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Daily physical activity and its relation to aerobic fitness in children aged 8-11 years

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Abstract

A positive relationship between daily physical activity and aerobic fitness exists in adults. Studies in children have given conflicting results, possibly because of differences in methods used to assess daily physical activity and fitness. No study in children has been published, where fitness has been assessed by direct measurement of maximum oxygen uptake and related to daily physical activity intensities by accelerometers. We examined 248 children (140 boys and 108 girls), aged 7.9-11.1 years. Maximum workload and maximal oxygen uptake (VO_{2PEAK}) by indirect calorimetry was measured during a maximum bicycle ergometer exercise test. Exercise capacity was adjusted for body mass and (body mass)$^{2/3}$. Daily physical activity was evaluated by accelerometers, worn around the waist for four days. Mean accelerometer counts, and time spent in vigorous physical activity were calculated. VO_{2PEAK} was correlated with mean accelerometer counts (r=0.23 for boys and r=0.23 for girls, both p<0.05), but somewhat better with time spent in vigorous activity (r=0.32 for boys, r=0.30 for girls, both p<0.05). All results remained virtually the same regardless of the method used to adjust for differences in body size.

Introduction

A positive relationship between daily physical activity and aerobic fitness is established in adults (U.S Department of Health and Human Services 1996), but not in children. The physical activity pattern in children is often random, sporadic and unsustained and therefore may not result in an improvement of aerobic fitness (Bailey et al. 1995; Rowland 1996b). Another reason for the diverse findings of previous investigations (Sundberg 1982; Morrow and Freedson 1994; Boreham et al. 1997; Rowlands et al. 1999; Ekelund et al. 2001a) is that a multitude of methods have been used both to assess daily physical activity and fitness. Methods used to assess fitness in previous studies included sub-maximal and maximal bicycle ergometer tests, sub-maximal and maximal treadmill tests and shuttle-run tests, with or without direct measurement of maximum oxygen uptake (VO_{2PEAK}). All indirect measures of VO_{2PEAK} introduce errors (Rowland 1996a) and therefore may dilute any existing relationship between daily physical activity and fitness. In addition, various scaling methods to adjust fitness to differences in body size have been used.

An important aspect when studying presumed physiological effects of daily physical activity is the inherent difficulties to obtain accurate assessments (Kohl et al. 2000). Previous studies on the activity versus fitness relationship have used a highly diverse range of methods. Self-report methods are commonly used (Morrow and Freedson 1994; Boreham et al. 1997). However, these methods are known to have limited accuracy in the assessment of daily physical activity in subjects of all ages and are considered to be inappropriate to use in children under the age of ten (Sallis and Saelens 2000; Kohl et al. 2000). Also, different objective methods, such as heart rate monitors (HRM) or pedometers, have been used, but these methods have limitations as well. HRM is influenced by a large number of factors including age, body size, emotional stress, temperature and fitness (Trost 2001). Pedometers

only measure the volume of activity and do not give any information about the intensity or duration of the activity (Trost 2001).

The introduction of accelerometers for measurement of daily physical activity in children represents a new era. Accelerometers provide objective and detailed measurements of the frequency, duration and intensity of activity and can be used over relatively long periods by children (Trost et al. 2000; Trost 2001; Riddoch et al. 2004). Accelerometers may therefore have the potential to overcome some of the limitations of previous methods and therefore give more accurate data. To date, no large-scale studies exist in children, where direct measurements of VO_{2PEAK} and accelerometers have been used to study the relationship between aerobic fitness and daily physical activity intensities. The purpose of this study was therefore to evaluate the relationship between daily physical activity and aerobic fitness in a population-based cohort of 8- to 11-year old children. A secondary objective was to evaluate if different methods to adjust fitness data for body size affected the conclusions.

Methods

Subjects

Recruitment of the study cohort has been presented previously (Dencker et al. in press). Shortly, 477 children received an invitation to participate in the study and 248 (140 boys and 108 girls), aged 8 to 11 years accepted the invitation. 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 assessment

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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). Body mass index (BMI) was calculated as body mass in kilograms divided by height in meters squared ($kg \cdot m^{-2}$). Puberty status was assessed by self-evaluation according to Tanner (Duke et al. 1980).

Measurement of physical activity

Methodology of physical activity assessment has been previously presented in detail (Dencker et al. in press). Shortly, an MTI model 7164 accelerometer (Manufacturing Technology Inc, Fort Walton Beach, Fl, USA) was worn around the hip for four consecutive days, including both weekdays and weekend days. The accelerometer sample and average data over a period of time called an epoch, and for this study a recording epoch of ten seconds was used. Accelerometer measured activities have been well validated in children against a range of outcomes (Freedson et al. 1997; Trost et al. 1998; Trost et al. 2000; Ekelund et al. 2001b; Brage et al. 2003). The accelerometer measurement took place within as short timeframe from the exercise test as possible, usually the same or the adjacent week.

Mean daily physical activity (MDPA) was defined as total accelerometer counts per valid minute of monitoring. Age and body mass-specific cut-off points exist for accelerometer counts representing activity of varying intensities (Freedson et al. 1997; Trost et al. 1998), which makes it possible to estimate the number of minutes the child was engaged in activity above a specific intensity threshold. The intensity was described as metabolic equivalents (METs). Time spent in 3-6 METs was considered moderate physical activity (MPA), such as

walking. Time spent above 6 METs was considered vigorous physical activity (VPA), such as running. Cut-off points used for all children were 167-583 counts/epoch for moderate activity and >583 counts/epoch for vigorous activity (Freedson et al. 1997; Trost et al. 1998).

Measurement of Aerobic Fitness

Aerobic fitness was determined by a maximum exercise test performed on an electrically braked bicycle 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. All children, regardless of gender, fitness, height and body mass, used the same protocol with an initial workload of 30 Watt (W) and an increase of 15 W per minute. Heart rate (HR) and respiratory exchange ratio (RER) were recorded and displayed throughout the test. Maximum workload in W (max W), maximum heart rate (max HR) and maximum RER (max RER) were recorded. VO_{2PEAK} was determined as the highest representative value recorded during the last minute of exercise. Both VO_{2PEAK} and max W were calculated per kilogram of body mass and also per (kilogram of body mass)$^{2/3}$, which are the two most common approaches to adjust fitness to body size (Rowland 1996a; Welsman and Armstrong 2000). The exercise test was considered acceptable if it met one of following criteria; RER $\geq$ 1.0, max HR >85% of predicted value ($\geq$ 178 beats/min) or signs of intense effort (e.g. hyperpnoea, facial flushing or difficulties in keeping up the speed of the bicycle), (Armstrong and Welsman 2000).

Statistical analyses

All analyses were made in Statistica 5.0 (StatSoft Inc, Tulsa, OK, USA). Descriptive statistics include mean and ± standard deviation (SD) unless otherwise stated. Univariate relationships between physical activity and fitness variables were assessed with Pearson correlation analysis. Group differences between mean values were tested using the unpaired Student´s t-test. Statistical significance was set at a level of $p<0.05$. Multiple forward regression analysis was used to evaluate the independency of VPA and MDPA vs. VO_{2PEAK}. In this analysis VO_{2PEAK} entered as dependent and VPA and MDPA was introduced into the model as independent variables together with possible confounders as gender, age, Tanner stage and number of days of accelerometer recordings.

Results

A total of 19 children (boys $n=12$ and girls $n=7$) were excluded because they did not fulfil the requirements for the assessment of daily physical activity. One child was excluded due to failure to adequately perform the exercise test. Thus, the final study group consisted of 228 children (boys $n=127$, girls $n=101$). All participants in this study met at least one of the criteria for an acceptable exercise test, 71% reached 85% of predicted max HR and 67% and RER $\geq$ 1.0. Five girls were Tanner stage 2 and all remaining 243 children were Tanner stage 1. Anthropometrics, age, daily physical activity and fitness are displayed in table 1.

The vast majority of the children achieved the full four days of accelerometer recording (80%), 20% achieved three days. Weekdays represented 64% of recorded days and weekend days 36% of recorded days. The average time span between the accelerometer measurement and the exercise test was 8.2±11.0 days. Both boys and girls who had three days of valid registrations recorded slightly higher MDPA than those who had four days of registrations (861 vs. 724 for

boys and 698 vs. 599 for girls, both p=0.001). However, there were no significant differences in MPA or VPA per day or in recording time per day between children that achieved three and four days of valid recordings.

Since there were no relationships, for neither boys nor girls, between age vs. MDPA, MPA, VPA, VO_{2PEAK} or max W (r=-0.14, -0.11, -0.06, 0.02, 0.02 for boys and r=0.10, -0.12, 0.16, 0.04, 0.07 for girls, p<0.05 for all) calculations were not corrected for age. The relationships between physical activity and fitness measurements are displayed in table 2. A weak, but significant, positive relation was found between VO_{2PEAK} and MDPA. When VO_{2PEAK} was related to minutes per day spent in VPA (fig 1 and 2) a tendency to a stronger correlation was found. The two different methods of adjusting fitness results to body size did not significantly alter the results, nor if analysing children with 3 and 4 days of valid accelerometer recordings combined vs. only analysing children with 4 days of valid recording (table 2). A highly significant relationship existed between max W and VO_{2PEAK}, r=0.91, p <0.05. Accordingly, no major difference was seen if physical activity was correlated with VO_{2PEAK} or max W (table 2). Multiple forward regression analysis concluded that VPA and MDPA explained 10% of the variability of VO_{2PEAK} (VPA 9% and MDPA 1%).

Discussion

This report evaluates the relationship between aerobic fitness and daily physical activity in a large population based cohort of young children, with fitness assessed by direct measurement of maximum oxygen uptake and physical activity intensities assessed with accelerometers. A weak, but positive, relationship was established between daily physical activity and VO_{2PEAK}, while a tendency to a stronger relationship was found if fitness was related to time spent performing VPA rather than to MDPA. No relationship was found between MPA and

VO$_{2PEAK}$. Accurate assessment of daily physical activity in younger children represents a challenge. The use of accelerometers is a new way of such assessment. Especially the possibility to measure the time that a child is involved in activity of different intensities is innovative.

Objective measurement of daily physical activity represents a major strength of this study. Children of this age tend to have a highly intermittent activity pattern and the use of a short epoch time should have been of advantage to capture short bursts of VPA. A previous study has shown that VPA may be substantially underestimated if a longer epoch time is used (Nilsson et al. 2002). One limitation of using the shorter epoch time is that this type of accelerometer can only record for four days, thus the price for a higher time resolution is a shorter observation time. Although accelerometers allow reasonable accuracy in the assessment of daily physical activity, they have possible limitations and these have been previously discussed in detail (Dencker et al, in press). Shortly, three main problems should be mentioned. Firstly, intra-accelerometer variability may cause poor accuracy in the assessment of physical activity, but this was minimised in our study by calibration of all accelerometers. Secondly, accelerometers underestimate physical activity during activities that involve a minimal vertical displacement of the body such as cycling. Vigorous activity is underestimated for the same reason, and linear relation exists to differences in speed during walking, but not during running (Brage et al. 2003). Finally, accelerometer cut-off points defining different activity intensities for children (Freedson et al. 1997; Trost et al. 1998) have been established in laboratory settings using treadmill exercise protocols and may not be entirely representative of the movements performed by free-living children. A possible weakness in the accelerometer measurements of our study was that not all children achieved the stipulated 4 days of recordings. There was a slight difference in MDPA, where those

children who had three days of measurements had higher values than those who hade four days of registration. No differences were observed in time spent in moderate or vigorous activity between children who had three days or four day of registration. Also, the difference in intraclass reliability coefficients between three- vs. four-days of accelerometer recordings are small, approximately 0.75 vs. 0.8 for children this age (Trost et al. 2000). This suggests that there was no major systematic error introduced by using three- and four-day measurements together. However, using stricter criteria for acceptance of measurements (such as excluding children with 3 days of accelerometer recording) did not alter the results concerning VPA vs. fitness measurement. For MDPA some correlations became statistically not significant presumably because loss of statistical power when 20% of the children were excluded (those with only 3 days of accelerometer recordings).

Direct measurement of VO_{2PEAK}, as used in the present study, is considered the optimal method to assess aerobic fitness (Rowland 1996a). A weakness of this method is the arbitrary criteria used to define a maximum effort. A possible limitation of our study is that only 71% of the children reached 85% of predicted max HR and even less children an RER $\geq$ 1.0, although they subjectively indicated that they had made a maximum effort. Since it is not ethically acceptable to force a child to continue the test when they feel exhausted, some children's VO_{2PEAK} and max W may have been underestimated. Furthermore, it is not clear how to account for differences in body size when evaluating fitness in children, since all such adjustments are empiric (Rowland 1996a; Welsman and Armstrong 2000). The two most commonly used approaches are to express VO_{2PEAK} and max W relative to body mass or (body mass)$^{2/3}$ (Rowland 1996a; Welsman and Armstrong 2000). In this study, the use of either algorithm did not alter the results, with the exception of a somewhat weaker positive relation between MDPA and fitness in boys when (body mass)$^{2/3}$ was applied.

There are a number of factors that influence VO_{2PEAK} such as cardiac output, oxygen carrying capacity of the blood, and perhaps peripheral diffusion gradients (Bassett and Howley 2000). In addition, genetic factors modify all of this (Bouchard et al. 1986). In the present study only the influence of daily physical activity was evaluated and approximately 10% of the variability in VO_{2PEAK} could be explained by differences in VPA and MDPA.

Most previous studies have focused on adolescents or groups of children with a wide age range, rather than young children only (Sundberg 1982, Morrow and Freedson 1994, Boreham et al. 1997, Ekelund et al. 2001a). In one of the few studies in which accelerometers have been used in younger children (Rowlands et al. 1999), 34 children aged 8-10-years, were evaluated with Tritrac-3D accelerometers for six days and fitness was evaluated on a treadmill test without measurement of maximum oxygen uptake. In the study by Rowlands et al, the authors reported a high correlation between physical activity and endurance time on treadmill test ($r=0.66$, $p <0.05$). Such strong relationship was not found in the current study. This might be explained by considerable difference in sample size and selection criteria. Furthermore, Rowlands et al used endurance time on treadmill test rather than VO_{2PEAK} as measure of fitness.

The objective data in this study strongly imply, albeit weakly, that the amount of daily physical activity in childhood is associated with aerobic fitness. This further emphasises the importance to expose children to a sufficient amount of physical activity since low fitness is associated with a less favourable cardiovascular risk factor profile in children (U.S Department of Health and Human Services 1996). Even if physical activity is only one of the factors linked to fitness, it is a factor that can be promoted, in a sense of an increase of VPA.

However, the cross-sectional nature of the current study can only highlight the positive association between activity and fitness. It does not show whether inactivity causes decreased fitness or if low levels of fitness cause children to be inactive, an issue we intend to address in a future, prospective part of this study.

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Table 1. Age, antropometic, fitness and physical activity data for all children with valid measurements. Values are presented as mean ± SD and range.

	Boys (*n*=127)	Girls (*n*=101)	p-value
Anthropometrics and age			
Age (years)	9.8±0.6 8.6-11.1	9.8±0.6 7.9-11.0	0.43 ns
Heigth (cm)	141±6.9 122-162	141±7.9 124-160	0.84 ns
Body mass (kg)	34.9±7.8 20-65	34.8±7.6 23-61	0.97 ns
BMI (kg $\cdot$ m^{-2})	17.4±2.8 12.8-28.1	17.5±2.9 13.4-26.8	0.88 ns
Fitness			
max W (W $\cdot$ kg^{-1})	3.3±0.6 1.4-4.5	2.9±0.6 1.1-4.2	<0.001
VO$_{2PEAK}$ (ml $\cdot$ min^{-1} kg^{-1})	42±7.4 22.0-58.3	36±6.3 17.5-48.3	<0.001
max HR (beats $\cdot$ min^{-1})	188±16.5 141-220	185±15.2 132-217	0.16 ns
max RER	1.0±0.1 0.8-1.2	1.0±0.1 0.7-1.2	0.81 ns
Physical activity			
Valid recording (min $\cdot$ day^{-1})	716±84 505-987	712±78 516-987	0.76 ns
MDPA (mean counts $\cdot$ min^{-1})	751±243 189-1504	618±154 211-1121	<0.001
MPA (min $\cdot$ day^{-1})	164±36 71-239	156±30 79-214	0.05 ns
VPA (min $\cdot$ day^{-1})	46±20 4-116	35±13 6-70	<0.001

Table 2. Univariate correlation between different estimations of physical activity and fitness according to different scaling methods in all children. Top table include both children with 3 and 4 days of valid recording combined, and bottom table only children with 4 days of valid recording. For all significant r-values, p<0.05.

Children with 3and 4 days of valid accelerometer recording combined.

	Boys (n=127)				Girls (n=101)			
	VO$_{2PEAK}$		max W		VO$_{2PEAK}$		max W	
	kg^{-1}	kg$^{-2/3}$	kg^{-1}	kg$^{-2/3}$	kg^{-1}	kg$^{-2/3}$	kg^{-1}	kg$^{-2/3}$
MDPA	0.23	0.16 ns	0.26	0.21	0.23	0.23	0.29	0.30
MPA	0.15 ns	0.15 ns	0.17 ns	0.17 ns	0.03 ns	0.03 ns	0.11 ns	0.12 ns
VPA	0.32	0.27	0.33	0.30	0.30	0.28	0.31	0.30

Only children with 4 days of valid accelerometer recording.

	Boys (n=102)				Girls (n=81)			
	VO$_{2PEAK}$		max W		VO$_{2PEAK}$		max W	
	kg^{-1}	kg$^{-2/3}$	kg^{-1}	kg$^{-2/3}$	kg^{-1}	kg$^{-2/3}$	kg^{-1}	kg$^{-2/3}$
MDPA	0.25	0.17 ns	0.30	0.24	0.16 ns	0.20 ns	0.23	0.27
MPA	0.16 ns	0.16 ns	0.20	0.21	0.02ns	0.03 ns	0.01 ns	0.10 ns
VPA	0.33	0.28	0.36	0.32	0.27	0.26	0.28	0.28

Figure legends

Fig 1. Relation between minutes of vigorous physical activity (VPA) per day and aerobic fitness VO_{2PEAK} (ml $\cdot$ min^{-1} $\cdot$ kg^{-1}) for boys ($n=127$).

Fig 2. Relation between minutes of vigorous physical activity (VPA) per day and aerobic fitness VO_{2PEAK} (ml $\cdot$ min^{-1} $\cdot$ kg^{-1}) for girls ($n=101$).