Daily physical activity related to aerobic fitness and body fat in an urban sample of children

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Abstract

This study evaluates associations between objectively measured daily physical activity versus aerobic fitness and body fat in children aged 8-11 years. Cross-sectional study of 225 children aged 7.9-11.1 years. Abdominal fat mass (AFM) and total body fat (TBF) were quantified by Dual-Energy X-Ray Absorptiometry. TBF was calculated as percentage of total body mass (BF%). Body fat distribution was calculated as AFM/TBF. Aerobic fitness was measured by indirect calorimetry during a maximal cycle ergometer exercise test. Daily physical activity was assessed by accelerometers for four days and daily accumulation of moderate-to-vigorous and vigorous activity were calculated. Significant relationships ($p<0.05$) existed for vigorous activity vs. ln BF% ($r=-0.40$), ln AFM ($r=-0.35$), TBF/AFM ($r=-0.22$) and aerobic fitness ($r=0.38$), whereas moderate-to-vigorous activity displayed weaker relationships (-0.22, -0.18, -0.12 ns, and 0.25). Multiple regression analyses with inclusion of possible confounders concluded that vigorous activity was independently related to aerobic fitness and ln BF% or ln AFM. Moderate-to-vigorous activity was only independently related to aerobic fitness. In this population, low daily accumulation of vigorous activity was, already in children aged 8-11 years, associated with more body fat and lower aerobic fitness. Similar relation was not detected for daily accumulation of moderate-to-vigorous activity.

Introduction

An identification of the type of physical activity which is most closely related to health parameters in children will enhance the promotion of physical activity for health, i.e. should we primarily promote more vigorous activity such as sports participation or more moderate activity such as play. Current guidelines for children and adolescents concerning adequate levels of physical activity are not based on an analysis of detailed information of physical activity against well-defined health outcome (Sallis & Patrick, 1994; Cavill, et al., 2001; US Department of Health and Human Services, 2004). On the contrary, the evidence base is quiet weak (Twisk, 2001). An important aspect when studying presumed physiological effects of daily physical activity in children is the inherent difficulties to obtain accurate assessments of daily physical activity. Activity patterns in younger children are by nature random, sporadic and unsustained (Bailey et al., 1995). It has up until now been difficult to capture many aspects of a child's physical activity (Kohl et al., 2000). Accelerometers represent a new tool for such assessments and can detect and record the intensity, frequency and duration of activity, and can be used by children over a relatively long period of time (Trost, 2001). Aerobic fitness and fatness are strongly associated with cardiovascular health and may therefore constitute a reasonable health outcome. An analysis of accelerometer data against fitness and fatness may therefore have the potential to give new insights about type, intensity and quantity of physical activity beneficial for cardiovascular health.

To our knowledge, no large-scale studies in younger children exist, where accelerometer measured daily physical activity has been related to direct measurements of aerobic fitness in combination with quantified body fat, by Dual-Energy X-Ray Absorptiometry (DXA). The purpose of this study was to evaluate in a combined and comprehensive analysis the relationship between daily accumulation of moderate-to-vigorous and vigorous physical activity versus aerobic fitness and body fat measurements in an urban sample of children aged 8-11 years.

Materials and Methods

Subjects

Recruitment of the study cohort has been presented previously (Dencker et al., 2006a, b, c, d; Dencker et al., 2007). In brief, 477 children (boys=259, girls=218) received an invitation to participate in the study, whereas 248 (boys=140 and girls=108) accepted the invitation. Height and body mass of all invited children were retrieved from the general health data registered by the school nurses, in order to evaluate if selection bias had occurred. The institutional ethics committee of the Lund University, Sweden, approved the study. Written informed consent was obtained from the parents of all participating children.

Anthropometric measures

Total body height and mass were measured in the laboratory with the child dressed in light clothing. Height was measured to the nearest cm using a fixed stadiometer (Hultafors AB, Hultafors, Sweden) and body mass was measured to the nearest kg with a standard scale (Avery Berkel model HL 120, Avery Weigh-Tronix Inc, Fairmont, MN, USA). Puberty status was assessed by self-evaluation according to Tanner (Duke et al., 1980).

Measurement of daily physical activity

Methodology of physical activity assessment has been previously presented in detail (Dencker et al., 2006a, b, c). In brief, an MTI model 7164 accelerometer (Manufacturing Technology Incorporated, Fort Walton Beach, Fl, USA) was worn around the right hip, by an elastic waist belt, for four consecutive days. The accelerometers sample and average data over a period of time called epoch. A recording epoch of 10 s was selected for this study. In order to minimise inter-instrumental variation, all accelerometers were calibrated against a standardised vertical movement. The calibration factor thus derived was then used when calculating the physical activity variables. 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 study. Age and body mass-specific cut-off points exist for accelerometer counts representing activity of varying intensities and these cut-off points made it possible to roughly estimate the number of minutes the child was engaged in activity above a specific intensity threshold (Freedson et al., 1997; Trost et al., 1998). The time the child spent in 3-5.9 metabolic equivalents (METs) was considered moderate physical activity, such as walking at different speeds. The time spent above 6 METs was considered vigorous physical activity, such as running. Time spent in moderate-to-vigorous activity was calculated by summing up time in vigorous and moderate activity. Cut-off points used for all children were 167-583 counts/epoch for a moderate and >583 counts/epoch for vigorous activity (Freedson et al., 1997; Trost et al., 1998).

DXA

Methodology of DXA measurements has been previously presented in detail (Dencker et al., 2006c, d; Dencker et al., 2007). In brief, whole-body composition was measured by DXA (DPX-L version 1.3z, Lunar, Madison, WI, USA). Total body fat mass (TBF) and abdominal fat mass (AFM) were quantified. TBF was expressed as percentage of total body mass times 100 (BF%). Body fat distribution was calculated as AFM/TBF. DXA has been shown to provide an accurate and precise measure of fat mass (Lohman et al., 2000), including abdominal fat (Glickman et al., 2004).

Measurement of Aerobic Fitness

Methodology of aerobic fitness testing has been previously presented in detail (Dencker et al., 2006b). In brief, aerobic fitness was determined by a maximal exercise test performed on an electrically braked cycle ergometer (Rodby rhc, model RE 990, Rodby Innovation AB, Karlskoga, Sweden). Expired gas was sampled continuously via a mixing chamber and analysed for the concentration of O_2 and CO_2 (Sensor Medics 2900, SensorMedics Inc, Yorba Linda, CA, USA). Measurements were obtained every 20 s during two minutes at rest and during exercise to volitional exhaustion. Heart rate (HR) and respiratory exchange ratio (RER) were recorded throughout the test. Maximum heart rate (max HR) and maximum RER (max RER) were recorded. Predicted max HR was considered 210 (220-age). Maximal oxygen uptake (VO_{2PEAK}) was determined as the highest value during the last minute of exercise. VO_{2PEAK} was scaled to (body mass)$^{2/3}$, in an attempt to create a dimension independent value of VO_{2PEAK} (Welsman & Armstrong, 2000). The exercise test was considered acceptable if it met one of the following criteria: RER ≥ 1.0, max HR >85% of predicted value (≥ 178 beats/min) or signs of intense effort (e.g. hyperpnoea, facial flushing or inability in keeping adequate revolutions/min (53-64)), (Armstrong & Welsman, 2000).

Statistical analyses

All analyses were made in Statistica 5.0 (StatSoft Inc, Tulsa, OK, USA). Descriptive statistics include mean± standard deviation and range. Pearson correlation coefficients, with adjustment for gender, between physical activity and body fat measurements or fitness were calculated. Group differences were tested using the unpaired Student´s t-tests between mean values. The distribution of fat measurements was skewed, with the exception of AFM/TBF, and values were logarithmically transformed. Forward stepwise multiple regression analysis (with intercept) was used to test independent relationship between physical activity versus differences in measurements of body fat and aerobic fitness. Dependent variables were moderate-to-vigorous or vigorous activity. Independent variables in all models were body fat measurements, VO_{2PEAK}, gender and possible confounders such as age, max HR, and days of accelerometer recording. Body fat measurements (ln BF%, ln AFM, AFM/TBF) entered the model all combined as independent variables in the first analysis (model 1), and then each separately in the additional models (model 2-4). Statistical significance was set at a level of $p<0.05$.

Results

A total of 20 children were excluded because they did not fulfil the requirements for the assessment of daily physical activity. DXA data was not available in two boys. One child was excluded due to failure to perform the exercise test. Thus, the final study group consisted of 225 children (boys *n*=124, girls *n*=101). Five girls were Tanner stage 2, all remaining 220 children of the final study group were Tanner stage 1. All participants in the final study group met at least one of the criteria for an acceptable exercise test, 73% reached max HR of ≥ 85% of predicted and 66 % RER ≥ 1.0. The average time span between accelerometer and DXA measurements was 8.2±11.0 days. The vast majority of children in the final study group (80%) achieved the full four days of valid accelerometer recording and 20% achieved three days. Weekdays represented 64% of recorded days and weekends 36% of recorded days. We have shown in one of our previous publications from this cohort that there were no significant differences in daily accumulation of moderate-to-vigorous or vigorous activity between boys or girls that achieved three or four days of accelerometer recording (Dencker et al., 2006a)

Anthropometric, age, DXA, daily physical activity and fitness data for the final study group are shown in table 1. Significant univariate correlations were found between moderate-to-vigorous or vigorous activity vs. ln BF %, ln AFM, AFM/TBF, and VO_{2PEAK} (table 2). The relationships tended to be stronger for vigorous than for moderate-to-vigorous activity. No significant relationships were detected for moderate activity and fat measurements, with the exception of only a very weak relationship with VO_{2PEAK}, which prohibits meaningful regression analysis. Multiple regression analysis showed that daily accumulation of moderate-to-vigorous activity had only independent relation with VO_{2PEAK} and not with any of the body fat measurements (table 3). In contrast, vigorous activity was independently linked to VO_{2PEAK} as well as each of the analysed body fat measurements (when entering the model separately), with the exception of body fat distribution (table 4). When all body fat measurements entered the model combined then only ln BF% were linked to vigorous activity among the different body fat measurements (table 4).

Discussion

The salient finding of the present study was the independent association between daily accumulation of vigorous activity and risk factors for cardiovascular disease (CVD) such as body fat, abdominal fat and aerobic fitness. Body fat distribution was not independently linked to vigorous activity, there was only a trend for significance. When all the body fat measurements entered the model all together, the only body fat prevailed as independent predictor of vigorous activity presumably because of the very close correlation between the various body fat measurements. Daily accumulation of moderate-to-vigorous activity displayed a significantly lower association with investigated health-related parameters, only weakly related to aerobic fitness and not independently to any of the fat measurements. The findings are of interest, even if we must emphasise that the cross-sectional nature of the present study can only present relationships, and doesn't answer the question of what is cause and effect.

The main strengths of our study were the use of DXA in order to quantify body fat, direct measurement of maximal oxygen uptake and the use of accelerometers to objectively assess physical activity. Weaknesses of the present study include a somewhat low inclusion frequency of 52%, 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., 2006c). Furthermore, all children did not fulfil the stipulated four days of accelerometer recording or the objective criteria for acceptable exercise test, days of accelerometer recording and max HR were therefore included in the multiple regression analyses to compensate for this.

It may be important to investigate health parameters such as aerobic fitness and body fat content already at an young age since obese children and adolescents have increased risk of developing adult obesity (Whitaker et al., 1997), and aerobic fitness has been shown to track somewhat from childhood into adulthood (Twisk et al., 2002; Trudeau et al., 2003). Furthermore, low aerobic fitness in late adolescence has been shown to be associated with increased risk for development of other risk factors for CVD in adulthood (Twisk et al., 2002). There have been published several reviews on the topic of the activity, aerobic fitness and body fat relationship in children and adolescents (Ward & Evans, 1995; Thomas et al., 2003; Strong et al., 2005), and in this report we focus only of recent reports that have used accelerometers to evaluate physical activity.

Cross-sectional reports of the activity vs. fatness relationship include, the European Youth Heart Study (EYHS) (Ekelund et al., 2004). They found that the time performing moderate-to-vigorous activity, measured by the same type of accelerometers as ours, correlated weakly with BMI. Only 0.5% of the variance in BMI could be explained by daily activity. This was in a multi centre study with 1292 children aged 9 to10 years from Denmark, Portugal, Estonia and Norway. As in our study, the weight of this population was normally distributed. A plausible explanation that our study showed a much higher correlation between body fat and activity could be the fact that the present study measured body fat directly and did not use BMI as a surrogate for fat content. Another explanation might be the use of a short epoch time in our study that should result in a better estimate of vigorous activity (Nilsson et al., 2002). Also, our study highlights the importance of intensity of activity. In our study no relation was observed between daily accumulation of moderate activity and body fat measurements, whereas such relations were detected for vigorous activity and moderate-to-vigorous activity. A report of a small study, 47 children aged 5 to10 years, supports the view that the intensity of activity is linked to body fat (Abbott & Davies, 2004). In this study, as in ours, time spent in moderately intense activity, assessed by accelerometers, was not related to objectively measured body fat. However, time performing vigorous and hard intensity activity was significantly correlated with percentage body fat ($r=-0.43$ and $r=-0.39$, respectively, $p<0.05$).

Two previous longitudinal studies of weight-related differences in children's activity add support for the hypothesis that daily physical activity is involved in accumulation of body fat. In one study, physical activity was assessed with the accelerometer for 3 to 5 days and body fat assessed by anthropometrical methods (Moore et al., 2003). This was part of the Framingham Children's Study, where 103 children were followed from age 4 to 11 years. The highest activity tertile had consistently lower BMI and sum of skinfolds compared to the lower activity tertiles. Similar findings were reported in a 3 year follow-up study of 454 American Indian children where physical activity, assessed by accelerometers on a single day, was associated with bioelectric impedance assessed body fat and sum of skinfolds (Stevens et al., 2004). None of these reports did, however, include aerobic fitness into the analysis.

Reports with combined analysis of accelerometer data versus body fat and aerobic fitness are scarce. Three recent cross-sectional studies are partly contradictory. Hansen and co-workers evaluated 696 Danish children, 6 to 7 years old, as part of the Copenhagen School Child Intervention Study (Hansen et al., 2005). Aerobic fitness was weakly associated with mean physical activity ($r = 0.12$, $p < 0.01$). No relation was detected between body fat and mean physical activity. Conversely, Gutin et al studied 421 black and white US high school students with a mean age of 16 years with use of DXA and accelerometers (Gutin et al., 2005). In this study higher aerobic fitness was associated with higher moderate-to-vigorous activity and vigorous activity. Also, lower amount of body fat was associated with higher vigorous activity, but not with moderate-to-vigorous activity. Ruiz et al reported results, from 780 children aged 9-10 years, which have similarities with ours (Ruiz et al., 2006). They used skinfold technique to assess body fat and evaluated aerobic fitness without direct measurement of VO_{2PEAK}. Their results in different regression analyses were that daily accumulation of moderate-to-vigorous activity was not linked to body fat, only to aerobic fitness. In contrast, vigorous activity was associated with both aerobic fitness and body fat, although they did not perform a combined analysis of aerobic fitness and body fat in relation to daily physical activity, as in the present report. Support for the hypothesis that the more activity the better, was provided from the EYHS data (Andersen et al., 2006). Andersen and co-workers did not investigate one single risk factor, but instead compared clustering of risk factors with daily accumulation of 5 or 10 minutes bouts of activity above 2000 counts/min. Their finding was a clear graded relationship where the quintile with highest activity displayed lowest accumulation of risk factors and a steady increase in accumulation of risk factors could be observed with decreasing activity quintiles.

Perspectives

The finding in the present report was that low daily accumulation of vigorous activity was independently linked to important health parameters such as increased amount of abdominal fat, higher percentage body fat and lower aerobic fitness, whereas daily accumulation of moderate-to-vigorous activity was only weakly linked to aerobic fitness. If the recommendations that stress daily accumulation of moderate-to-vigorous activity are appropriate, then one would not expect to observe the significant differences in the relationships between daily accumulation of moderate-to-vigorous activity and vigorous activity versus investigated health parameters such as aerobic fitness and body fat. Our study suggests that health promotion should perhaps stress the importance of vigorous activity and not focus on moderate-to-vigorous activity. However, the pathways from childhood activity, fitness and health into adulthood are far from conclusive (Twisk, 2001; Malina, 2001). Furthermore, the accumulation of accurate data is critical if better estimates of the true association between physical activity and health risk factors are to be achieved. This report could therefore have implications for public health policies and recommendation for physical activity for children this age.

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Figure legends

Figure 1. Display of percentage body fat (logarithmic values) stratified by quartiles of daily accumulation of vigorous activity for boys and girls (*n*=225). Values are mean±SD. The range for each quartile of vigorous activity (min/day) is stated in the parenthesis.
* indicate significant ($p<0.01$) differences between upper and lower activity quartiles.

Figure 2. Display of aerobic fitness stratified by quartiles of daily accumulation of vigorous activity for boys and girls (*n*=225). Values are mean±SD. The range for each quartile of vigorous activity (min/day) is stated in the parenthesis.
* indicate significant ($p<0.01$) differences between upper and lower activity quartiles.

Figure 1

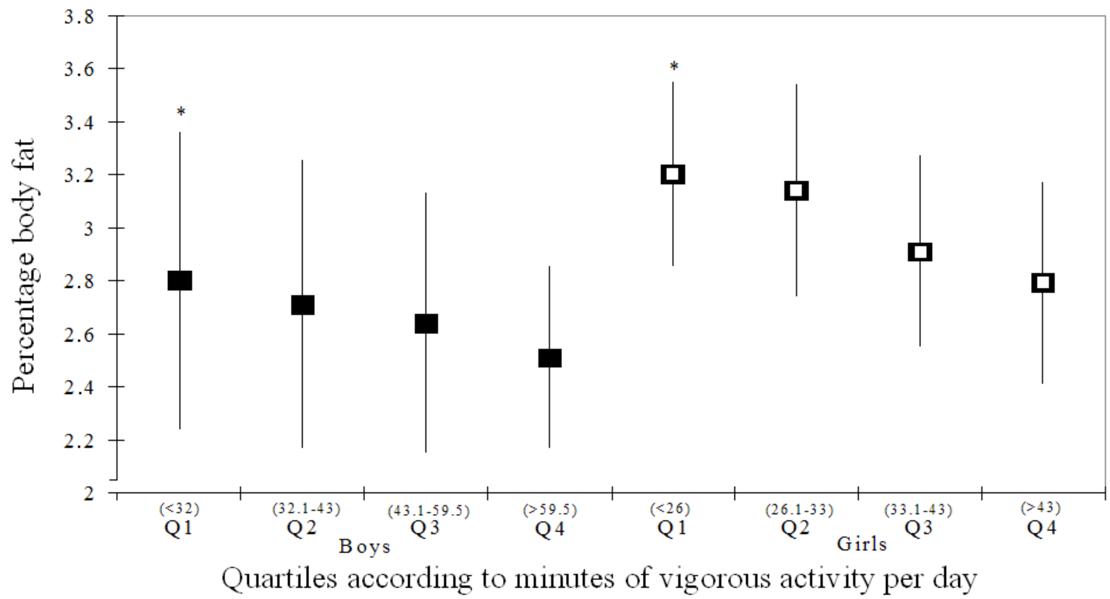

Figure 2

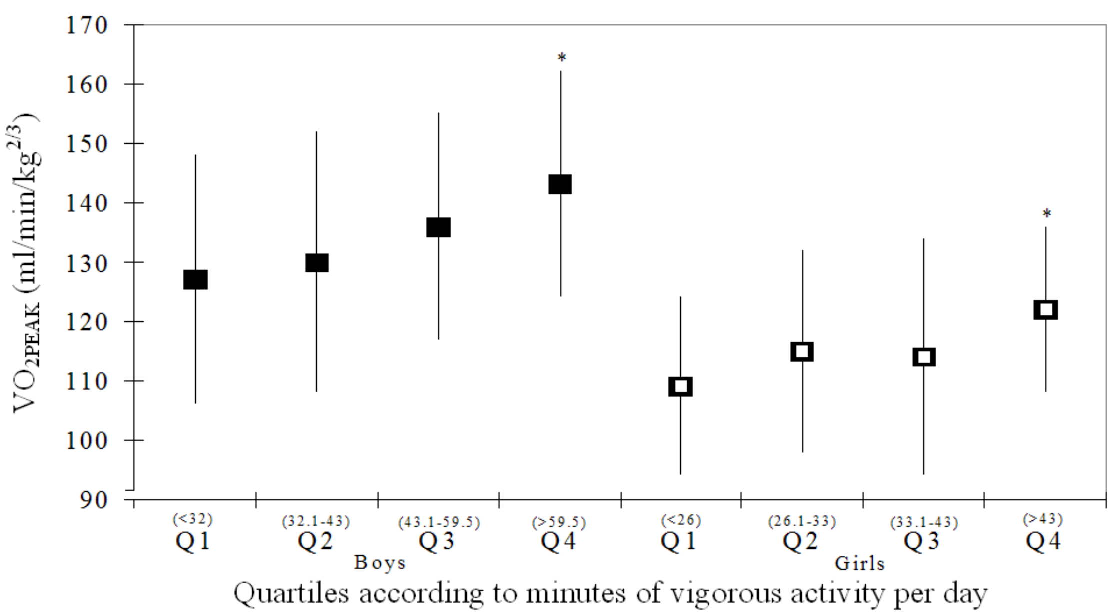

Table 1. Age, antropometric, DXA, physical activity and fitness data for children with valid measurements (*n*=225). Values are mean ± standard deviation and range.

	Boys (*n*=124)	Girls (*n*=101)	p-value
Anthropometrics and age			
Age (y)	9.8±0.6 (8.6-11.1)	9.8±0.6 (7.911.0)	0.36 ns
Height (cm)	141±7 (122-162)	141±8 (124-160)	0.95 ns
Body mass (kg)	34.8±7.8 (20-65)	34.8±7.6 (23-61)	0.98 ns
Fitness			
VO_{2PEAK} (ml/min/kg$^{2/3}$)	134±21 (83-183)	115±17 (64-154)	<0.001
max HR (beats/min)	188±16 (141-220)	185±15 (132-227)	0.17 ns
max RER	1.0±0.1 (0.8-1.2)	1.0±0.1 (0.7-1.2)	0.87 ns
DXA			
Total body fat mass (kg)	6.3±5.1 (1.3-28.3)	8.2±5.2 (1.5-26.3)	0.005
Percent body fat (%)	16.4±8.9 (6.2-44.4)	22.1±8.9 (6.4-45.7)	<0.001
Abdominal fat mass (kg)	2.4±2.3 (0.4-11.4)	3.3±2.4 (0.6-11.1)	0.01
Body fat Distribution	0.36±0.04 (0.27-0.49)	0.38±0.04 (0.28-0.48)	0.06 ns
Physical activity			
Valid recording (hours/day)	12.0±1.4 (8.4-16.4)	11.9±1.3 (8.6-16.4)	0.64 ns
Moderate activity (min/day)	165±36 (71-239)	156±30 (79-214)	0.047
Moderate-to-Vigorous activity (min/day)	210±51 (76-325)	190±38 (89-283)	0.002
Vigorous activity (min/day)	45±20 (4-116)	35±13 (6-70)	<0.001

Table 2. Pearson correlations coefficients, with adjustment for gender, for physical activity versus fitness and fat measurements in all children with valid measurements (*n*=225). For all significant r-values, $p<0.05$.

Variables	Moderate activity (min/day)	Moderate-to-vigorous activity (min/day)	Vigorous activity (min/day)
Percent body fat *	-0.09 ns	-0.22	-0.40
Abdominal fat *	-0.07 ns	-0.18	-0.35
Body fat distribution	-0.05 ns	-0.12 ns	-0.22
Aerobic fitness ($ml/min/kg^{2/3}$)	0.14	0.25	0.38

* logarithmic values

Table 3. Forward stepwise multiple regression analyses with minutes of moderate-to-vigorous activity per day as dependent variable. Independent variables were aerobic fitness, gender, age, max HR, number of days of accelerometer recording, and all body fat measurements (model 1), only ln percent body fat (model 2), only ln abdominal fat mass (model 3), and only body fat distribution (model 4). Children with valid measurements included (*n*=225).

Model	Independent variables	r^2	Beta	SE Beta	p-value
1	Aerobic fitness	0.07	0.31	0.08	<0.001
	max HR	0.09	-0.16	0.07	0.03
	Age	0.10	-0.11	0.06	0.10 ns
	Days of recording	0.11	-0.09	0.06	0.17 ns
	Gender	0.12	-0.09	0.07	0.20 ns
	(ln percent body fat, ln abdominal fat mass, and ln body fat distribution - also ns)				
2	Aerobic fitness	0.07	0.31	0.08	<0.001
	max HR	0.09	-0.16	0.07	0.03
	Age	0.10	-0.11	0.06	0.10 ns
	Days of recording	0.11	-0.09	0.06	0.17 ns
	Gender	0.12	-0.09	0.07	0.21 ns
	(ln percent body fat also ns)				
3	Aerobic fitness	0.07	0.31	0.08	<0.001
	max HR	0.09	-0.16	0.07	0.03
	Age	0.10	-0.11	0.06	0.10 ns
	Days of recording	0.11	-0.09	0.06	0.17 ns
	Gender	0.12	-0.09	0.07	0.21 ns
	(ln abdominal fat mass also ns)				
4	Aerobic fitness	0.07	0.31	0.08	<0.001
	max HR	0.09	-0.16	0.07	0.03
	Age	0.10	-0.11	0.06	0.10 ns
	Days of recording	0.11	-0.09	0.06	0.17 ns
	Gender	0.12	-0.09	0.07	0.21 ns
	(ln body fat distribution also ns)				

Table 4. Forward stepwise multiple regression analyses with minutes of vigorous activity per day as dependent variable. Independent variables in were aerobic fitness, gender, age, max HR, number of days of accelerometer and all body fat measurements (model 1), only ln percent body fat (model 2), only ln abdominal fat mass (model 3), and only body fat distribution (model 4). Children with valid measurements included (*n*=225).

Model	Independent variables	r^2	Beta	SE Beta	p-value
1	Percent body fat	0.15	-0.23	0.07	0.001
	Aerobic fitness	0.19	0.20	0.07	0.006
	Days of recording	0.21	-0.13	0.06	0.03
	(ln abdominal fat mass, body fat distribution, age, gender, and max HR - all ns)				
2	Percent body fat	0.15	-0.23	0.07	0.001
	Aerobic fitness	0.19	0.20	0.07	0.006
	Days of recording	0.21	-0.13	0.06	0.03
	(age, gender, and max HR - all ns)				
3	Aerobic fitness	0.14	0.22	0.07	0.002
	Abdominal fat mass	0.18	-0.20	0.07	0.003
	Days of recording	0.19	-0.13	0.06	0.03
	Gender	0.21	-0.14	0.07	0.03
	(age and max HR - ns)				
4	Aerobic fitness	0.14	0.32	0.08	<0.001
	Gender	0.16	-0.14	0.07	0.04
	Days of recording	0.18	-0.12	0.06	0.04
	Body fat distribution	0.19	-0.11	0.06	0.08 ns
	max HR	0.20	-0.08	0.07	0.23 ns
	(age also ns)				