Journal of Sports Sciences

ISSN: 0264-0414 (Print) 1466-447X (Online) Journal homepage: http://www.tandfonline.com/loi/rjsp20

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Journal of Sports Sciences, January 15th 2010; 28(2): 139–145

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(Accepted 3 November 2009)

Abstract

The purpose of this study was to investigate by direct measurement the cross-sectional relationship between accelerometer-measured physical activity and peak oxygen uptake ($\dot{V}O_{2peak}$: ml · min^{-1} · kg^{-1}), in a population-based cohort of young children, since such data are scarce. The study included 468 children (246 boys, 222 girls) aged 6.7 $\pm$ 0.4 years, recruited from a population-based cohort. Peak oxygen uptake was measured by indirect calorimetry during a maximal treadmill exercise test. Physical activity was assessed by accelerometers over a 4-day period. Minutes of sedentary, light, moderate, moderate-to-vigorous, and vigorous activity per day were calculated. Mean counts per minute were considered to reflect total physical activity. Pearson correlation coefficients indicated a weak relationship between daily physical activity variables and $\dot{V}O_{2peak}$ in boys ($r = 0.15$–0.28, $P < 0.05$), with the exception of time in sedentary and light activity, which was not related to $\dot{V}O_{2peak}$. None of the daily physical activity variables were related to $\dot{V}O_{2peak}$ in girls, with the exception of a very weak relationship for moderate activity ($r = 0.14$, $P < 0.05$). Multiple regression analyses indicated that the various physical activity variables explained between 2 and 8% of the variance in $\dot{V}O_{2peak}$ in boys. In this population-based cohort, most daily activity variables were positively related to aerobic fitness in boys, whereas less clear relationships were observed in girls. Our finding that physical activity was only uniformly related to aerobic fitness in boys partly contradicts previous studies in older children and adolescents.

Keywords: *Peak oxygen uptake, aerobic fitness, accelerometers, daily physical activity, children*

Introduction

Aerobic fitness, defined as peak oxygen uptake ($\dot{V}O_{2peak}$), is generally considered to be the best single marker for the functional capacity of the cardiorespiratory system. Low aerobic fitness in adults has been shown to be a strong predictor for a variety of diseases and all causes of death (US Department of Health and Human Services, 1996). Low aerobic fitness in children has been associated with risk factors for cardiovascular disease (CVD) (Anderssen et al., 2007; Eiberg et al., 2005a; US Department of Health and Human Services, 1996). Aerobic fitness has been shown to track from childhood into adulthood (Andersen & Haraldsdottir, 1993; Trudeau, Shephard, Arsenault, & Laurencelle, 2003; Twisk, Kemper, & van Mechelen, 2002), and 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 (Hasselstrøm, Hansen, Froberg, & Andersen, 2002; Twisk et al., 2002). It is therefore of interest to study how a presumably modifiable factor such as physical activity is related to $\dot{V}O_{2peak}$ in childhood. Peak oxygen uptake is naturally influenced by other factors, independent of physical activity such as genetics and body composition (Bouchard et al., 1986; Dencker et al., 2007). It should also be noted that the pathways between physical activity, aerobic fitness, and health are far from straightforward (Steele, Brage, Corder, Wareham, Ekelund, 2008). However, the accumulation of accurate data is critical for better estimates of the true association between physical activity and health risk factors, thereby achieving evidence-based public health policies.

While a positive relationship between daily physical activity and aerobic fitness has been established in adults (US Department of Health and Human

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ISSN 0264-0414 print/ISSN 1466-447X online © 2010 Taylor & Francis
DOI: 10.1080/02640410903460726

Services, 1996), no such relationship has been established 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, 1996). An important aspect when studying presumed physiological effects of daily physical activity is the inherent difficulty of obtaining accurate assessments (Kohl, Fulton, & Caspersen, 2000). Previous studies on the activity–fitness relationship have used a highly diverse range of methods, such as various self-report methods, heart rate monitors, and pedometers, all of which have limited accuracy (Kohl et al., 2000; Sallis & Saelens, 2000; Trost, 2001). The introduction of accelerometers for the measurement of daily physical activity in children represents a considerable improvement over previous methods. Accelerometers provide objective and detailed measurements of the frequency, duration, and intensity of activity and can be used over relatively long periods by children (Dencker & Andersen, 2008; Trost, 2001). Accelerometers, therefore, may have the potential to overcome some of the limitations of previous methods and provide more accurate data. Moreover, 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 $\dot{V}O_{2peak}$. All indirect measures of $\dot{V}O_{2peak}$ introduce errors (Dencker et al., 2008; Rowland, 1996) and therefore may dilute any existing relationship between daily physical activity and fitness.

The purpose of this study was to investigate the cross-sectional relationship between accelerometer-measured daily physical activity (both volume and intensity) and $\dot{V}O_{2peak}$ by direct measurement from a maximal treadmill exercise test, in a large population-based cohort of young children, since such data are scarce.

Materials and methods

Participants and anthropometry

Recruitment of the study cohort has previously been presented in detail (Eiberg et al., 2005a, 2005b; Hansen, Hasselstrom, Gronfeldt, Froberg, & Andersen, 2005; Hasselstrøm et al., 2006, 2007). In brief, the Copenhagen School Child Intervention Study is an urban population-based intervention study. Children from 46 preschool classes (6–7 years of age) in 18 schools in two suburban communities in the Copenhagen area were invited to participate in the study, and the participation rate was 69%. Based on school-records, there were no significant differences in age, height, weight or body mass index between participants and non-participants for either sex, which suggests that no fundamental selection bias occurred. This report is based on baseline data before any intervention.

Height was measured by a Harpenden stadiometer to the nearest millimetre and body weight was measured to the nearest 0.1 kg using a SECA 882 electronic scale. Body mass index (BMI) was calculated as weight/height^2 ($kg \cdot m^{-2}$). Pubertal status was assessed by self-evaluation according to Tanner (Duke, Litt, & Gross, 1980). The Ethical Committee of Copenhagen County approved the study.

Measurement of daily physical activity

Daily physical activity was measured by an Actigraph 7164 activity monitor (Actigraph Inc., Pensacola, FL, USA), which is a highly validated monitor (Dencker & Andersen, 2008). The Actigraph was secured directly to the skin at the lower back using an elastic belt, and the children were instructed to use the accelerometer for four consecutive days, two weekdays, and two weekend days. They wore the accelerometer during the entire day and only removed it during activities that could damage it (this type of accelerometer is not waterproof). A recording epoch of 10 s was selected for this study. All continuous sequences of 60 consecutive epochs (i.e. 10 min) or more with zero counts were deleted (Baquet, Stratton, Van Praagh, & Berthoin, 2007; Riddoch et al., 2004). This was done based on the assumption that all such sequences of zeroes lasting longer than 10 min were caused by the accelerometer not being worn. Children failing to provide a minimum of three separate days of 8 h of valid recording, after removal of missing data, were excluded from the analysis. To minimize inter-instrument variation, all accelerometers were calibrated against a standardized vertical movement. The calibration factor thus derived was then used to adjust the raw data from the accelerometers before calculating the physical activity variables.

Several physical activity variables were estimated. First, the overall physical activity was labelled "total physical activity", and was considered to be the total accelerometer counts per valid minute of monitoring (mean counts per minute). A previous validation study has shown that this variable correlates with total physical activity measured by doubly labelled water in children ($r = 0.58$, $P < 0.01$) (Ekelund et al., 2001). Second, the duration of time was evaluated that the child was engaged in the activity of different intensities. Previous validation studies have generated cut-off points for accelerometer counts corresponding to activities of varying intensities (Mattocks et al., 2007; Puyau, Adolph, Vohra, & Butte, 2002; Sirard, Trost, Pfeiffer, Dowda, & Pate, 2005; Treuth et al., 2004; Trost et al., 1998). These cut-off points made it possible to estimate roughly the number of minutes the child was engaged in an activity above a specific intensity threshold. Daily accumulation of moderate physical activity such as walking and vigorous physical activity such as running was calculated. Daily accumulation of moderate-to-vigorous physical activity was assessed by summing moderate physical activity and vigorous physical activity. Cut-off points used for all children were as follows: sedentary, <1000 counts $\cdot$ min^{-1}; light physical activity, 1000–2499 counts $\cdot$ min^{-1}; moderate physical activity, 2500–5000 counts $\cdot$ min^{-1}; and vigorous physical activity, >5000 counts $\cdot$ min^{-1} (Mattocks et al., 2007; Puyau et al., 2002; Sirard et al., 2005; Treuth et al., 2004; Trost et al., 1998).

Measurement of aerobic fitness

Peak oxygen uptake was determined with an AMIS 2001 Cardiopulmonary Function Test System (Innovision, Odense, Denmark) with a Hans Rudolph mouthpiece, especially designed for children, with a volume of 15 ml. The $\dot{V}O_2$ data were stored digitally every 5 s for later analysis, and the six consecutive highest values were averaged and used as $\dot{V}O_{2peak}$ (highest 30 s). Heart rate was measured continuously every fifth second (Polar Sport Tester). A continuous walking and running protocol on a treadmill was used (Eiberg et al., 2005b). The velocity on the treadmill was set to 4 km $\cdot$ h^{-1} without inclination for the first 3 min to familiarize the children with the treadmill. At 3 min the velocity was increased to 8 km $\cdot$ h^{-1}, and at 5 min the inclination of the treadmill was raised to 3%. At 7, 9, and 11 min, the inclination was increased to 6%, 9%, and 11%, respectively. If the child could endure more, the velocity was increased to 9 km $\cdot$ h^{-1} after 13 min and then 10 km $\cdot$ h^{-1} at 15 min. No child completed the last workload. The children were instructed to run until exhaustion. One subjective and three objective criteria were used to determine if the test was maximal. Every child had to meet the subjective criterion and at least one of the three objective criteria. The objective criteria were: (1) maximal heart rate >195 beats $\cdot$ min^{-1}; (2) respiratory exchange ratio (RER) ≥ 0.99; or (3) a defined plateau of $\dot{V}O_2$ (Armstrong & Welsman, 2000). The subjective criterion was signs of intense effort, such as unsteady running pattern, sweating, facial flushing or a clear unwillingness to continue running in spite of repeated strong verbal encouragement.

Statistical analyses

All analyses were made in Statistica 7.1 (StatSoft Inc, Tulsa, OK, USA). Univariate relationships between $\dot{V}O_{2peak}$ and accelerometer-measured daily physical activity variables were assessed with Pearson correlation analysis, with adjustment for days of accelerometer recording. Group differences between mean values were tested using Student's unpaired *t*-tests. Stepwise multiple forward regression analysis, with intercept, was used in boys to evaluate the independence of $\dot{V}O_{2peak}$ and total physical activity, moderate physical activity, moderate-to-vigorous physical activity, and vigorous physical activity. In these analyses, $\dot{V}O_{2peak}$ was entered as a dependent variable. Total physical activity, moderate-to-vigorous physical activity, and vigorous physical activity were introduced separately, whereas moderate physical activity was introduced together with vigorous physical activity, as independent variables, together with possible confounders such as age and number of days of accelerometer recordings. Additional analyses were made where body mass index was also introduced into the model. These analyses were only performed for moderate physical activity in girls because no statistically significant relationships were observed between the other physical activity variables and aerobic fitness. Statistical significance was set at $P < 0.05$.

Results

All children were Tanner stage 1. A complete data set for $\dot{V}O_{2peak}$, obtained by direct measurement, acceptable accelerometer measurement, and anthropometric data were available for 468 children (246 boys, 222 girls) aged 6.7 ± 0.4 years (range 5.7–8.2). A summary of the anthropometric data, aerobic fitness, and daily physical activity is given in Table I. Boys were slightly older, taller, and had more body mass than girls, whereas body mass index did not differ between the sexes. All children fulfilled the subjective criterion for an acceptable exercise test, and all children fulfilled at least one of the objective criteria for an acceptable exercise test. A total of 12 girls and 15 boys did not have heart rate data of acceptable quality and in those cases the other two objective criteria were used (i.e. RER ≥ 0.99 or a defined plateau in $\dot{V}O_2$) to establish that an acceptable maximal effort had been performed. Boys had higher $\dot{V}O_{2peak}$ than girls, whereas girls had a slightly higher RER and maximal heart rate. Boys preformed more physical activity than girls, the only exceptions being time in sedentary and light physical activity, which did not differ between the sexes. There was no difference between boys and girls concerning days of accelerometer monitoring or hours of accelerometer registration per day. A total of 430 children completed 4 days of acceptable accelerometer monitoring, and 38 children fulfilled 3 days of acceptable accelerometer monitoring.

Table I. Age, anthropometric data, daily physical activity, and fitness results of the final study group (mean ± s).

	Boys ($n = 246$)	Girls ($n = 222$)	P-value
Age and anthropometry			
Age (years)	6.8 ± 0.4	6.7 ± 0.3	< 0.001
Height (m)	1.24 ± 0.05	1.22 ± 0.05	< 0.001
Body mass (kg)	24.5 ± 3.7	23.8 ± 3.5	0.04
Body mass index ($kg \cdot m^{-2}$)	15.9 ± 1.8	16.0 ± 1.6	0.83#
Fitness variables			
$\dot{V}O_{2peak}$ ($ml \cdot min^{-1} \cdot kg^{-1}$)	48.7 ± 6.2	44.8 ± 5.5	< 0.001
Maximum heart rate (beats $\cdot min^{-1}$)	197 ± 9	199 ± 9	0.01
Maximum respiratory exchange ratio	1.06 ± 0.11	1.11 ± 0.12	< 0.001
Daily physical activity			
Days of monitoring (n)	3.9 ± 0.3	3.9 ± 0.3	0.73#
Valid registration ($h \cdot day^{-1}$)	11.7 ± 1.3	11.6 ± 1.3	0.24#
Total physical activity (counts $\cdot min^{-1}$)	774 ± 223	704 ± 163	< 0.001
Sedentary ($min \cdot day^{-1}$)	523 ± 80	534 ± 71	0.13#
Light physical activity (counts $\cdot min^{-1}$)	124 ± 33	119 ± 30	0.10#
Moderate physical activity (counts $\cdot min^{-1}$)	45 ± 21	34 ± 14	< 0.001
Moderate-to-vigorous physical activity (counts $\cdot min^{-1}$)	56 ± 27	42 ± 18	< 0.001
Vigorous physical activity (counts $\cdot min^{-1}$)	11 ± 9	9 ± 6	< 0.001

#Values are not statistically significant.

A summary of Pearson correlation coefficients between $\dot{V}O_{2peak}$ and physical activity variables is presented in Tables II and III. Most daily activity variables were weakly positively related to $\dot{V}O_{2peak}$ in boys, with the exception of time in sedentary and light physical activity, which was not related to $\dot{V}O_{2peak}$ (Table II). No relationships could be detected between $\dot{V}O_{2peak}$ and physical activity variables in girls, with the exception of a very weak relationship between $\dot{V}O_{2peak}$ and moderate physical activity (Table III). Multiple regression analysis in boys indicated an r^2 for the model of 0.03 for total physical activity, 0.08 for moderate physical activity, 0.07 for moderate-to-vigorous physical activity, and 0.02 for vigorous physical activity, indicating that the various physical activity variables explained between 2 and 8% of the variance in $\dot{V}O_{2peak}$ in boys. Multiple regression analysis in boys with inclusion of body mass index in the model indicated similar findings. The various physical activity variables explained between 2 and 6% of the variance in $\dot{V}O_{2peak}$ in boys after adjustment for body mass index. Body mass index explained 10% of the variance in $\dot{V}O_{2peak}$ in boys after adjustment for various physical activity parameters. Table IV provides a regression summary.

Multiple regression analysis in girls indicated an r^2 for moderate physical activity of 0.02, and body mass

Table II. Pearson correlation coefficients, with adjustment for days of accelerometer recording and with adjustment for body mass index, between various physical activity variables and $\dot{V}O_{2peak}$ in boys ($n = 246$).

Physical activity variable	Adjustment for days of accelerometer recording	Adjustment for body mass index
Total physical activity	0.16	0.17
Sedentary	0.00#	0.00#
Light physical activity	0.08#	0.06#
Moderate physical activity	0.28	0.28
Moderate-to-vigorous physical activity	0.27	0.27
Vigorous physical activity	0.15	0.16

Note: For all significant r-values, $P < 0.05$. #Values are not statistically significant.

Table III. Pearson correlation coefficients, with adjustment for days of accelerometer recording and with adjustment for body mass index, between various physical activity variables and $\dot{V}O_{2peak}$ in girls ($n = 222$).

Physical activity variable	Adjustment for days of accelerometer recording	Adjustment for body mass index
Total physical activity	0.06#	0.05#
Sedentary	−0.06#	−0.06#
Light physical activity	0.04#	0.04#
Moderate physical activity	0.14	0.14
Moderate-to-vigorous physical activity	0.13#	0.12#
Vigorous physical activity	0.07#	0.07#

Note: For all significant r-values, $P < 0.05$. #Values are not statistically significant.

Table IV. Regression summaries for boys ($n = 246$) with inclusion of body mass index into the model.

Value	β	Standard error of β	Accumulation of r^2	P-value
Total physical activity				
BMI	−0.32	0.06	0.10	< 0.001
TPA	0.18	0.06	0.13	< 0.001
Moderate physical activity				
BMI	−0.31	0.06	0.10	< 0.001
MPA	0.28	0.06	0.18	< 0.001
Moderate-to-vigorous physical activity				
BMI	−0.31	0.06	0.10	< 0.001
MVPA	0.26	0.06	0.17	< 0.001
Vigorous physical activity				
BMI	−0.31	0.06	0.10	< 0.001
VPA	0.14	0.06	0.12	0.02

Note: The dependent variable was $\dot{V}O_{2peak}$ per kilogram of body mass. The independent variables were number of days of accelerometer recordings, body mass (BMI), and total physical activity (TPA), moderate activity (MPA), moderate-to-vigorous (MVPA), or vigorous activity (VPA) per day.

index explained 18% of the variance in $\dot{V}O_{2peak}$ after adjustment for moderate physical activity. Table V provides a regression summary.

Discussion

The main finding of the present, population-based investigation was a weak positive relationship between accelerometer-measured daily physical activity variables (both volume of activity and activity of different intensities) and aerobic fitness in boys, with the exception of time in sedentary and light physical activity, which was not related to aerobic fitness. After adjustment for body mass index in the regression models, a modest 2–8% of the variance in $\dot{V}O_{2peak}$ could be explained by different physical activity variables in boys. In girls, only 2% of the variance in $\dot{V}O_{2peak}$ could be explained by moderate physical activity, which was the only activity variable that was related to $\dot{V}O_{2peak}$. One should be cautious when interpreting cross-sectional data, since such studies cannot differentiate cause and effect. Moreover, one has to keep in mind that $\dot{V}O_{2peak}$ is highly genetically determined (Bouchard et al., 1986), which was not investigated in the present study. Our finding that time in sedentary and light physical activity was not related to $\dot{V}O_{2PEAK}$ is, however, in agreement with the notion that physical activity of certain intensity is required to alter $\dot{V}O_{2PEAK}$. Our finding that physical activity was basically only related to aerobic fitness in boys is partly at odds with previous research (Butte, Puyau, Adolph, Vohra, & Zakeri, 2007; Dencker et al., 2006; Gutin, Yin, Humphries, & Barbeau, 2005). One can speculate whether there is a true difference between the sexes in the susceptibility of $\dot{V}O_{2peak}$ to physical activity at this age, or if our finding is related to differences in physical activity. In the present study, boys had 10% higher total physical activity levels, 32% higher moderate physical activity levels, 33% higher moderate-to-vigorous physical activity levels, and 22% higher vigorous physical activity levels, whereas no significant difference could be detected for time in sedentary and light physical activity. These differences in physical activity might possibly help to explain the differences in the relationship between physical activity and $\dot{V}O_{2peak}$. Moreover, the range for the activity parameters was substantial, as described by the significant standard deviations. The variation in activity was, however, larger in boys than in girls, which could also be a factor.

There are limited data on the relationship between objectively measured physical activity and $\dot{V}O_{2peak}$ measured directly from a maximal exercise test, in reasonably large populations of children. We have only been able to identify three previous investigations (Butte et al., 2007; Dencker et al., 2006; Gutin et al., 2005). Butte et al. (2007) studied 897 US children aged 4–19 years and found a weak correlation between $\dot{V}O_{2peak}$ and time spent performing vigorous physical activity ($r = 0.11$, $P < 0.01$) and total physical activity ($r = 0.15$, $P < 0.001$). Dencker et al. (2006) evaluated 228 Swedish children aged 8–11 years and reported a weak positive relationship between $\dot{V}O_{2peak}$ and total physical activity ($r = 0.23$ for both boys and girls, $P < 0.05$). When $\dot{V}O_{2peak}$ was related to vigorous physical activity, a tendency towards a stronger correlation was found ($r = 0.32$ for boys and $r = 0.30$ girls, $P < 0.05$). Gutin et al. (2005) investigated a US cohort of teenagers aged 16 years. They found a moderate correlation, for both sexes combined, between $\dot{V}O_{2peak}$ and moderate physical activity ($r = 0.30$, $P < 0.01$), but a stronger correlation between $\dot{V}O_{2peak}$ and vigorous physical activity ($r = 0.45$, $P < 0.001$). This should be compared with our findings of ($r = 0.15$–0.28, $P < 0.05$) in boys and ($r = 0.07$–0.14, all but one non-significant) in girls. These studies included children who were older than those who participated in the current study, with the exception of Butte et al. (2007), whose study included children and adolescents with a wide age-span. The possibility exists that older children adopt an adult-like pattern of physical activity once they become teenagers, with polarization into those who actively engage themselves in sports and those who do not. It is possible, therefore, that in studies of older children, the effect of training is studied, rather than the causal relationship between habitual activity and fitness. Additional aspects could be differences in accelerometer methodology. Dencker et al. (2006) and Gutin et al. (2005) both used the Actigraph with similar cut-off points. The accelerometer cut-off points selected in the present investigation to define the different physical activity intensities were higher than those used in the two previous investigations. Our definition of moderate physical activity corresponds more closely to the defintion of vigorous physical activity used by Dencker et al. (2006) and Gutin et al. (2005). Butte et al. (2007) used a completely

Table V. Regression summaries for girls ($n = 222$) with inclusion of body mass index into the model.

Value	β	Standard error of β	Accumulation of r^2	P-value
Moderate physical activity				
BMI	−0.42	0.06	0.18	<0.001
MPA	0.15	0.06	0.20	0.01

Note: The dependent variable was $\dot{V}O_{2peak}$ per kilogram of body mass. The independent variables were number of days of accelerometer recordings, body mass index (BMI), and moderate activity (MPA).

different accelerometer methodology, an Actiwatch with wrist placement, which makes comparison difficult.

Major strengths of the present investigation include the large urban population-based sample and the objective measurements. Direct measurement of $\dot{V}O_{2peak}$ is considered the optimal method, since all indirect measures of $\dot{V}O_{2peak}$ introduce errors (Dencker et al., 2008; Rowland, 1996), and therefore may dilute any existing relationship between daily physical activity and fitness. Furthermore, younger children tend to have a highly intermittent activity pattern (Bailey et al., 1995), and the use of a short epoch as in the present investigation should be an advantage in capturing short bursts of high activity (Nilsson, Ekelund, Yngve, & Sjöström, 2002). One disadvantage of using the shorter epoch is that the version of the Actigraph used in the present investigation could only record four consecutive days with an epoch of 10 s. Thus the cost of a higher time resolution is a shorter observation time.

There is no "gold standard" method for measuring daily physical activity. Accelerometers have in recent years gained popularity as an objective measurement device for daily physical activity, and represent a substantial improvement over self-reporting methods. However, accelerometers may have limitations. There is always the possibility of reactivity, although we mounted the accelerometer the day before it started to sample to minimize this. Furthermore, the accumulation of physical activity data over a couple of days' monitoring may not represent the true mean of the participants' physical activity levels, but only a rough estimate of a child's activity. However, Dencker and Andersen (2008) summarized 16 studies that had reported total physical activity data from the Actigraph. These studies included 11,202 children aged 2–16 years. Dencker and Andersen (2008) also summarized 23 studies that had reported differences between the sexes as measured by the Actigraph in 13,237 children and adolescents aged 2–18 years. The findings of the present study do not differ significantly from the findings in previous investigations, suggesting that the physical activity data in the present study are probably representative of children this age.

A critical issue is how to select cut-off points to define different activity intensities. There is no consensus regarding which cut-off points to use (Dencker & Andersen, 2008). There are several proposed cut-off points, and the range for defining the lower limit for various intensities is substantial. Validation studies have either included a limited number of children with a wide age span or included a reasonably large population with a narrow age span and they have been established predominantly in laboratory settings using treadmill exercise protocols. The age span in the validation studies of accelerometer cut-off points is perhaps not a major issue, as shown by a recent study by Reilly and co-workers (2008). Our selection of cut-off points was based on a combination of five different validation studies (Mattocks et al., 2007; Puyau et al., 2002; Sirard et al., 2005; Treuth et al., 2004; Trost et al., 1998), which appears a reasonable approach absent a conclusive and comprehensive validation study.

In conclusion, the objective data from this study are partly at odds with previous studies in older children and adolescents, all of which showed a weak-to-moderate relationship between physical activity and $\dot{V}O_{2peak}$. We found that the amount of physical activity was associated with aerobic fitness, albeit weakly, in boys. No such uniform relationship was detected in girls. The findings of the present investigation contribute, in part, to the knowledge base for more evidence-based public health policies.

Acknowledgement

Financial support for this study was provided by the Crafoord Foundation, the Swedish Heart and Lung Association, and grants from Lund University.

References

Andersen, L. B., & Haraldsdottir, J. (1993). Tracking of cardiovascular disease risk factors including maximal oxygen uptake and physical activity from late teenage to adulthood: An 8-year follow-up study. *Journal of Internal Medicine*, *234*, 309–315.

Anderssen, S. A., Cooper, A. R., Riddoch, C., Sardinha, L. B., Harro, M., Brage, S., et al. (2007). Low cardiorespiratory fitness is a strong predictor for clustering of cardiovascular disease risk factors in children independent of country, age and sex. *European Journal of Cardiovascular Prevention and Rehabilitation*, *14*, 526–531.

Armstrong, N., & Welsman, J. R. (2000). Aerobic fitness. In N. Armstrong & W. Van Mechelen (Eds.), *Paediatric exercise science and medicine* (pp. 173–182). Oxford: Oxford University Press.

Bailey, R. C., Olson, J., Pepper, S. L., Porszasz, J., Barstow, T. J., & Cooper, D. M. (1995). The level and tempo of children's physical activities: An observational study. *Medicine and Science in Sports and Exercise*, *27*, 1033–1041.

Baquet, G., Stratton, G., Van Praagh, E., & Berthoin, S. (2007). Improving physical activity assessment in prepubertal children with high-frequency accelerometry monitoring: A methodological issue. *Preventive Medicine*, *44*, 143–147.

Bouchard, C., Lesage, R., Lortie, G., Simoneau, J. A., Hamel, P., Boulay, M. R., et al. (1986). Aerobic performance in brothers, dizygotic and monozygotic twins. *Medicine and Science in Sports and Exercise*, *18*, 639–646.

Butte, N. F., Puyau, M. R., Adolph, A. L., Vohra, F. A., & Zakeri, I. (2007). Physical activity in nonoverweight and overweight Hispanic children and adolescents. *Medicine and Science in Sports and Exercise*, *39*, 1257–1266.

Dencker, M., & Andersen, L. B. (2008). Health related aspects of objectively measured daily physical activity in children. *Clinical Physiology and Functional Imaging*, *28*, 133–144.

Dencker, M., Thorsson, O., Karlsson, M. K., Lindén, C., Eiberg, S., Wollmer, P., et al. (2007). Gender differences and determinants of aerobic fitness in children aged 8–11 years. *European Journal of Applied Physiology*, *99*, 19–26.

Dencker, M., Thorsson, O., Karlsson, M. K., Lindén, C., Svensson, J., Wollmer, P., et al. (2006). Daily physical activity and its relation to aerobic fitness in children aged 8–11 years. *European Journal of Applied Physiology*, *96*, 587–592.

Dencker, M., Thorsson, O., Karlsson, M. K., Lindén, C., Wollmer, P., & Andersen, L. B. (2008). Maximum oxygen uptake versus maximum power output in children. *Journal of Sports Sciences*, *26*, 1397–1402.

Duke, P. M., Litt, I. F., & Gross, R. T. (1980). Adolescents' self-assessment of sexual maturation. *Pediatrics*, *66*, 918–920.

Eiberg, S., Hasselstrom, H., Gronfeldt, V., Froberg, K., Cooper, A., & Andersen, L. B. (2005a). Physical fitness as a predictor of cardiovascular disease risk factors in 6- to 7-year-old Danish children: The Copenhagen School Child Intervention Study. *Pediatric Exercise Science*, *17*, 55–64.

Eiberg, S., Hasselstrom, H., Gronfeldt, V., Froberg, K., Svensson, J., & Andersen, L. B. (2005b). Maximum oxygen uptake and objectively measured physical activity in Danish children 6–7 years of age: The Copenhagen School Child Intervention Study. *British Journal of Sports Medicine*, *39*, 725–730.

Ekelund, U., Sjostrom, M., Yngve, A., Poortvliet, E., Nilsson, A., Froberg, K., et al. (2001). Physical activity assessed by activity monitor and doubly labeled water in children. *Medicine and Science in Sports and Exercise*, *33*, 275–281.

Gutin, B., Yin, Z., Humphries, M. C., & Barbeau, P. (2005). Relations of moderate and vigorous physical activity to fitness and fatness in adolescents. *American Journal of Clinical Nutrition*, *81*, 746–750.

Hansen, S. E., Hasselstrom, H., Gronfeldt, V., Froberg, K., & Andersen, L. B. (2005). Cardiovascular disease risk factors in 6–7-year-old Danish children: The Copenhagen School Child Intervention Study. *Preventive Medicine*, *40*, 740–746.

Hasselstrøm, H., Hansen, S. E., Froberg, K., & Andersen, L. B. (2002). Physical fitness and physical activity during adolescence as predictors of cardiovascular disease risk in young adulthood. Danish Youth and Sports Study: An eight-year follow-up study. *International Journal of Sports Medicine*, *23* (suppl. 1), S27–S31.

Hasselstrøm, H., Karlsson, K. M., Hansen, S. E., Grønfeldt, V., Froberg, K., & Andersen, L. B. (2007). Peripheral bone mineral density and different intensities of physical activity in children 6–8 years old: The Copenhagen School Child Intervention Study. *Calcified Tissue International*, *80*, 31–38.

Hasselstrøm, H., Karlsson, K. M., Hansen, S. E., Grønfeldt, V., Froberg, K., & Andersen, L. B. (2006). Sex differences in bone size and bone mineral density exist before puberty: The Copenhagen School Child Intervention Study (CoSCIS). *Calcified Tissue International*, *79*, 7–14.

Kohl, H. W., III, Fulton, J. E., & Caspersen, C. J. (2000). Assessment of physical activity among children and adolescents: A review and synthesis. *Preventive Medicine*, *31*, S54–S76.

Mattocks, C., Leary, S., Ness, A., Deere, K., Saunders, J., Tilling, K., et al. (2007). Calibration of an accelerometer during free-living activities in children. *International Journal of Pediatric Obesity*, *2*, 218–226.

Nilsson, A., Ekelund, U., Yngve, A., & Sjöström, M. (2002). Assessing physical activity among children with accelerometers using different time sampling intervals and placements. *Pediatric Exercise Science*, *14*, 87–96.

Puyau, M. R., Adolph, A. L., Vohra, F. A., & Butte, N. F. (2002). Validation and calibration of physical activity monitors in children. *Obesity Research*, *10*, 150–157.

Reilly, J. J., Penpraze, V., Hislop, J., Davies, G., Grant, S., & Paton, J. Y. (2008). Objective measurement of physical activity and sedentary behaviour: Review with new data. *Archives of Disease in Childhood*, *93*, 614–619.

Riddoch, C. J., Andersen, L. B., Wedderkopp, N., Harro, M., Klasson-Heggebø, L., Sardinha, L. B., et al. (2004). Physical activity levels and patterns of 9- and 15-year-old European children. *Medicine and Science in Sports and Exercise*, *36*, 86–92.

Rowland, T. W. (1996). *Developmental exercise physiology*. Champaign, IL: Human Kinetics.

Sallis, J. F., & Saelens, B. E. (2000). Assessment of physical activity by self-report: Status, limitations and future directions. *Research Quarterly for Exercise and Sport*, *71*, 1–14.

Sirard, J. R., Trost, S. G., Pfeiffer, K. A., Dowda, M., & Pate, R. P. (2005). Calibration and evaluation of an objective measure of physical activity in preschool children. *Journal of Physical Activity and Health*, *2*, 345–357.

Steele, R. M., Brage, S., Corder, K., Wareham, N. J., & Ekelund, U. (2008). Physical activity, cardiorespiratory fitness, and the metabolic syndrome in youth. *Journal of Applied Physiology*, *105*, 342–351.

Treuth, M. S., Schmitz, K., Catellier, D. J., McMurray, R. G., Murray, D. M., Almeida, M. J., et al. (2004). Defining accelerometer thresholds for activity intensities in adolescent girls. *Medicine and Science in Sports and Exercise*, *36*, 1259–1266.

Trost, S. G. (2001). Objective measures of physical activity with youth: Current issues, future directions. *Exercise and Sport Sciences Reviews*, *29*, 32–36.

Trost, S. G., Ward, D. S., Moorehead, S. M., Watson, P. D., Riner, W., & Burke, J. R. (1998). Validity of the Computer Science and Applications (CSA) activity monitor in children. *Medicine and Science in Sports and Exercise*, *30*, 629–633.

Trudeau, F., Shephard, R. J., Arsenault, F., & Laurencelle, L. (2003). Tracking of physical fitness from childhood to adulthood. *Canadian Journal of Applied Physiology*, *28*, 257–271.

Twisk, J. W., Kemper, H. C., & van Mechelen, W. (2002). The relationship between physical fitness and physical activity during adolescence and cardiovascular disease risk factors at adult age: The Amsterdam Growth and Health Longitudinal Study. *International Journal of Sports Medicine*, *23* (suppl. 1), S8–S14.

US Department of Health and Human Services. (1996). *Physical activity and health: A report of the Surgeon General*. Atlanta, GA: US Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Chronic Disease Prevention and Health Promotion.