provides a correlation of the estimated $\dot{V}_{O_{2\,max}}$ to the directly measured $\dot{V}_{O_{2\,max}}$, which is too low for reliable use in establishing individual fitness levels.

In a common multi-stage exercise test performed in young men a very close relationship has been found between the relative work load in percentage maximal aerobic power (%$\dot{V}_{O_{2\,max}}$) and the relative work load in percentage maximal mechanical power output (% W_{max}) (Pedersen and Nielsen 1984). This paper reports the evaluation of a similar indirect test of $\dot{V}_{O_{2max}}$ in children, based on a calculation from maximal mechanical power (W_{max}). The paper also reports the significance of the procedure for establishing relative work load in the assessment of exercise response of a physiological variable.

Subjects and methods

Two experiments were performed. All subjects in both experiments received a full explanation of the procedures. Informed consent was obtained in both experiments from each child and guardian before participation. The study was approved by the Research Ethics Committee of the Medical Faculty of the University of Odense.

First experiment. Eighteen healthy children aged 10–11 years participated. One boy and one girl were excluded, due to failure in Douglas bag air collection at maximal work load. The physical characteristics of the subjects are shown in Table 1.

Second experiment. Twenty-one healthy children aged 9–11 years participated. One boy did not meet the criteria for maximal work and was excluded. The physical characteristics of the subjects are shown in Table 1.

Procedures

First experiment. This experiment was performed partly to determine a correction factor used in the calculation of $\dot{V}_{O_{2max}}$ from W_{max} and partly to establish an appropriate increase in the work load of the test. The subjects pedalled an electrically braked cycle ergometer (Siemens-Elema, Simonsen and Weel, Copenhagen, Denmark) continuously at 60–80 rpm (Test 1.1). The initial work load was 20 W with an increase of 20 W every 3rd min until voluntary exhaustion. The child was verbally encouraged throughout the test. The criteria for acceptance of the work being maximal were HR ≥ 185 bpm, the ventilatory coefficient ($\dot{V}_E : \dot{V}_{O_2}$) ≥ 30 and the respiratory exchange ratio > 1.0.

Second experiment. To determine the accuracy and validity of the test, a second experiment, independent of the first experiment, was performed. With a time interval of exactly 1 week between the tests the subjects twice pedalled an electrically braked cycle ergometer (Meditronic 40-3, Kivex, Copenhagen, Denmark) continuously at 60–80 rpm (test 2.1 and test 2.2). On both occasions the initial work load was 25 W with an increase of 20 W or 25 W, depending on the height of the subject, every 3rd min until exhaustion. The same criteria as in the first experiment were applied for the maximal exercise test to be acceptable.

Measurements

First experiment. During the last minute of every work interval HR was measured from electrocardiogram recordings and the oxygen uptake was determined using the conventional Douglas bag technique. Oxygen and carbon dioxide contents of the expired air were measured using paramagnetic (Servomex OA 184, Simonsen and Weel, Copenhagen, Denmark) and infra-red (Beckman LB2, Simonsen and Weel, Copenhagen, Denmark) analysers respectively. Calibration of the analysers was performed by frequent comparisons with test gas analyses obtained using the micro-Scholander method.

Transforming the equation for calculation of the mechanical net efficiency of work, $\dot{V}_{O_{2max}}$ can be calculated as

$$\dot{V}_{O_{2max}}(\mathrm{ml \cdot min^{-1}}) = k_1 \cdot W_{max}(\mathrm{W}) + 5 \cdot \mathrm{weight(kg)}$$

where k_1 is the correction factor for the physical units, caloric equivalent for oxygen, and mechanical efficiency for muscular work and 5 · weight the resting metabolic rate of children (Izukawa and Drash 1968).

Second experiment. The HR was monitored by telemetry (Sport tester PE-3000, Polar Electro, Kempele, Finland) throughout the test and recorded at the end of every work load. Once, randomly (test 2.1), the oxygen uptake during the test was determined using the conventional Douglas bag technique as described for the first experiment. In both tests $\dot{V}_{O_{2max}}$ was calculated from W_{max}. Neither the investigator nor the child knew the time taken to complete the other test.

Working capacity and relative work load

The protocol employed provided two expressions of maximal work capacity and two expressions of relative work load. Firstly, the determination of oxygen uptake at every submaximal and maximal work load allowed the calculation of the relative aerobic work load, i.e. the oxygen uptake as % $\dot{V}_{O_{2max}}$. Secondly, W_{max} was determined from the equation

$$W_{max} = W_h + W_d \cdot t \cdot 180^{-1}$$

where W_d is the increase in work load, W_h the highest work load carried out over a complete 3-min period, and t the work time in s in the subsequent work period. After determining W_{max} the employed absolute work loads in watts could be converted to % W_{max}.

Table 1. Physical characteristics of the subjects (mean ± SD)

	First experiment		Second experiment	
	Boys ($n=8$)	Girls ($n=8$)	Boys ($n=9$)	Girls ($n=11$)
Age (years)	10.5 ± 0.3	10.5 ± 0.3	10.2 ± 0.4	10.3 ± 0.3
Weight (kg)	36.3 ± 7.9	34.2 ± 7.6	32.4 ± 3.5	38.2 ± 9.3
Height (cm)	144.0 ± 7.1	143.5 ± 6.2	141.7 ± 5.1	145.3 ± 5.8

Table 2. Maximal measured and calculated values of aerobic power ($\dot{V}_{O_{2max}}$), heart rate (HR) and respiratory quotient (R) (mean ±SD)

	First experiment		Second experiment	
	Boys	Girls	Boys	Girls
Direct $\dot{V}_{O_{2max}}$				
(l·min^{-1})	1.64± 0.20[a,b]	1.45±0.32[b]	1.82±0.22[a]	1.75± 0.25
(ml·kg^{-1}·min^{-1})	46.2 ± 6.7[a,b]	42.5 ±4.5[b]	56.4 ±4.6[a]	47.1 ± 8.0
Calculated $\dot{V}_{O_{2max}}$				
(l·min^{-1})	1.58± 0.13[a,b]	1.42±0.32[b]	1.82±0.21[a]	1.75± 0.28
(ml·kg^{-1}·min^{-1})	44.6 ± 6.7[a,b]	41.7 ±4.9[b]	56.2 ±4.9[a]	47.0 ± 8.4
Maximal HR (beats·min^{-1})	199 ±10	203 ±8	197 ±8	199 ±11
Maximal R	1.02± 0.06	1.06±0.06	1.03±0.11	1.06± 0.06

$p<0.05$; [a] compared to girls; [b] compared to second experiment

Statistics

Standard parametric statistical methods were used for calculation of mean, standard deviation (SD) and the correlation coefficient. Regression analyses were carried out by the least squares method. Differences between the directly measured and the estimated values of subjects were assessed by a paired Student *t*-test, and differences between the sexes and between the pair of experiments on the subjects were assessed by a two-tailed Student *t*-test. A probability value of less than 0.05 determined statistical significance.

Results

Table 2 presents the data on directly measured and calculated $\dot{V}_{O_{2max}}$, HR and respiratory quotient from each of the two experiments. Mean values of $\dot{V}_{O_{2max}}$ for the boys were significantly higher than those values obtained for the girls in both experiments. In both sexes the mean values of $\dot{V}_{O_{2max}}$ were significantly higher in the second experiment compared to the first experiment. There were no significant differences between values of $\dot{V}_{O_{2max}}$ measured directly and those calculated.

Maximal HR and respiratory quotients were not significantly different either between the sexes or between the two experiments.

In the first experiment the correction factor k_1 was calculated from the directly measured $\dot{V}_{O_{2max}}$ and W_{max}. No significant difference between the mean values of the boys and girls was found, and the mean value of 12 from both the sexes combined was used in the estimation of $\dot{V}_{O_{2max}}$.

The inter-relationships in the first experiment of $\dot{V}_{O_{2max}}$ measured directly and that calculated from the equation are presented as a correlation matrix in Table 3. All correlation coefficients for measured and calculated values of $\dot{V}_{O_{2max}}$ were statistically significant and ranged from 0.67 to 0.93. A higher correlation between calculated and directly measured $\dot{V}_{O_{2max}}$ was demonstrated in the second experiment (Table 4). All correlation coefficients were highly significant and ranged from 0.84 to 0.96.

Table 3. Correlation coefficients for maximal aerobic power ($\dot{V}_{O_{2max}}$) measured and calculated in the first experiment

	Direct $\dot{V}_{O_{2max}}$			
	l·min^{-1}		ml·kg^{-1}·min^{-1}	
	Boys	Girls	Boys	Girls
Calculated $\dot{V}_{O_{2max}}$				
(l·min^{-1})	0.67**	0.93*		
(ml·kg^{-1}·min^{-1})			0.79*	0.68**

* $p<0.01$
** $p<0.05$

Table 4. Correlation coefficients* for maximal aerobic power ($\dot{V}_{O_{2max}}$) measured (test 2.1) and calculated (test 2.2) in the second experiment

	Measured $\dot{V}_{O_{2max}}$ (test 2.1)			
	l·min^{-1}		ml·kg^{-1}·min^{-1}	
Test 2.2	Boys	Girls	Boys	Girls
Calculated $\dot{V}_{O_{2max}}$				
(l·min^{-1})	0.90	0.95		
(ml·kg^{-1}·min^{-1})			0.84	0.96

* All coefficients were $p<0.01$

A highly significant correlation was found in test 2.1 of the second experiment between the measured and calculated values of $\dot{V}_{O_{2max}}$, both with $\dot{V}_{O_2}$ expressed as $l \cdot min^{-1}$ ($r=0.970$, $p<0.001$) and with $\dot{V}_{O_2}$ expressed as $ml \cdot kg^{-1} \cdot min^{-1}$ ($r=0.980$, $p<0.001$) as presented in Fig. 1a and b. The directly measured value (dependent value) could be predicted from the calculated value (independent value) with an average standard error of estimation of 0.06 $l \cdot min^{-1}$ and 1.6 $ml \cdot kg^{-1} \cdot min^{-1}$ respectively and, hence, a 95% confidence limit of ± 0.12 $l \cdot min^{-1}$ and ± 3.2 $ml \cdot kg^{-1} \cdot min^{-1}$, respectively.

Results from test 2.1 of the second experiment after the transformation of absolute work loads into relative work loads are presented as individual values and regression lines in Fig. 2. A highly significant correlation ($r=0.989$, $p<0.001$) was found between the two expressions of the relative work load. The relative work load in $\%\dot{V}_{O_{2max}}$ (dependent variable) could be predicted from the relative work load in $\%W_{max}$ (independent variable) with an average standard error of estimation of 3.8% and, hence, a 95% confidence limit of $\pm 7.6\%$.

A significant correlation could also be demonstrated between relative work load in $\%\dot{V}_{O_{2max}}$ and HR as presented in Fig. 3. However, the accuracy of this variable as a predicter of $\%\dot{V}_{O_{2max}}$ was considerably less than that of $\%W_{max}$. The standard error of estimation for HR on $\%\dot{V}_{O_{2max}}$ was more than twice as big, yielding 95% confidence limits of $\pm 16.8\%$.

No statistical differences could be demonstrated in the second experiment between test 2.1 and test 2.2 in either W_{max} (133 ± 19 W vs.

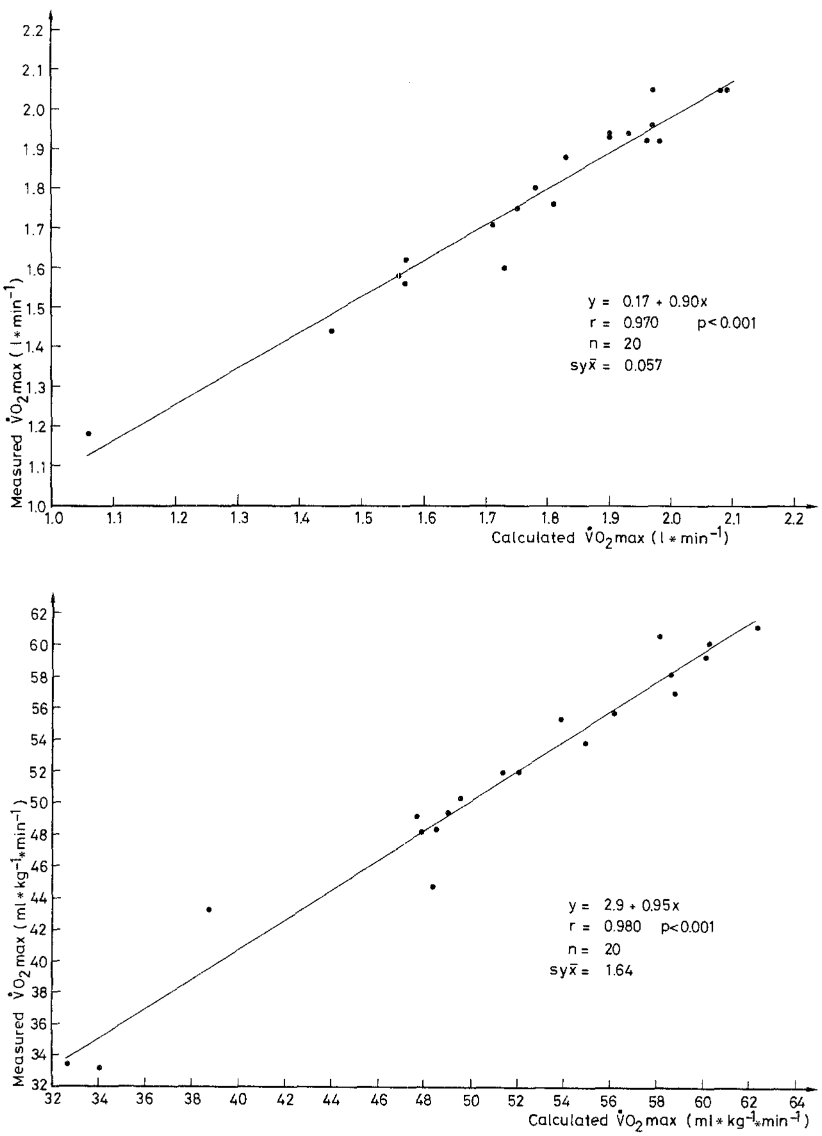

Fig. 1. a Regression line and individual values for maximal aerobic power ($\dot{V}_{O_{2max}}$) expressed as $l \cdot min^{-1}$ for measured values plotted against corresponding calculated values. **b** Regression line and individual values for ($\dot{V}_{O_{2max}}$) expressed as $ml \cdot kg^{-1} \cdot min^{-1}$ for measured values plotted against corresponding calculated values. sy$\bar{x}$: standard error of estimation for calculated $\dot{V}_{O_{2max}}$ on measured $\dot{V}_{O_{2max}}$

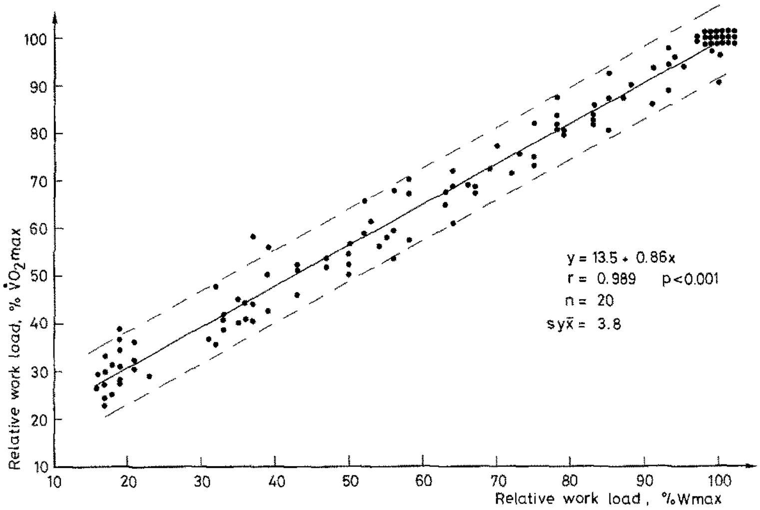

Fig. 2. Regression line and individual values for relative work load in %$\dot{V}_{O_{2max}}$ plotted against corresponding values for relative work load in %W_{max}. The *dotted lines* indicate 95% confidence limits. syx̄: standard error of estimation for %W_{max} on %$\dot{V}_{O_{2max}}$

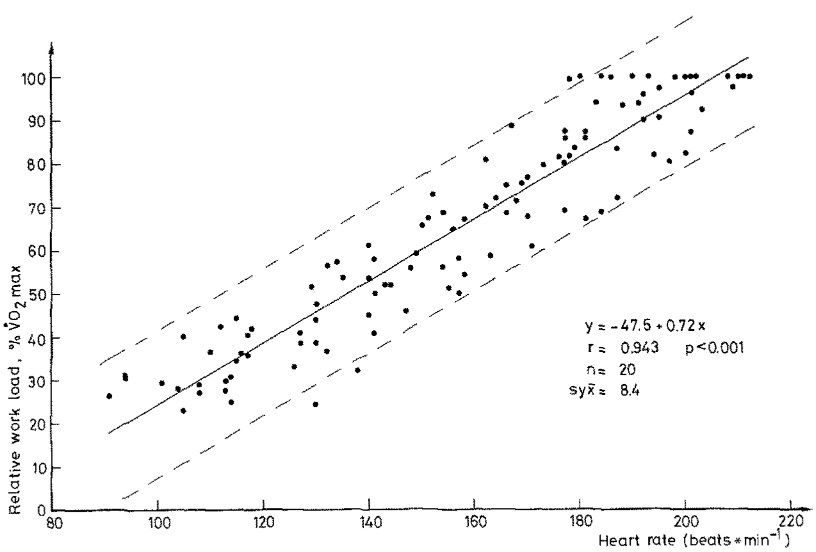

Fig. 3. Regression line and individual values for relative work load in %$\dot{V}_{O_{2max}}$ plotted against corresponding values for heart rate. The *dotted lines* indicate 95% confidence limits. syx̄: standard error of estimation for heart rate on %$\dot{V}_{O_{2max}}$

136±20 W) or calculated $\dot{V}_{O_{2max}}$ (51.1±8.4 ml·kg^{-1}·min^{-1} vs. 51.9±8.5 ml·kg^{-1}·min^{-1}).

In test 2.2 13 children (65%) stopped the exercise test within the sixth work period; 3 children (15%) stopped in the fifth period; 1 (5%) in the fourth and the last 3 (15%) within the 1st min of the seventh period.

Discussion

The main purpose of this study was to evaluate an indirect method of estimating $\dot{V}_{O_{2max}}$ in children using a maximal multi-stage cycle ergometer exercise test.

The exercise test employed, in which a progressive fixed increase in work load was added over time without a resting period between the changes in work load, is a commonly used test procedure in the evaluation of children, young adults and adults in the practice of clinical cardiology (American Heart Association 1982). In the present study 3-min exercise periods were performed so that a steady state was attained by the end of the period. Three-minute intervals appeared to be a reasonable compromise between the intention of achieving a steady state or near steady state of oxygen consumption (Åstrand and Saltin 1961; Bar-Or 1983) and the absence of local muscle fatigue, which could limit the exercise performance (Davies et al. 1972).

In the first experiment of the present study the children performed four to seven consecutive 3-min periods of exercising before exhaustion. This was, in most cases, sufficient to describe adequately the dynamic exercise response of the physiological variable in question. However, the description would be more reliable if all the subjects performed exactly the same number of exercise periods. It was calculated that adjusting for height and sex gave the model of best fit, and that 75%-85% of the children would stop at the end of or within the fifth exercise period, if an exercise increment was used which was based on 0.16 $W \cdot cm^{-1}$ of height in boys and 0.15 $W \cdot cm^{-1}$ in girls. Alternative procedures of individual load increments based on body surface area (Goldberg et al. 1966) and body weight (Mocellin et al. 1971) have been suggested. The second experiment, following our protocol, demonstrated that the majority of the children (65%) stopped within the sixth period, which corresponded to the higher $\dot{V}_{O_{2max}}$ of the children in the second experiment. It seemed as if the applied rates of increase in load were appropriate.

The test implied the attainment of a steady state during the submaximal work loads, and since mechanical efficiency during cycle ergometer exercise has been shown to be remarkably constant (Gaesser and Brooks 1975), the oxygen consumption for a given work load should be independent of the performance of previous exercise periods. Hence, unless the rate of increase significantly affects the W_{max}, for example because of fatigue, we would expect the quantitative relationship between oxygen consumption and mechanical work load to be unaffected.

A significant difference in $\dot{V}_{O_{2max}}$ was demonstrated between the subjects in the first and second experiments. There was no difference in either maximal HR or respiratory quotient at maximal effort, which implied that the differences could be attributed to random biological variation.

In the present study, a remarkable and extremely high correlation was demonstrated between the directly measured value of $\dot{V}_{O_{2max}}$ and the calculated value (Table 4). This high degree of correlation is also demonstrated in the regression analysis, where the average standard error of estimation for $\dot{V}_{O_{2max}}$ (calculated) on $\dot{V}_{O_{2max}}$ (measured) is 0.06 $l \cdot min^{-1}$ and 1.6 $l \cdot kg^{-1} \cdot min^{-1}$, respectively, which corresponded to a standard error of estimation of less than 3.2% in the mean values of measured $\dot{V}_{O_{2max}}$, and indicated that this method of predicting $\dot{V}_{O_{2max}}$ could be used as an accurate and valid method of establishing individual physical fitness levels.

Relative work loads were employed in the present study in an attempt to induce a homogeneous and comparable exercise stress in all individuals, irrespective of differences in working capacity. Another procedure used to apply the same relative stress to the subjects has been the introduction of HR-controlled ergometry (Arstila 1972; Ekelund 1973; Hursti et al. 1980). The relationship between HR and $\%\dot{V}_{O_{2max}}$, however, is less precise than the relationship between $\%W_{max}$ and $\%\dot{V}_{O_{2max}}$ (Figs. 2, 3). The significance of this procedure for establishing relative work loads has been demonstrated by Pedersen and Nielsen (1984) in young male subjects, with almost a halving of the variation coefficients for some variables when observed at a given relative ($\%\dot{V}_{O_{2max}}$ or $\%W_{max}$) rather than absolute (number of watts) exercise level. They also reported that the relative work load in $\%\dot{V}_{O_{2max}}$ could be predicted from the relative work load in $\%W_{max}$ with an average standard error of 2.8%. In the present study, the standard error of estimation for relative work load in $\%W_{max}$ on relative work load in $\%\dot{V}_{O_{2max}}$ was 3.8%, indicating a similiar significance in children in establishing relative work loads in the evaluation of exercise response for a physiological variable such as blood pressure or HR.

In conclusion, the data suggest that in children the $\dot{V}_{O_{2max}}$ calculated from the W_{max} of a relatively simple cycle ergometer test, which can be applied to a larger group of individuals as a field test, yields a valid and accurate estimate of directly measured $\dot{V}_{O_{2max}}$, providing an index of the level of individual aerobic fitness.

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References

American Heart Association ad hoc committee on exercise testing (1982) Standards for exercise testing in the pediatric age group. Circulation 66:1377A-1397A

Arstila M (1972) Pulse-conducted triangular-exercise-ECG test. Acta Med Scand [Suppl] 529:1-101

Åstrand PO, Rodahl K (eds) (1986) Textbook of work physiology, 3rd edn. McGraw-Hill, New York, pp 354-390

Åstrand PO, Ryhming I (1954) A nomogram for calculation of aerobic capacity (physical fitness) from pulse rate during submaximal work. J Appl Physiol 7:218-221

Åstrand PO, Saltin B (1961) Oxygen uptake during the first minutes of heavy muscular exercise. J Appl Physiol 16:971-976

Bar-Or O (1983) Pediatric sports medicine for the practitioner. Springer, Berlin Heidelberg New York Tokyo, p 16

Bengtsson E (1956) The working capacity in normal children, evaluated by submaximal exercise on the bicycle ergometer and compared with adults. Acta Med Scand 154:91-109

Davies CTM, Barnes C, Godfrey S (1972) Body composition and maximal exercise performance in children. Hum Biol 44:195-214

Ekelund LG (1973) Heart rate controlled ergometry. Br J Sports Med 7:121-123

Gaesser GA, Brooks GA (1975) Muscular efficiency during steady-rate exercise: effects of speed and work rate. J Appl Physiol 38:1132-1139

Goldberg SJ, Weiss R, Adams FH (1966) A comparison of the maximal endurance of normal children and patients with congenital cardiac disease. J Pediatr 69:46-55

Harrison MH, Bruce DL, Brown GA, Cochrane LA (1980) A comparison of some indirect methods for predicting maximal oxygen uptake. Aviat Space Environ Med 51:1128-1133

Hursti ML, Pihlakoski L, Antila K, Halkola L, Välimäki I (1980) Experience of pulse-conducted ergometry in trained, normal and physically inactive schoolchildren. In: Berg K, Eriksson BO (eds) Children and exercise. University Park Press, Baltimore, pp 128-138

Issekutz B Jr, Birkhead NC, Rodahl K (1962) Use of respiratory quotients in assessment of aerobic work capacity. J Appl Physiol 17:47-50

Izukawa T, Drash A (1968) Oxygen consumption with exercise. In: Cheek DB (ed) Human growth. Lea and Febiger, Philadelphia, pp 501-514

Margaria R, Aghemo P, Rovelli E (1965) Indirect determination of maximal O_2 consumption in man. J Appl Physiol 20:1070-1073

Maritz JS, Morrison JF, Peter J, Strydom NB, Wyndham CH (1961) A practical method of estimating an individual's maximal oxygen intake. Ergonomics 4:97-122

Mocellin R, Lindemann H, Rutenfranz J, Sbresny W (1971) Determination of W170 and maximal oxygen uptake in children by different methods. Acta Paediatr Scand [Suppl] 217:13-17

Myles WS, Toft RJ (1982) A cycle ergometer test of maximal aerobic power. Eur J Appl Physiol 49:121-129

Patton JF, Vogel JA, Mello RP (1982) Evaluation of a maximal predictive cycle ergometer test of aerobic power. Eur J Appl Physiol 49:131-140

Pedersen PK, Nielsen JR (1984) Absolute or relative work load in exercise testing-significance of individual differences in working capacity. Scand J Clin Lab Invest 44:635-642

Shephard RJ (1984) Tests of maximum oxygen intake: a critical review. Sports Med 1:99-124

Wyndham CH, Strydom NB, Leary WP, Williams CG (1966) Studies of the maximum capacity of men for physical effort. Int Z Angew Physiol 22:285-295

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