Gender differences and determinants of aerobic fitness in children aged 8-11 years

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Abstract

Previous studies of gender differences in maximum oxygen uptake have come to different conclusions. Limited data exists where the determinants of maximum oxygen uptake have been evaluated in a comprehensive manner. Thus, we examined 248 children (140 boys and 108 girls), aged 7.9-11.1 years. Body composition was determined by dual-energy X-ray absorptiometry, measured variables were total body fat (TBF) and lean body mass (LBM). Maximal oxygen uptake (VO_{2PEAK}) was measured by indirect calorimetry during a maximal cycle exercise test. Daily physical activity was assessed by accelerometers and duration of vigorous activity per day (VPA) was calculated. Left ventricular inner diastolic diameter (LVDD) was measured by echocardiography. Lung function was evaluated with spirometric testing and whole body pletysmography. Boys had between 8-18% higher values than girls for VO_{2PEAK}, dependent upon whether VO_{2PEAK} was expressed in absolute values or scaled to body mass, lean body mass (LBM) or if allometric scaling was used. In multiple regression analysis absolute values of aerobic fitness were independently related to LBM, maximal heart rate (Max HR), gender, LVDD and VPA. Furthermore, when VO_{2PEAK} was scaled to body mass it was independently related to ln TBF, Max HR, gender, VPA, and LVDD. Lung function had no relation to VO_{2PEAK}. Our study concludes that body composition is the main predictor for VO_{2PEAK}, in children aged 8-11 years, whereas VPA or LVDD has only a modest impact. Existing gender differences in VO_{2PEAK} cannot be explained only by differences in body composition, physical activity or heart size.

Keywords: maximum oxygen uptake, accelerometers, dual-energy X-ray absorptiometry, echocardiography, children.

Introduction

Maximum aerobic fitness, defined as maximum oxygen uptake (VO_{2peak}), is generally considered to be the best single marker for the functional capacity of the cardio-respiratory system. In children low aerobic fitness has been associated with risk factors for cardiovascular disease (Eiberg et al. 2005a; Eisenmann et al. 2005) and aerobic fitness has been shown to track from childhood into adulthood (Twisk et al. 2002; Trudeau et al. 2003). However, if aerobic fitness, which is often the case, is reported as oxygen uptake per kg of body mass then fatness will be introduced as a confounding factor. Instead, by displaying aerobic fitness per kg of lean body mass (LBM) one would presumably acquire direct information of relationships between aerobic fitness and its determinants. Also, the concept of allometric scaling as a way of acquiring a dimension free entity has in recent years gained attention but previous studies that have applied this technique have come to different conclusions (Armstrong et al. 1995; Welsman and Armstrong 2000; Rowland et al. 2000; Vinet et al. 2003; Eiberg et al. 2005b). It is therefore of physiological interest to investigate how different factors, such as physical activity, pulmonary function, left ventricular size, gender, body fat, or lean body mass are associated with aerobic fitness in early childhood. However, VO_{2peak} has been shown to be highly influenced by genetic factors (Bouchard et al. 1986), and this was not investigated in the present study. We have previously reported the relationship between VO_{2PEAK} and physical activity for this cohort (Dencker et al. 2006a). To date, no large-scale study exist in children, where direct measurement of VO_{2PEAK} has been related to accelerometer-measured daily physical activity, body composition by DXA, heart size by echocardiography, and lung function. The purpose of this report was therefore by using these objective methods, to investigate: 1) gender differences in aerobic fitness and to evaluate if differences depend on scaling methods 2) the determinants of absolute values of VO_{2PEAK} in children of this age and the respective contribution of each factor and 3) the determinants for VO_{2PEAK} scaled per kg body mass or kg LBM.

Methods

Subjects and anthropometric assessment

Recruitment and anthropometric assessment of the study cohort have been presented previously (Dencker et al. 2006a, b, c). Shortly, 477 children received an invitation to participate in the study whereas 248 (140 boys and 108 girls), aged 8 to 11 years, accepted the invitation. The institutional ethics committee of Lund University, Sweden, approved the study. Written, informed consent was obtained from the parents of all participating children. Total body height and body mass were measured using a fixed stadiometer and standard scale. Puberty status was assessed by self-evaluation from viewing photographs representing different stages of puberty development (Duke et al. 1980), and the sexual characteristics that were self assessed were: breasts (girls), genitals (boys), and pubic hair (girls and boys). Children with no evidence of onset of puberty were designated Stage 1, and children with evidence of onset of puberty were designated Stage 2. Body surface area (BSA) was calculated as $(\text{height in cm})^{0.725}$ x $(\text{body mass in kg})^{0.425}$ x 0.00718 (Du Bois and Du Bois 1916). A separate analysis of anthropometric data retrieved from school records for all children that received an invitation to participate in the study revealed no significant differences in height, body mass or BMI between children who participated in the study and those who did not (Dencker et al 2006b).

Measurement of physical activity

Methodology of physical activity assessment has previously been presented in detail (Dencker et al. 2006a, b, c). Briefly, the MTI model 7164 accelerometer (Manufacturing Technology

Incorporated, Fort Walton Beach, Fl, USA) was worn around the waist at the hip for four consecutive days. Accelerometer data was summed over a period of time called an epoch and downloaded to a computer for analysis. In this study a recording epoch of ten seconds was used. Children failing to provide a minimum of three separate days of eight hours of valid recording, after removal of missing data, were excluded from the part of the study that included physical activity measurements. The accelerometer measurement took place within as short timeframe from the DXA measurement and the exercise test as possible, usually the same or the adjacent week. The time spent above 583 counts per epoch was considered to reflect vigorous physical activity (VPA), such as running (Freedson et al. 1997; Trost et al. 1998). Daily accumulation of VPA was calculated by summing up all epoch segments above this threshold. The same cut-off point was used for all children and this cut-off point is similar to those used in most other field-based evaluations of physical activity with this type of accelerometer (Trost et al. 2002; Pate et al. 2002). The rationale for only analysing VPA is that in our previous report of the relationship between VO_{2PEAK} and physical activity for this cohort, we found that this was the activity parameter that was most closely related to VO_{2PEAK} (Dencker et al. 2006a). In that report we also analysed mean physical activity and time spent in moderate activity (defined as walking at different speeds), which had a weaker relation with VO_{2PEAK} (Dencker et al. 2006a).

Measurement of Aerobic Fitness

The methodology of aerobic fitness testing has previously been presented in detail (Dencker et al. 2006a). A maximal exercise test was performed on a cycle ergometer and VO_{2PEAK} was determined by indirect calorimetry. Expired gases were sampled every 20 seconds during the exercise test. The highest value recorded during the last minute of exercise was used. Maximal heart rate (Max HR) and maximal respiratory exchange ratio (RER) were recorded.

The exercise test was considered acceptable if it met one of the following criteria: RER ≥ 1.0, Max HR >85% of predicted value ($\geq$ 178 beats · min^{-1}) or signs of intense effort (e.g. hyperpnoea, facial flushing or difficulties in keeping up the speed of the cycle), (Armstrong and Welshman, 2000). For a comparison of differences between genders several analyses were made. VO_{2PEAK} was compared untransformed and with adjustments for body size. VO_{2PEAK} was divided by body mass in kilogram and by LBM. Also, two methods of allometric scaling were used. Data from this study were used to find the scaling factors. In the analyses, the scaling exponent b was identified in the allometric equation $VO_{2PEAK} = a_1 + a_2X^b$, where X is the anthropometric scaling variable (body mass or LBM). To obtain b, both the VO_{2PEAK} and X were log transformed, and least squares regression identified the b in the equation $\ln(VO_{2PEAK}) = \ln(a_2) + b\ln(X)$.

Dual-Energy X-Ray Absorptiometry

Methodology of body composition assessment has been previously presented in detail (Dencker et al. 2006b). Whole-body composition was measured by dual-energy X-ray absorptiometry (DXA) (DPX-L version 1.3z, Lunar, Madison, WI, USA). Pediatric software was used for children with a weight below 35 kg. Lean body mass (LBM) and total body fat mass (TBF) were quantified. The precision of duplicate DXA measurements from our laboratory has been reported previously and they were for LBM 0.6% and for TBF 4.1% (Linden et al. 2006). DXA has been shown to provide accurate and precise measurements of body composition (Lohman et al. 2000).

Echocardiography

Echocardiographic examination was performed with subjects in the left lateral supine position with Sonos 2500 (Philips Inc, Eindhoven, the Netherlands) or Aspen (Acuson Inc, Mountain

View, CA, USA) equipments. Studies were performed, by highly trained personnel, with 2-dimensional guided M-mode echocardiography obtained in the parasternal short-axis view, in accordance with American Society of Echocardiography recommendations (Sahn et al. 1978) and end-diastolic left ventricular inner diameter (LVDD) was measured. A separate study of intra- and interobserver variability concluded low variability in LVDD measurements; 2.4 % for intraobserver and 2.7% interobserver variability.

Pulmonary function testing

Spirometric testing and whole body pletysmography were performed on a whole body pletysmograph (Jaeger, Wűrzburg, Germany) according to the guidelines of the European Respiratory Society (Quanjer et al. 1993). Variables assessed were: forced expiratory volume in 1 second ($FEV_{1.0}$) and vital capacity (VC). Measured values were calculated as percentage of expected values (Cotes 1995).

Statistical analyses

All analyses were made in Statistica 5.0 (StatSoft Inc, Tulsa, OK, USA). Descriptive statistics include mean ± standard deviation (SD) unless otherwise stated. Univariate relationships were assessed with Pearson correlation analysis. Statistical significance of difference between two r-values was tested with the program for such purpose within the Statistica program. Group differences between mean values were tested using the unpaired Student´s t-test. Due to the considerably skewed distribution of TBF, logarithmic transformed values were used in all regression analyses. Multiple stepwise regression analysis (with intercept) was used to test the independence of relationships between aerobic fitness versus different variables. Firstly, a multiple regression analysis was performed with all children who had acceptable exercise tests (n=245) to assess the relation of body composition, gender and LVDD (absolute values) with absolute values of VO_{2PEAK}. Secondly, different multiple regression analyses were performed to assess comprehensively contributing factors for absolute values of VO_{2PEAK} and VO_{2PEAK} per LBM or kg body mass. In the first multiple regression analysis the dependent variable was absolute value of VO_{2PEAK} and independent variables were: LBM, lnTBF, Max HR, VPA, LVDD (absolute values), gender and also possible confounders such as age and days of accelerometer recording. Puberty status was not included in this regression analysis because it had not statistical relation to absolute values of VO_{2PEAK}. In the multiple regression analyses to test the independence of relationships between aerobic fitness per LBM or kg body mass versus different variables the dependent variables were: VO_{2PEAK} per LBM or kg body mass. Independent variables were: gender, Max HR, VPA, LVDD (adjusted to BSA), and possible confounders such as lnTBF, age, days of accelerometer recording, and puberty status because it had a weak but significant relation to both VO_{2PEAK} per kg body mass and per LBM. Statistical significance was set at a level of $p<0.05$.

Results

One child was excluded due to failure to perform the exercise test, all other participants in this study met at least one of the criteria for an acceptable exercise test, 72% (178/247) of the children reached ≥ 85% of predicted Max HR and 66% (163/247) a RER ≥ 1.0. DXA measurements were not available in two boys. A total of 19 children (12 boys and 7 girls) were excluded because they did not fulfil the requirements for the assessment of daily physical activity. Thus, the study group used for multiple regression analysis consisted of 226 children (boys n=125, girls n=101). Five girls were Satge 2 and all remaining 221 children were Stage 1. Puberty status had no relation to absolute values of VO_{2PEAK} (r=-0.02, ns) and was therefore not included in that regression analysis. However, a weak relation existed between puberty status and VO_{2PEAK} per body mass or LBM (r= -0.16 and -0.16, $p<0.05$) and puberty status was therefore included in those regression analyses. In the analysis of between group differences in mean values between genders, all children with valid measurements were included (n=245). Anthropometrics, age, activity, LVDD and DXA data are displayed in table 1.

The average time span between accelerometer measurements vs. other tests was 8.2±11.0 days. The vast majority of the children achieved the full four days of accelerometer recording (80%), 20% achieved three days. There were no differences, for neither boys nor girls, in VPA between children with 3 or 4 days of accelerometer recording (boys 51 vs. 44 min, p=0.14; girls 39 vs. 34 min, p=0.10). All children were therefore pooled together in a combined analysis model.

Gender differences of maximum oxygen uptake according to various scaling methods are displayed in table 2. Gender differences existed, where girls had consistently lower VO_{2PEAK} irrespective of the scaling method used.

When absolute values of VO_{2PEAK} was related to body mass and LBM (fig 3) significantly better ($p<0.001$) correlation was detected when fitness was related to LBM ($r=0.69$, $p<0.05$) than to body mass ($r= 0.46$, $p<0.05$). Lung function parameters had no relation to VO_{2PEAK} (data not shown) and were therefore not included in the different regression analyses.

The first multiple regression analysis showed that independent variables predicting absolute values for VO_{2PEAK} were LBM, Max HR, gender, and LVDD (inclusion of BSA to the model did not add any significance), accumulation of r^2 for the respective variables in the model were; 0.47, 0.62, 0.65 and 0.66. In the multiple regression analysis of those children who had acceptable measurement in all tests (n=226) absolute values of VO_{2PEAK} were independently related to LBM, Max HR, gender, LVDD, and VPA. Multiple regression analysis of VO_{2PEAK} per kg body mass displayed independent relationship between VO_{2PEAK} and ln TBF, Max HR, Gender, VPA, and LVDD. In multiple regression analysis of VO_{2PEAK} per LBM it was independently related to Max HR, Gender, VPA, and LVDD. Summary of regression analyses is displayed in table 3.

Discussion

Gender differences existed in VO_{2PEAK}, where boys had higher VO_{2PEAK} than girls. This was the case for absolute VO_{2PEAK} values and for VO_{2PEAK} values relative to body mass, to LBM, and after allometric scaling. The most important contributing factors for explaining the variance in VO_{2PEAK} were LBM, max HR and gender, whereas LVDD and VPA only had a modest additional contribution. Factors predicting VO_{2PEAK} per kg body mass were TBF, max HR and gender. VPA and LVDD had again an independent but small explanatory value. Factors contributing to VO_{2PEAK} per LBM were mainly max HR and gender, with VPA, and LVDD having a small explanatory portion of the variance of VO_{2PEAK} per LBM. Pulmonary function had no association with VO_{2PEAK}, disregarding which scaling method that was used for VO_{2PEAK}, which is in conjunction with what have been proposed for humans exercising at sea level (Bassett and Howley 2000).

Major strengths of our study were direct measurement of oxygen uptake, the use of DXA to quantify body composition and objective measurement of daily physical activity with accelerometers. There are, however, several potential methodological limitations of the present study. Needles to say, the accumulation of physical activity over four days may not represent the true mean of the subject, but only give a rough estimate of a child’s activity level. It is, however, considered superior to self-reported physical activity (Kohl et al. 2000). Not all children fulfilled the stipulated four days of accelerometer recording, but no difference was observed in time spent performing VPA when comparing children with 3 or 4 days of recording. This suggests that there was no major systematic error introduced by using three- and four-day measurements together. The inclusion of the days of accelerometer recording into the multiple regression analyses was also done to compensate for any possible effect that may have existed. An additional limitation of our study is that only about 70% of the children reached 85% of predicted Max HR and slightly less a RER ≥ 1.0, although they subjectively indicated that they had made a maximum effort. But, as it is not ethically acceptable to force a child to continue the test when they feel exhausted, some children's VO_{2PEAK} may have been underestimated. Maximum heart rate is obviously influenced by a child's motivation to exercise until exhaustion. A considerable inter-individual variation in Max HR exists and Max HR is also dependent upon type of exercise protocol and whether ergometer or treadmill running is used (Armstrong and Welsmann 2000). The inclusion of Max HR into the multiple regression analyses was done to compensate for this factor. Blood samples were not available, hence it is not possible to rule out that differences in hemoglobin concentration was not a factor, although mean hemoglobin concentration is known to be similar in boys and girls before puberty (Dallman and Siimes 1979). An inclusion frequency of 52% was somewhat low but a separate study of anthropometrical data from all children that received an invitation to participate in the study showed no significant differences in height, body mass or BMI between the children that chose to participate and those who did not (Dencker et al. 2006b). This suggests that no fundamental selection bias occurred. All schools were situated in residential, middle class, areas and our result may not be representative of children living in rural areas or socio-economically deprived areas. However, middle class urban living represents the most prevalent lifestyle in Scandinavian countries.

The gender differences in aerobic fitness in our study ranged from 8 to 18% depending on scaling method used. The most prominent differences were detected for absolute values or values scaled to body mass (16-18%), whereas values scaled to LBM were lower (8%). Also, the multiple regression analyses clearly displayed the existence of gender differences in our study that could not be explained by differences in body composition, physical activity, heart size, Max HR or lung function. Previous studies of children at this age using direct measurements of VO_{2PEAK} have produced somewhat different results. Most previous studies that have evaluated gender differences in aerobic fitness have used anthropometrical methods to assess body composition (Sundergård and Bratteby 1986; Washington et al. 1988; Armstrong et al. 1995; Rowland et al. 2000; Rump et al. 2002; Eiberg et al. 2005b), which could give less accurate results and dilute existing differences. In addition, many studies have not evaluated the impact of different scaling methods on gender differences of VO_{2PEAK}.

A large scale study, of 151 children aged 7-12 years, displayed 7-15% gender differences of VO_{2PEAK} values per kg body mass depending on which BSA group the children were divided into (Washington et al. 1988). However, the impact of allometric scaling was not investigated in this study. Armstrong et al (1995) investigated 111 boys and 53 girls aged 11 years and found 22% difference in absolute values of VO_{2PEAK}, 13% difference when adjusted for kg body mass, and the differences remained after allometric scaling. The impact of LBM was not investigated in any of these studies (Washington et al. 1988; Armstrong et al. 1995). Sundergård and Bratteby (1987) reported gender differences in VO_{2PEAK} of 20 boys and 20 girls aged 8 years. The differences were 9% in absolute values, 15% per kg body mass and 7% per kg LBM. Corresponding results for 50 boys and 50 girls aged 7-8 year reported by Rump et al (2002) were 9, 11 and 4 %. Sundergård´s and Bratteby´s results are similar to our findings, the slightly different results from Rump et al could be attributed to the fact that they used treadmill testing whereas our study as well as Sundergård´s and Bratteby´s used cycle ergometer protocols. Recent investigations of children with similar age as in our study came to opposite conclusions when allometric scaling was applied (Rowland et al. 2000, Eiberg et al. 2005b). Rowland et al (2000) found a difference between genders of 6-17% depending on if absolute values or values scaled to body mass or LBM were compared, and the gender differences persisted after allometric scaling. The fact that the difference between the genders existed even after allometric scaling was stated, by the authors, to indicate that both body composition and cardiac functional capacity accounted for the difference between boys and girls. Also, Rowland et al argued that anthropometric and aerobic physiological factors cannot entirely explain the magnitude of the gender differences and our findings clearly supports this hypothesis. By far the largest study to evaluate gender differences in VO_{2PEAK} is the one by Eiberg et al (2005b), which included 366 boys and 332 girls aged 6-7 years. They found 12% differences between boys and girls in absolute values, 8% for VO_{2PEAK} per kg body mass, and 9% when allometric scaling were applied. They only found a 2% gender difference in VO_{2PEAK} when scaled to LBM. Furthermore, when allometric scaling was applied with LBM, the gender difference dropped to 1%, which was statistically insignificant. A plausible explanation of the different findings in our study is that we measured body composition directly by DXA and not indirectly through the skinfold-method.

There are difficulties in comparing values of VO_{2PEAK} in the previously mentioned studies because they have used either maximum treadmill or cycle ergometer protocols of various modifications. Maximum treadmill or cycle ergometer testing are known to give different results, where treadmill testing consistently give higher VO_{2PEAK} compared to cycle ergometer protocol (LeMura et al. 2001).

Investigations that have combined DXA for body composition with direct measurement of VO_{2PEAK} in children with a relative normal body mass distribution are scarce. A smaller study by Vinet et al (2003), investigated 17 girls and 18 boys aged 10.5 years. Boys had higher absolute values of VO_{2PEAK} (15%), also when adjusted for body mass, but the difference failed to reach statistical significance when VO_{2PEAK} was adjusted for LBM and virtually disappeared after allometric scaling. Furthermore, Vinet et al (2003) found no difference in stroke volume, by echocardiography during exercise, and VO_{2PEAK} after allometric scaling and stated that body composition (and not cardiac functional capacity) could account for the gender difference. Their finding contradicts ours, which perhaps is not surprising given the considerable difference in sample size. Also, we did not perform echocardiography during exercise so such a comparison is beyond the scope of this study.

To our knowledge the only larger study up until now in younger children that has addressed heart size with respect to VO_{2PEAK} was performed by Obert et al (2005). They evaluated 142 children aged 10-11 years with echocardiography, VO_{2PEAK} by direct measurement during maximum cycle exercise test and body composition using the skinfold technique. As in our study they found that LVDD explained only a small portion of the variance in VO_{2PEAK} (8%), after differences in body size had been taken into account. Our finding was only 1%, which was statistically significant but perhaps not physiologically interesting. Obert et al performed their multiple regression analysis without separation of gender, which makes it difficult for direct comparison of the results. When we included more parameters into a more comprehensive regression model the significance of LVDD existed for absolute values of VO_{2PEAK}, and also VO_{2PEAK} per body mass or LBM. Our findings suggest that heart size is associated to VO_{2PEAK} (albeit weakly), but the existing gender differences in VO_{2PEAK} can not be explained by this.

When assessing aerobic fitness, VO_{2PEAK} has in most cases been scaled to body mass (kg), thus introducing both body fat and bone mass as potential confounders. As shown in fig 1, a significantly better relationship exists between VO_{2PEAK} and LBM than when using body mass in the model, this because of the confounding effect of body fat and bone mass. Also, the multiple regression analysis displayed that TBF had the most important contribution to the model of all factors analysed (r^2 =0.46). Scaling VO_{2PEAK} to kilogram of body mass makes sense if aerobic fitness in terms of work capacity or endurance is evaluated, especially if weight bearing activity, such as running, is involved. However, when comparing physical activity with the general physiological ability to maximally consume oxygen it makes more sense to relate VO_{2PEAK} to LBM, since fat mass and bone mass receive <9 % of the total blood flow during rest, and substantially less during exercise when the blood flow is redirected primarily to the skeletal muscle (Guyton 1986). A recent, small-scale study, suggested that lower leg muscle volume measured by MRI in combination with allometric scaling was superior to body mass or fat free mass for scaling of VO_{2PEAK} in order to adjust for differences in body size and composition (Tolfrey et al. 2006). VO_{2PEAK} is inversely related to the risk of several diseases (Laukkanen et al. 2004; LaMonte et al. 2005). When VO_{2PEAK} has been used to investigate health outcomes it has been scaled to body mass. To the best of our knowledge other, perhaps better, methods such as scaling to LBM, fat free mass or lower leg muscle volume have not been evaluated in this context.

Conclusions

We found gender differences for VO_{2PEAK} where boys had 8-18% higher values than girls even before puberty has caused the known biological differences in hemoglobin and body composition. This was present for absolute VO_{2PEAK} values and for VO_{2PEAK} values scaled to body mass or LBM, and also after allometric scaling. Most important contributing factors for absolute values of VO_{2PEAK} were LBM, Max HR and gender, whereas VPA and LVDD only had a modest contribution. Multiple regression analyses indicates that 3-5% of the existing gender differences in VO_{2PEAK} cannot be explained by differences in body composition, heart size or physical activity. However, the cross-sectional nature of the current study can only highlight the association between VO_{2peak} and various factors. Causes and consequences of these associations can only be demonstrated in a longitudinal study, an issue we hope to be able to address in the future when achieving the prospective part of this study.

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Table 1. Age, anthropometrics, LVDD, and lung function data of all children. DXA, and physical activity data in children with valid measurements. Values are presented as mean ± SD. Vital capacity (VC). Forced expiratory volume in 1 second ($FEV_{1.0}$). End-diastolic left ventricular inner diameter (LVDD). Lean body mass (LBM). Total body fat mass (TBF). Minutes of vigorous physical activity per day (VPA).

Variable	Boys	Girls	p-value
	n=140	n=108	
Age (yrs)	9.9±0.6	9.7±0.6	0.07 ns
Heigth (cm)	141±6.8	140±7.8	0.37 ns
Body mass (kg)	35.0±7.6	34.6±7.7	0.65 ns
BMI ($kg \cdot m^{-2}$)	17.4±2.8	17.4±2.9	0.99 ns
VC (l)	2.4±0.4	2.2±0.4	<0.001
$FEV_{1.0}$ (l)	2.0±0.3	1.9±0.3	0.003
LVDD (mm)	42.1±3.4	40.7±3.1	<0.001
DXA measurements	n=138	n=108	
TBF (kg)	6.4±5.1	8.1±5.2	0.008
LBM (kg)	26.1±3.4	24.1±3.5	<0.001
Physical activity	n=128	n=101	
Valid recording ($min \cdot day^{-1}$)	716±83	712±82	0.53 ns
VPA ($min \cdot day^{-1}$)	46±20	35±13	<0.001

Table 2. Maximal exercise values for boys and girls according to various scaling models to body mass or lean body mass (LBM). Note that in this analysis all children with valid exercise test and DXA measurements were included (n=245). Maximal respiratory exchange ratio (RER). Maximal heart rate (Max HR).

Values	Boys (n=137)	Girls (n=108)	p-value
RER	1.02±0.07	1.02±0.08	0.89 ns
Max HR (beats · min^{-1})	188±16	185±16	0.17 ns
VO_{2PEAK} (ml · min^{-1})	1423±259	1208±204	<0.001
VO_{2PEAK} (ml · min^{-1} · kg^{-1})	41.4±7.2	35.8±6.4	<0.001
VO_{2PEAK} (ml · min^{-1} · $kg^{-0.47}$)*	268.7±40.8	229.9±32.8	<0.001
VO_{2PEAK} (ml · min^{-1} · LBM^{-1})	54.5±7.0	50.5±6.9	<0.001
VO_{2PEAK} (ml · min^{-1} · $LBM^{-0.96}$)*	62.6±8.0	57.8±7.8	<0.001

*indicates allometric scaling

Table 3. Regression summaries for children with complete data (n=226). Dependent variables were: Absolute values of VO_{2PEAK}, VO_{2PEAK} per kg body mass or VO_{2PEAK} per kg LBM.

Absolute values of VO_{2PEAK}

Value	BETA	SE of BETA	r^2	p-value
Intercpt				<0.001
LBM	0.52	0.058	0.46	<0.001
Max HR	0.38	0.040	0.61	<0.001
Gender	-0.20	0.046	0.65	<0.001
LVDD	0.09	0.046	0.66	0.04
VPA	0.09	0.043	0.67	0.04
Age	0.06	0.044	0.67	0.15 ns
TBF*	0.06	0.052	0.67	0.26 ns

VO_{2PEAK} per kg body mass

Value	BETA	SE of BETA	r^2	p-value
Intercpt				
TBF *	-0.52	0.059	0.46	<0.001
Max HR	0.36	0.039	0.60	<0.001
Gender	-0.15	0.046	0.64	0.001
VPA	0.10	0.043	0.65	0.02
LVDD	0.15	0.060	0.66	0.01

VO_{2PEAK} per LBM

Value	BETA	SE of BETA	r^2	p-value
Intercpt				
Max HR	0.51	0.054	0.28	<0.001
Gender	-0.20	0.057	0.34	<0.001
LVDD	0.19	0.073	0.36	0.009
VPA	0.13	0.058	0.37	0.02

* Indicate logarithmic values

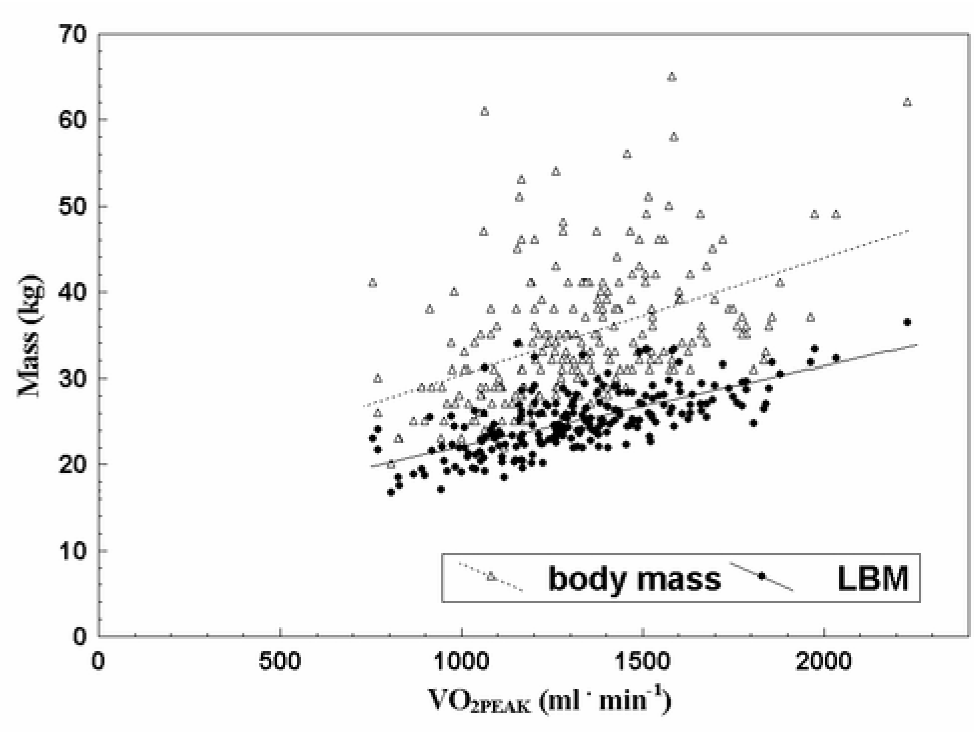
<u>Abbreviations</u>

End-diastolic left ventricular inner diameter (LVDD)
Lean body mass (LBM)
Total body fat mass (TBF)
Maximal heart rate (Max HR)
Minutes of vigorous physical activity per day (VPA)

Figure legend

Fig 1. Relationships between absolute values of VO_{2PEAK} (ml · min^{-1}) vs. LBM (kg) and body mass (kg), in all subjects with valid exercise test and DXA measurement (n=245).

Figure 1



70
60
50
40
30
20
10
0
Mass (kg)
0
500
1000
1500
2000
VO2PEAK (ml · min-1)
body mass
LBM