Health related aspects of objectively measured daily physical activity in children

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Summary

It is well established that physical inactivity in adults is associated with increased mortality and morbidity. Whether daily physical activity level is related to risk factors for cardiovascular disease in children has been debated. Furthermore, objective data on the habitual daily physical activity in children have at large been scare in the literature. The main reason for this is the fact that daily physical activity is very difficult to measure in children. A new device, the accelerometer, has in recent years emerged as a frequently used instrument for the measurement of daily physical activity. This paper summarizes recently published studies that have used accelerometers to measure daily physical activity in children and related activity data to known risk factors for cardiovascular disease.

Introduction

The genetic constitution of human beings has remained virtually the same over thousands and thousands of years (Torroni et al., 2006), whereas the living conditions for children and adults in the western world have changed dramatically. Daily physical activity was in pre-modern society a natural part of daily life and also a necessity for survival. This is no longer true in modern western society. Evidence of the health implications associated with lack of physical activity among children is constantly growing. Physical activity is, however, very difficult to measure and there is no gold standard measurement for daily physical activity. Wide ranges of self-report methods are most commonly used in health research because of their low cost and ease of administration. This is problematic because they are known to have limited accuracy in the measurement of daily physical activity in subjects of all ages and are considered inappropriate to use in children under the age of 10-12 years (Kohl et al., 2000; Harro & Riddoch, 2000; Sallis & Saelens, 2000). An increasing number of investigators have in recent years used a new device, the accelerometer, to obtain measurements of body movements per se (volume, intensity, and frequency) and relate it to various health parameters. The purpose of this paper is to evaluate health related aspects of daily physical activity as measured by accelerometry in children.

Objective measurement of daily physical activity with accelerometers

Accelerometers have in recent years gained popularity as an objective measurement device for daily physical activity. There are several different models. The first commonly used accelerometer was the single plane, rather bulky (7 x 7 x 2 cm), Caltrac accelerometer (Freedson & Miller, 2000). The by far most commonly used accelerometer in physical activity studies is the Actigraph (also called MTI, CSA or WAM). The Actigraph has a rather small size (5 x 4 x 1.5 cm) and low weight (about 40 g) (ActiGraph LLC, Pensacola, FL, USA).

Additional accelerometers that have been used in physical activity studies are the Actiwatch and the Actical (Mini Mitter Co, Bend OR, USA). Both are small and light, Actiwatch has a weight of 16 g and a size of 2.8 x 2.7 x 1 cm and the Actical has a weight of 17 g and a size of 2.8 x 2.7 x 1 cm. There is also the tri-plane older Tritrac, now superseded by the RT3 accelerometer (Stayhealthy Inc., Monrovia, CA, USA). The RT3 accelerometer is bigger and heavier than the single-plane accelerometers with a weight of 65 g and a size of 7.1 x 5.6 x 2.8 cm. By far the best validated accelerometer is the Actigraph that has been well validated in children and adolescents against a range of outcomes (Freedson et al., 1997; Trost et al., 1998; Eston et al. 1998; Louie et al., 1999; Rowlands et al., 1999; Trost et al., 2000; Ekelund et al., 2001; Nilsson et al., 2002; Puyau et al., 2002; Brage et al., 2003a; Eisenmann et al., 2004; Treuth et al., 2004; Trost et al., 2006; Mattocks et al., 2007a,b). An obvious limitation with accelerometers for measurement of physical activity in children is the fact that the child knows that he or she is monitored. There is always the possibility of reactivity, i.e. that the child changes his or hers natural physical activity behaviour because of the monitoring. Needless to say, the accumulation of physical activity over a couple of monitored days may not represent the true mean of the subject, but only give a rough estimate of a child’s daily physical activity. There is also a substantial intra-individual variation in physical activity (Mattocks et al., 2007a). Accelerometer-measured physical activity represents a substantial improvement compared to self-report methods, although accelerometers may have limitations. A critical issue is how to select cut-off points to define different activity intensities. There is no consensus of which cut-off points to use (Freedson et al., 2005). There are several proposed cuff-off points (Freedson et al., 1997; Trost et al., 1998; Eston et al., 1998; Puyau et al., 2002; Treuth et al., 2004; Mattocks et al., 2007b), and the range for defining the lower limit for various intensities is substantial. For example the lower limit for defining moderate activity ranges approximately from 500 to 3500 counts/minute (Freedson et al., 2005;

Mattocks et al., 2007b). Validation studies have either included a limited number of children with a large age span or included a reasonably large population but with a narrow age span. Moreover, they have been established predominantly in laboratory settings using treadmill exercise protocols. The predictive value of three different equations was recently evaluated (Trost et al., 2006), and this investigation added support for the cut-off points proposed by Freedson et al. (1997) and those by Trost et al. (1998). The authors concluded, however, that additional validation studies were urgently needed to develop more precise prediction equations for free-living children. There are also possible technical and physiological limitations with accelerometers. For example intra-accelerometer variability may exist, which may cause poor accuracy in the physical activity assessment (Brage et al., 2003b). Calibration of all accelerometers should be done to eliminate this potential source of error. In addition, accelerometers underestimate activity during activities that involve a minimal vertical displacement of the body, as for example skating, weight-lifting or cycling. Also, accelerometers may underestimate high activity because of a linear relation to differences in speed during walking, but not during running (Brage et al., 2003a; Brage et al., 2003b). The main reason for counts to level off when speed is increased over 10 km/h is that vertical accelerations is only slightly increased and increase in speed is mainly reflected in increased horizontal acceleration. One could argue that this would less affect multi-plane accelerometers in comparison with single-plane, but a validation study by Eston and co-workers (Eston et al., 1998) shows very modest differences. Also, Trost and co-workers reviewed the literature recently and argued that there were no significant differences in the measuring capacity of single-plane versus multi-plane accelerometers (Trost et al., 2005). An epoch is the time that the accelerometer averages physical activity data over, thus the time resolution of the measurement. Children of younger age tend to have a highly intermittent activity pattern (Bailey et al., 1995), and the use of a short epoch could be of advantage to capture short bursts of high activity. A validation study with the Actigraph has shown that minutes of high activity are substantially underestimated when using longer epoch time, i.e. one-minute epoch (Nilsson et al., 2002). One limitation of using the shorter epoch is that the older versions of the Actigraph could only record four consecutive days with an epoch of 10 sec, thus the price for a higher time resolution is a shorter observation time. There are newer versions on the market that have increased memory capacity and can record for more than one week with high time resolution (epoch between 5-10 sec). Perhaps obvious, but accelerometers are capable of detecting acceleration in the vertical direction caused by body movements, nothing can be said if these body movements have been performed by spontaneous physical activity or in an organized fashion by for example sports participation.

How active are children?

Many reports have assessed physical activity of children with the use of accelerometers (Pate et al., 2002; Trost et al., 2002; Janz et al., 2002; Santos et al., 2003; Jackson et al., 2003; Pate et al 2004; Reilly et al., 2004; Riddoch et al., 2004; Kelly et al., 2005; Janz et al., 2005; Eiberg et al., 2006; Tremblay et al., 2006; Trayers et al., 2006; Dencker et al., 2006c; Pate et al., 2006; Reilly et al., 2006; Butte et al., 2007; Riddoch et al., 2007; Rizzo et al., 2007; Kristensen et al., 2007; Kelly et al., 2007; Hussey et al., 2007; Metallinos-Katsaras et al., 2007; Lopes et al., 2007). It is difficult to compare studies since they have used different accelerometers, different measurement protocols and have analysed data in different ways. Furthermore, as there is no consensus how to define intensities, most studies have defined moderate physical activity (MPA) as between 3-6 metabolic equivalents (METs), vigorous physical activity (VPA) above 6 METS, and moderate to vigorous physical activity (MVPA) above 3 METs. In general, younger children tend to be very active, boys are more active than girls, and physical activity decreases through the teenage years.

Table 1 summarises the findings from selected studies that have used the Actigraph and reported general physical activity (GPA) in mean counts/min, which is a reasonably robust parameter that is not affected by epoch length. The highest values for GPA come from reports in younger children (aged 4-6 years) and consistently lowest values for teenagers.

Riddoch et al. (2004) reported accelerometer data from 2185 children aged 9 and 15 years in four different countries (Denmark, Portugal, Estonia and Norway) in the European Youth Heart Study (EYHS). This data also highlight one of the problems with the accelerometer, because Denmark had the lowest mean count, but the highest fitness level, which may be explained by the extensive use of the bicycle in Denmark. Riddoch et al. (2007) reported accelerometer data for 5595 boys and girls aged 11 years that participated in the Avon Longitudinal Study of Parents and Children (ALSPAC). There are similarities between these report and the findings from other studies of children with similar age, when it comes to GPA (Dencker et al., 2006; Trayers et al., 2006; Tremblay et al., 2006; Kristensen et al., 2007), suggesting a rather similar physical activity level in children and adolescents of the Western World.

The United Kingdom Expert Consensus Group proposed that each child should accumulate at least 60 minutes of activity of at least moderate intensity each day (Cavill et al., 2001). Compliance with these activity guidelines has been evaluated in several studies (Santos et al., 2003; Pate et al., 2002; Riddoch et al., 2004; Tremblay et al., 2006; Trayers et al., 2006; Dencker et al., 2006c; Pate et al., 2006; Lopes et al., 2007; Riddoch et al., 2007), although these guidelines have no evidence base (Twisk, 2001). Two smaller studies (Santos et al., 2003; Trayers et al., 2006) reported that almost all children fulfilled the recommendations for daily physical activity set by the United Kingdom Expert Consensus Group (Cavill et al., 2001). Trayers and co-workers evaluated 41 children aged 10 years from the most deprived areas of Bristol, UK and and reported that all children fulfilled the guideline. Santos et al. (2003) investigated 157 Portuguese children aged 8-16 years and reported that all children, with the exception of girls aged 11-13 years meet the guidelines. In a US population of 375 children aged 7-16 years (Pate et al., 2002), 90-100% of the younger children (aged 7-10 years) were found to fulfil the guidelines by Cavill et al. (2001), whereas considerably lower fulfilment rate (25-60%) were reported for the older children (12-16 years). Similar findings were reported in the EYHS (Riddoch et al., 2004), where 97-98% of children aged 9 fulfil the guidelines, while the corresponding findings for the older children aged 15 years were 62% (girls) and 82% (boys). Tremblay et al. (2006) investigated 399 children aged 8-13 years from a mixed Canadian study-population that consisted of Old Order Mennonites, Urban children, and Rural children, and 97% of the children were found to fulfil the guidelines by Cavill et al. (2001). In a similar age population (aged 8-11 years) of urban Swedish children, Dencker et al. (2006c) found that 100% of the boys and girls fulfilled these guidelines. The Trial of Activity for Adolescent Girls (TAAG) consisted of US girls only (Pate et al., 2006), 79-95% and 80-90% of the girls fulfilled the guidelines depending on geographic location and ethnicity. Lopes et al. (2007) evaluated 503 urban subjects aged 6-18 years from northern Portugal, and all age-groups were found to fulfil the guidelines. All previously mentioned studies have used similar cut-off points (Freedson et al., 1997; Trost et al., 1998) and similar intensity threshold to define MVPA (3 METs).

A very different finding was reported from the ALSPAC study (Riddoch et al., 2007), only 5% of the boys and 0.4% of the girls fulfil the guidelines. This could be explained by a combination of selecting 4 METs instead of 3 METs as cut-off for MVPA combined with a considerably higher accelerometer cut-off points to define this intensity threshold in comparison with previous studies (Mattocks et al., 2007b). It should be mentioned that the selection of 3 or 4 METs as appropriate intensity cut-off points for health is arbitrary. Furthermore, the selections of accelerometer cut-off points for these intensities are far from straightforward as previously mentioned. Three studies (Trayers et al., 2006; Guinhouya et al., 2006; Pate et al., 2006) have evaluated compliance with the 60 min/day MVPA guideline using the most commonly used cut-off points, proposed by Freedson et al. (1997) and those by Trost et al. (1998), and the considerably higher cut-off points suggested by Puyau et al. (2002) or Treuth et al. (2004). Their finding was hardly surprising, if using higher cut-off points for MVPA then the percentage of children fulfilling guidelines will drop dramatically. The debate of appropriate accelerometer cut-off point for children this age will without any doubt continue for some time.

The evidence is conlusive that boys are more active than girls disregarding age, geografic location and ethnicity (Trost et al., 2002; Janz et al., 2002; Santos et al., 2003; Jackson et al., 2003; Pate et al., 2004; Reilly et al., 2004; Riddoch et al., 2004; Kelly et al., 2005; Eiberg et al., 2006; Tremblay et al., 2006; Trayers et al., 2006; Dencker et al., 2006c; Reilly et al., 2006; Rizzo et al., 2007; Butte et al., 2007; Riddoch et al., 2007; Kristensen et al., 2007; Kelly et al., 2007; Hussey et al., 2007; Metallinos-Katsaras et al., 2007; Lopes et al., 2007). Gender differences in GPA, MVPA, and VPA vary between studies, but the gender differences tend to be bigger for VPA compared to GPA, MPA and MVPA. Several studies have evaluated gender differences in physical activity of very young children, aged 2-7 years (Janz et al., 2002; Jackson et al., 2003; Pate et al., 2004; Reilly et al., 2004; Kelly et al., 2005; Eiberg et al., 2006; Reilly et al., 2006; Kelly et al., 2007; Metallinos-Katsaras et al., 2007). Gender differences in physical activity of children aged 8-13 years have also been evaluated (Dencker et al., 2006c; Tremblay et al., 2006; Trayers et al., 2006; Hussey et al., 2007; Riddoch et al., 2007). There are also additional reports of gender differences in physical activity from cohorts with a mixed age-span (Trost et al., 2002; Santos et al., 2003; Riddoch et al., 2004; Rizzo et al., 2007; Butte et al., 2007; Kristensen et al., 2007; Lopes et al., 2007). Table 2 summarises the findings from selected studies that have used the Actigraph and reported gender differences in physical activity.

Physical activity consistently changes with age, where teenagers are substantially less active compared to younger children. It seems that the physical activity increases from age 3 to 4 years (Jackson et al., 2003), from 3 to 5 years (Reilly et al., 2004), from 4 to 6 years (Kelly et al., 2007), and from 5 to 8 years (Janz et al., 2005). In contrast, cross-sectional data indicate a steady decline in physical activity from age 7 up to age 18 (Trost et al., 2002; Santos et al., 2003; Riddoch et al., 2004; Thompson et al., 2005; Butte et al., 2007; Lopes et al., 2007; Rizzo et al., 2007). Only one longitudinal study has evaluated physical activity at age 10 and at 16 years (Kristensen et al., 2007). Kristensen et al. (2007) evaluated GPA in 96 boys and 112 girls, from Denmark, at age 10 and 16 years. The drop in GPA was 31 % for boys and 34 % for girls. This is to our knowledge the only longitudinal study so far that has followed accelerometer measured physical activity from childhood into teenage years. Some longitudinal studies have reported tracking data (Jackson et al., 2003; Janz et al., 2005; Kelly et al., 2007; Kristensen et al., 2007). Tracking coefficients varies from low-moderate to moderate. Jackson et al. (2003) reported r=0.40 for GPA over one year. Janz et al. (2005) reported coefficients of r=0.18 to 0.39 over three years. Kelly et al. (2007) reported r=0.35 for GPA and r=0.37 for MVPA over two years. Kristensen et al. (2007) found for GPA r=0.53 in boys and r=0.48 in girls over six years, this was however after adjustment for seasonality and day-to-day variation.

It can be concluded that accelerometers have successfully been used in numerous field-based studies in children of various ages, ethnical groups and geographic locations. This sets a solid foundation to monitor secular trends in physical activity on a population-base.

Physical activity and body fat

The prevalence of obesity among children and adolescents is increasing rapidly (Steinbeck, 2001; Dietz, 2004; Slyper, 2004; Ekblom et al., 2004; Mårild et al., 2004; Neovius et al., 2006). This represents a substantial present and future public health problem. Obese children and adolescents have increased risk of developing adult obesity (Mossberg, 1989; Whitaker et al., 1997) and are more likely to experience significant short and long-term health problems such as cardiovascular disease (CVD), hyperlipidemia, hypertension, glucose intolerance, type 2 diabetes, psychiatric disorders and orthopaedic complications (Kiess, 2001; Miller et al., 2004). Lack of physical activity is hypothesized to be associated with childhood obesity by several authors (Molnar et al., 2000; Kiess, 2001; Steinbeck, 2001; Slyper, 2004; Miller et al., 2004). The relationship between physical activity, measured by accelerometers, and body fat content, by various methods, has been evaluated in several recent studies (Trost et al., 2001; Ekelund et al., 2002; Janz et al., 2002; Trost et al., 2003; Moore et al., 2003; Abbott and Davies, 2004; Stevens et al., 2004; Ekelund et al., 2004; Treuth et al., 2005; Thompson et al., 2005; Gutin et al., 2005; Janz et al., 2005; Dencker et al., 2006a; Lohman et al., 2006; Ruiz et al., 2006; Butte et al., 2007; Hussey et al., 2007; Ness et al., 2007; Metallinos-Katsaras et al., 2007).

The largest cross-sectional reports of accelerometer and obesity-related data come from the Physical Activity in Children and Youth (PACY) study (Thompson et al., 2005), the EYHS (Ekelund et al., 2004), the TAAG (Lohman et al., 2006), and the ALSPAC (Ness et al., 2007).

Thompson et al. (2005) evaluated 1653 Canadian children aged 8, 12 or 16 years. A clear graded decline in GPA could be detected for children, disregarding age, with overweight or at risk for overweight compared to normal weight children. Thompson et al. (2005) only used BMI to define obesity status. Lohman et al. (2006) reported from the TAAG cohort (1553 girls aged 12) a correlation between percent body fat (BF%) vs. MVPA ($r=-0.16$) and VPA ($r=-0.19$), $P<0.002$ for both. A similar finding was reported for the ALSPAC study (Ness et al., 2007), where total body fat (TBF) was measured by dual-energy X-ray absorptiometry (DXA) and related to GPA and MVPA. A clear negative association was found between total TBF and MVPA ($r=0.25$, $P<0.01$), after controlling for puberty status, anthropometric variables, TV viewing, and social factors. In contrast, time performing MVPA correlated only weakly with BMI, only 0.5% of the variance in BMI could be explained by daily accumulation of MVPA, after adjustment for gender, study location, birth weight, maturity, and parental BMI (Ekelund et al., 2004). A plausible explanation for the fact that the EYHS study showed a much lower correlation between obesity status and activity could be the fact that body fat was measured directly in the ALSPAC (Ness et al., 2007), or indirectly by skinfold-method (Lohman et al., 2006), instead of using BMI as a surrogate.

Treuth et al. (2005) reported cross-sectional data from 229 rural US boys and girls, aged 7 to 19 years. In this study no relation was detected between body fat measured by bioelectrical impedance and GPA, MPA or VPA. In contrast, Butte et al. (2007) reported from the VIVA LA FAMILIA Study, 897 children aged 4-19 years, a weak relation between BF% measured by DXA and GPA (r=-0.13, P<0.001), MPA (-0.07, P<0.05), but not for VPA (-0.03, ns). Gutin et al. (2005) investigated an urban US cohort with a narrow age span (aged 16 years), with use of accelerometers and DXA. This study found a correlation between TBF vs. MPA (r=-0.19, P<0.01) and VPA (r=-0.34, P<0.001). A report of a small study, 47 younger children aged 5-10 years, supports the view that the intensity of activity is of importance when addressing possible links between physical activity and body fat (Abbott and Davies, 2004). In this study time spent in MPA 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, P<0.05). Moreover, Dencker et al. (2006a) reported DXA and accelerometer data for 229 children, aged 8-11 years. Univariate relationships between VPA vs. BF% and TBF were r=-0.38 and r=-0.34, P<0.05. MPA displayed no such relationships (r=-0.07 and r=0.09, both ns). Both these studies highlight the importance of intensity of activity since no relations were observed between MPA and body fat measurements, whereas such relations were detected in both studies for VPA. Furthermore, a report from Ruiz et al (2006) gives additional support for a relationship between body fat (by skinfold technique) and accelerometer measured physical activity, and also for the intensity aspect. Ruiz et al (2006) found that only VPA was associated with the sum of 5 skinfold thickness, whereas MPA and MVPA were not linked to it.

There are also, in addition to previosly mention studies, several case-controll studies that have shown that obese children are less active compared to normal-weight controll children (Trost et al., 2001; Ekelund et al., 2002; Trost et al., 2003; Metallinos-Katsaras et al., 2007).

Combining all these report gives a rather uniform picture that there is a low to moderate relationship between physical activity and body fat. It is not surprising that associations are weak, because obesity develops over many years and physical activity measurement rarely include more than one week of measurements. The cross-sectional design of all these studies precludes inferring a causal relationship between daily physical activity and obesity status. Thus, the lower activity profile exhibited by children with higher percentage body fat relative to their counterparts with lower percentage body fat may have been the consequence of obesity and not its cause, however, there are good biological plausible mechanisms to support that inactivity could be one of the causes of obesity.

Longitudinal studies include The IOWA Bone Development Study that investigated children from age 5.6 to 8.6 years (Janz et al., 2002; Janz et al., 2005). Janz and co-workers reported cross-sectional (Janz et al., 2002) and longitudinal (Janz et al., 2005) DXA and accelerometer data for 467 and 379 children, respectively. The children were on average 5.6 years old in the cross-sectional investigation and 8.6 years at follow-up. Their findings in the first, cross-sectional, investigation were univariate relationships between BF% vs. GPA and VPA (r=-0.19 and r=-0.26 for boys and r=-0.25 and r=-0.30 for girls, all P<0.01), and between TBF vs. GPA and VPA (r=-0.15 and r=-0.22 for boys and r=-0.19 and r=-0.25 for girls, P<0.05). No relations were found between MVPA vs. BF% or TBF. In the follow-up they reported that children who were in the lowest quartile for rate of BF% increase had slightly more daily accumulation of VPA (3 min) compared to the other three quartiles. Another longitudinal study, with physical activity assessed with the Caltrac accelerometer for 3-5 days, added support for the hypothesis that daily physical activity is involved in accumulation of body fat, assessed by anthropometric methods (Moore et al., 2003). This was part of the Framingham Children's Study, where 103 children were followed from age 4 to 11 yrs and the highest activity tertile had consistently lower BMI and sum of skinfolds. Similar findings were reported in a 3-year follow-up study of 454 American Indian children, where physical activity assessed with accelerometer on a single day was associated with bioelectric impedance assessed body fat and sum of skinfolds (Stevens et al., 2004).

Even if physical activity is only one of the factors linked to obesity, it is presumably one that could be modified, by various types of interventions aiming to expose children to increased physical activity. Also, the fact that the relation between activity and body fat is displayed at an early age indicates the importance of early intervention. However, various types of intervention studies in the past have shown very bleak results (Summerbell et al., 2005; Reilly et al., 2006; Lazaar et al., 2007). A major limitation of several studies is that only one parameter was usually studied, i.e. physical activity. Other factors that may contribute to obesity, such as dietary, birth weight (Rogers et al., 2006) or genetic factors (Dowda et al., 2001) were usually not studied. Reasonably exact estimate of dietary habits in large groups of younger children is very difficult to obtain (Montgomery et al., 2005; Winkler, 2005), and has therefore not been attempted in many investigations. It is, however, known that physical activity is not only about expending energy intake, there are also numerous endocrine and metabolic effects of physical activity (Froberg & Andersen, 2006).

Physical activity and aerobic fitness

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. Low aerobic fitness has, in adults, been shown to be a strong predictor for a variety of diseases and all causes of death (U.S. Department of Health and Human Services, 1996). Low aerobic fitness has, in children, been associated with risk factors for CVD (U.S. Department of Health and Human Services, 1996; Eiberg et al., 2005a; Anderssen et al., 2007). Aerobic fitness has been shown to track from childhood into adulthood (Andersen & Haraldsdottir, 1993; Twisk et al., 2002; Trudeau et al., 2003), 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 (Twisk et al., 2002; Hasselström et al., 2002). A positive relationship between physical activity and aerobic fitness is established in adults (U.S. Department of Health and Human Services, 1996), but if a similar relationship exists in children has been debated. Several recent reports have addressed this issue (Rowlands et al., 1999; Hansen et al., 2005; Eiberg et al., 2005b; Dencker et al., 2006b; Ruiz et al., 2006; Hussey et al., 2007; Butte et al., 2007).

In one small study 34 children, aged 8-10 years, were evaluated with Tritrac-accelerometers for six days and fitness was evaluated on a treadmill test without measurement of maximum oxygen uptake (Rowlands et al., 1999). The authors reported a high correlation between physical activity and endurance time on treadmill test ($r=0.66$, $P<0.05$). Such strong relationship has not been found in subsequent studies. In contrast, Hussey et al. (2007) evaluated 152 children aged 7-10 years, and found a correlation between time spent performing VPA and VO_{2PEAK} estimated from a 20 m multistage running test in combined analysis of both genders ($r=0.23$, $P<0.01$). This relation failed to reach significance when boys and girls were analysed separately. Butte et al. (2007) reported from 897 children, aged 4-19 years, a correlation between VO_{2PEAK}, measured by indirect calorimetry from a maximal exercise test, versus time spent performing VPA ($r=0.11$, $P<0.01$) and for GPA ($r=0.15$, $P<0.001$). Dencker et al. (2006b) evaluated 228 children, aged 8 to 11 years, with a maximal exercise test and VO_{2PEAK} measured by indirect calorimetry. A positive relation was found between VO_{2PEAK} and GPA ($r=0.23$ for both boys and girls, $P<0.05$). When VO_{2PEAK} was related to VPA, a tendency to a stronger correlation was found ($r=0.32$ for boys and $r=0.30$ girls, $P<0.05$). Two recent cross-sectional studies support this finding. Copenhagen School

Child Intervention Study evaluated almost 700 Danish children aged 6-7 years (Hansen et al., 2005; Eiberg et al., 2005b). VO_{2PEAK} by indirect calorimetry was associated weakly to GPA ($r = 0.12$, $P<0.05$), and better to number of 5 minutes bouts above 2000 counts/min ($r = 0.24$, $P<0.05$). Ruiz and co-workers reported, from 780 children aged 9-10 years, a graded relationship between VPA and aerobic fitness without direct measurement of VO_{2PEAK} (Ruiz et al., 2006). Children that performed less than 18 minutes of VPA per day had lower fitness compared with children who performed more. However, the fitness levels continue to increase with even higher daily accumulation of VPA.

The objective data from all these studies strongly imply that the amount of physical activity in childhood is associated with aerobic fitness, albeit weakly. There is always a possibility that when children become teenagers they adopt an adult-like pattern of physical activity with polarisation into those who actively engage themselves in sports and those who do not. It is therefore possible that in studies of older children, the effect of training, rather than the causal relationship between habitual activity and fitness is studied.

Physical activity and combined risk factors for CVD

It is well established that patients with type 2 diabetes mellitus have a much higher risk of CVD (Davidson, 2007). Moreover, an important underlying mechanism of type 2 diabetes is development of insulin resistance, which is characterized by high insulin concentrations (Ten & Maclaren, 2004). Previous studies using accelerometers in large-scale paediatric populations have given diverging results concerning possible relation between various indices of insulin resistance and physical activity. In the report from The EarlyBird Study (Murphy et al., 2004), no relation was found between total physical activity and Log Homeostasis assessment model-insulin resistance (HOMA-IR) in 307 children with an average age of five.

In contrast, Brage and co-workers (Brage et al., 2004c) reported in children of the Danish part of EYHS with an average age of 9.7 years, an inverse relationship between activity (GPA) and insulin concentrations in girls, but not in boys. Despite the large sample size, 310 girls and 279 boys, no relationship between activity and insulin concentrations could be found among boys. In further analysis from the Danish part of EYHS (Brage et al., 2004b), Z score of several risk factors (Insulin, HDL, LDL, Triglycerides, systolic and diastolic BP, and sum of skinfolds) was constructed. Aggregation of negative Z score were found in declining quartiles of physical activity. This study also incorporated fitness, and aggregation of negative Z score were present in both low and high fit children. It was, however, most pronounced in the low fit group suggesting that any beneficial effect of physical activity may be most pronounced in this group. Moreover, Ekelund et al. (2007) found in pooled data (n=1709) from the EYHS an association between clustering of risk factors for CVD (Waist circumference, Insulin, HDL, Triglycerides, systolic and diastolic BP) and physical activity, and this association was in further analysis independent of adiposity. Rizzo et al. (2007) investigated 273 boys and girls aged 10 and 256 adolescents aged 16 years, and only found a relation between physical activity and clustered risk among adolescent girls, not among younger boys and girls, nor among adolescent boys. Ruiz et al. (2007) investigated 74 boys and 68 girls, aged 9-10 years, and found no relation between low grade inflammation (C-reactive protein, fibrinogen, and complement factors C3 and C4), which may suggest that the inflammatory reaction associated with arteriosclerosis is not dependent on physical activity at this early age. Further studies are warranted to confirm this finding. Hurtig-Wennlöf et al. (2007) evaluated 590 boys and girls aged 9-10 years, and 535 boys and girls aged 15-16 years. Physical activity (GPA and MVPA) was related to risk factors for CVD (Insulin, Glucose, HDL, Total cholesterol, Triglycerides, systolic and diastolic BP, and sum of skinfolds). Interesting gender differences were detected in the relationships between physical activity and CVD risk. In the younger population (aged 9-10 years) MVPA and GPA were combined related to 5 risk factors for both boys and girls, this was also the finding among the adolescent boys aged 15-16 years. However, in adolescent girls, aged 15-16 years, MVPA and GPA were related to a total of 10 risk factors for CVD. This study suggests that adolescent girls are a priority population if an intervention is to be attempted. Andersen and co-workers investigated both single risk factors and also performed a comprehensive analysis of clustering of risk factors for CVD with GPA and daily accumulation of 5 or 10 min bouts of physical activity above 2000 counts/min (Andersen et al., 2006). 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. Time spent above 2000 counts/min per day was 167 min in the most active 9-year-old quintile. The authors concluded that the current guidelines of 60 min of MVPA could be an underestimation of the activity necessary to prevent clustering of risk factors in younger children. However, the end-points to be used when defining potential health hazards in children have not yet been established. Should activity levels observed in children with normal risk for CVD, diabetes and other diseases be accepted as appropriate? Or should the results of tracking studies, where the activity of children that develop into healthy adults be used? There are currently no definite answers to these questions but some support for the hypothesis that more is better when it comes to physical activity was provided from the EYHS data (Andersen et al., 2006).

Conclusion

It can be concluded that accelerometers have successfully been used in numerous field-based studies in children of various ages and locations. This sets a solid foundation to monitor secular trends in physical activity on a population-base. Moreover, to accumulate accurate physical activity data is important in order better to estimate the true association between physical activity and health risk factors. It is by no means clear, however, that the current physical activity recommendations for young children are appropriate in order to minimize prevalence of risk factors for disease in youth and later in adulthood (Twisk, 2001). A high priority area is to establish a standardized measurement protocol including data reduction. Moreover comprehensive validation studies are urgently needed to develop more precise prediction equations for free-living children. A novel method for better assessment of daily physical activity has been tested in laboratory environment (Brage et al., 2004a; Corder et al., 2005; Brage et al., 2005). This method incorporates combined analysis of accelerometer counts and heart rate, which solve some of the problems related to activities such as bicycling and uphill walking. One device, Actiheart, is commercially available (Respironics Inc., Murrysville, PA, USA). Although tested in a small-scale free-living validation study (Brage et al., 2006), it remains to be proven that this approach actually results in improved daily physical activity assessment in large field-based epidemiological studies.

References

Abbott RA, Davies PS. Habitual physical activity and physical activity intensity: their relation to body composition in 5.0-10.5-y-old children. Eur J Clin Nutr (2004); 58: 285-291.

Andersen LB, Haraldsdottir J. Tracking of cardiovascular disease risk factors including maximal oxygen uptake and physical activity from late teenage to adulthood. An 8-year follow-up study. J Intern Med (1993); 234: 309-315.

Andersen LB, Harro M, Sardinha LB, Froberg K, Ekelund U, Brage S, Anderssen SA. Physical activity and clustered cardiovascular risk in children: a cross-sectional study (The European Youth Heart Study). Lancet (2006); 368: 299-304.

Anderssen SA, Cooper AR, Riddoch C, Sardinha LB, Harro M, Brage S, Andersen LB. Low cardiorespiratory fitness is a strong predictor for clustering of cardiovascular disease risk factors in children independent of country, age and sex. Eur J Cardiovasc Prev Rehabil (2007); 14: 526-531.

Bailey RC, Olson J, Pepper SL, Porszasz J, Barstow TJ, Cooper DM. The level and tempo of children's physical activities: an observational study. Med Sci Sports Exerc (1995); 27: 1033-1041.

Brage S, Brage N, Ekelund U, Luan J, Franks PW, Froberg K, Wareham NJ. Effect of combined movement and heart rate monitor placement on physical activity estimates during treadmill locomotion and free-living. Eur J Appl Physiol (2006); 96: 517-524.

Brage S, Brage N, Franks PW, Ekelund U, Wareham NJ. Reliability and validity of the combined heart rate and movement sensor Actiheart. Eur J Clin Nutr (2005); 59: 561-570.

Brage S, Brage N, Franks PW, Ekelund U, Wong MY, Andersen LB, Froberg K, Wareham NJ. Branched equation modeling of simultaneous accelerometry and heart rate monitoring improves estimate of directly measured physical activity energy expenditure. J Appl Physiol (2004a); 96: 343-351.

Brage S, Wedderkopp N, Andersen LB, Froberg K. Influence of step frequency on movement intensity predictions with the CSA accelerometer. A field validation study in children. Pediatr Exerc Sci (2003a); 15: 277-287.

Brage S, Wedderkopp N, Ekelund U, Franks PW, Wareham NJ, Andersen LB, Froberg K; European Youth Heart Study (EYHS). Features of the metabolic syndrome are associated with objectively measured physical activity and fitness in Danish children: the European Youth Heart Study (EYHS). Diabetes Care (2004b); 27: 2141-2148.

Brage S, Wedderkopp N, Ekelund U, Franks PW, Wareham NJ, Andersen LB, Froberg K. Objectively measured physical activity correlates with indices of insulin resistance in Danish children. The European Youth Heart Study (EYHS). Int J Obes Relat Metab Disord (2004c); 28: 1503-1508.

Brage S, Wedderkopp N, Franks PW, Andersen LB, Froberg K. Reexamination of validity and reliability of the CSA monitor in walking and running. Med Sci Sports Exerc (2003b); 35: 1447-1454.

Butte NF, Puyau MR, Adolph AL, Vohra FA, Zakeri I. Physical activity in nonoverweight and overweight Hispanic children and adolescents. Med Sci Sports Exerc (2007); 39 : 1257-1266.

Cavill N, Biddle S, Sallis JF. Health enhancing physical activity for young people: Statement of the United Kingdom Expert Consensus Conference. Pediatr Exerc Sci (2001); 13: 12-25.

Corder K, Brage S, Wareham NJ, Ekelund U. Comparison of PAEE from combined and separate heart rate and movement models in children. Med Sci Sports Exerc (2005); 37: 1761-1767.

Davidson MH. Global risk management in patients with type 2 diabetes mellitus. Am J Cardiol (2007); 99: 41B-50B.

Dencker M, Thorsson O, Karlsson M.K, Lindén C, Eiberg S, Wollmer P, Andersen L.B. Daily physical activity related to body fat in children aged 8-11 years. J Pediatr (2006a); 149: 38-42

Dencker M, Thorsson O, Karlsson M.K, Lindén C, Svensson J, Wollmer P, Andersen L.B. Daily physical activity and its relation aerobic fitness in children aged 8-11 years. Eur J Appl Physiol (2006b); 96: 587-592

Dencker M, Thorsson O, Karlsson M.K, Lindén C, Svensson J, Wollmer P, Andersen L.B. Daily physical activity in Swedish children aged 8-11 years. Scand J Med Sci Sports (2006c); 16: 252-257

Dietz WH. Overweight in Childhood and Adolescence. N Engl J Med (2004); 350: 855-857.

Dowda M, Ainsworth BE, Addy CL, Saunders R, Riner W. Environmental influences, physical activity, and weight status in 8- to 16-year-olds. Arch Pediatr Adolesc Med (2001); 155: 711-717.

Eiberg S, Hasselstrom H, Gronfeldt V, Froberg K, Cooper A, Andersen LB. Physical fitness as a predictor of cardiovascular disease risk factors in 6- to 7- year old Danish children: The Copenhagen school child intervention study. Pediatr Exerc Sci (2005a); 17: 55-64.

Eiberg S, Hasselstrom H, Gronfeldt V, Froberg K, Svensson J, Andersen LB. Maximum oxygen uptake and objectively measured physical activity in Danish children 6-7 years of age: the Copenhagen school child intervention study. Br J Sports Med (2005b); 39: 725-730.

Eisenmann JC, Strath SJ, Shadrick D, Rigsby P, Hirsch N, Jacobson L. Validity of uniaxial accelerometry during activities of daily living in children. Eur J Appl Physiol (2004); 91: 259-263.

Ekblom O, Oddsson K, Ekblom B. Prevalence and regional differences in overweight in 2001 and trends in BMI distribution in Swedish children from 1987 to 2001. Scand J Public Health (2004); 32: 257-263.

Ekelund U, Anderssen SA, Froberg K, Sardinha LB, Andersen LB, Brage S; European Youth Heart Study Group. Independent associations of physical activity and cardiorespiratory fitness with metabolic risk factors in children: the European youth heart study. Diabetologia (2007); 50: 1832-1840.

Ekelund U, Aman J, Yngve A, Renman C, Westerterp K, Sjostrom M. Physical activity but not energy expenditure is reduced in obese adolescents: a case-control study. Am J Clin Nutr (2002); 76: 935-941.

Ekelund U, Sardinha LB, Anderssen SA, Harro M, Franks PW, Brage S, Cooper AR, Andersen LB, Riddoch C, Froberg K. Associations between objectively assessed physical activity and indicators of body fatness in 9- to 10-y-old European children: a population-based study from 4 distinct regions in Europe (the European Youth Heart Study). Am J Clin Nutr (2004); 80: 584-590.

Ekelund U, Sjostrom M, Yngve A, Poortvliet E, Nilsson A, Froberg K, Wedderkopp N, Westerterp K. Physical activity assessed by activity monitor and doubly labeled water in children. Med Sci Sports Exerc (2001); 33: 275-281.

Eston, RG, Rowlands AV, Ingledew DK. Validity of heart rate, pedometry and accelerometry for predicting the energy cost of children's activities. J Appl Physiol (1998); 84: 362-371.

Freedson PS, Miller K. Objective monitoring of physical activity using motion sensors and heart rate. Res Q Exerc Sport (2000); 71 (2 Suppl): S21-S29.

Freedson P, Pober D, Janz KF. Calibration of accelerometer output for children. Med Sci Sports Exerc (2005); 37 (suppl 11): S523-S530.

Freedson PS, Sirard J, Dehold E, Pate R, Dowda M, Trost S, Sallis J. Calibration of the Computer Science and Applications, Inc. (CSA) accelerometer. Med Sci Sports Exerc (1997); 29 (suppl): S45.

Froberg K, Andersen LB. Mini review: physical activity and fitness and its relations to cardiovascular disease risk factors in children. Int J Obes (Lond) (2005); 29 (suppl 2): S34-S39.

Guinhouya CB, Hubert H, Soubrier S, Vilhelm C, Lemdani M, Durocher A. Moderate-to-vigorous physical activity among children: discrepancies in accelerometry-based cut-off points. Obesity (Silver Spring) (2006); 14: 774-777.

Gutin B, Yin Z, Humphries MC, Barbeau P. Relations of moderate and vigorous physical activity to fitness and fatness in adolescents. Am J Clin Nutr (2005); 81: 746-750.

Hansen SE, Hasselstrom H, Gronfeldt V, Froberg K, Andersen LB. Cardiovascular disease risk factors in 6-7-year-old Danish children: the Copenhagen School Child Intervention Study. Prev Med (2005); 40: 740-746.

Harro M, Riddoch C (2000). Physical activity. In: Armstrong N, van Mechelen W ,eds. Paediatric exercise science and medicine (pp 77-84). Oxford University Press, Oxford, UK.

Hasselström H, Hansen SE, Froberg K, Andersen LB. 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. Int J Sports Med (2002); 23 Suppl 1: S27-S31.

Hurtig-Wennlöf A, Ruiz JR, Harro M, Sjostrom M. Cardiorespiratory fitness relates more strongly than physical activity to cardiovascular disease risk factors in healthy children and adolescents: the European Youth Heart Study. Eur J Cardiovasc Prev Rehabil (2007); 14: 575-581.

Hussey J, Bell C, Bennett K, O'Dwyer J, Gormley J. Relationship between the intensity of physical activity, inactivity, cardiorespiratory fitness and body composition in 7-10-year-old Dublin children. Br J Sports Med (2007); 41: 311-316.

Jackson DM, Reilly JJ, Kelly LA, Montgomery C, Grant S, Paton JY. Objectively measured physical activity in a representative sample of 3- to 4-year-old children.
Obes Res (2003); 11: 420-425.

Janz KF, Burns TL, Levy SM. Iowa Bone Development Study. Tracking of activity and sedentary behaviors in childhood: the Iowa Bone Development Study. Am J Prev Med (2005); 29: 171-178.

Janz KF, Levy SM, Burns TL, Torner JC, Willing MC, Warren JJ. Fatness, physical activity, and television viewing in children during the adiposity rebound period: the Iowa Bone Development Study. Prev Med (2002); 35: 563-571.

Kelly LA, Reilly JJ, Grant S, Paton JY. Low physical activity levels and high levels of sedentary behaviour are characteristic of rural Irish primary school children. Ir Med J (2005); 98: 138-141.

Kelly LA, Reilly JJ, Jackson DM, Montgomery C, Grant S, Paton JY. Tracking physical activity and sedentary behavior in young children. Pediatr Exerc Sci (2007); 19: 51-60.

Kiess W, Galler A, Reich A, Muller G, Kapellen T, Deutscher J, Raile K, Kratzsch J. Clinical aspects of obesity in childhood and adolescence. Obes Rev (2001); 2: 29-36.

Kohl III HW, Fulton JE, Caspersen CJ. Assessment of physical activity among children and adolescents: a review and synthesis. Prev Med (2000); 31: S54-S76.

Kristensen PL, Moller NC, Korsholm L, Wedderkopp N, Andersen LB, Froberg K. Tracking of objectively measured physical activity from childhood to adolescence: The European youth heart study. Scand J Med Sci Sports (2007); Jun 6 [Epub ahead of print] DOI: 10.1111/j.1600-0838.2006.00622.x.

Lazaar N, Aucouturier J, Ratel S, Rance M, Meyer M, Duche P. Effect of physical activity intervention on body composition in young children: influence of body mass index status and gender. Acta Paediatr (2007); 96: 1315-1320.

Lohman TG, Ring K, Schmitz KH, Treuth MS, Loftin M, Yang S, Sothern M, Going S. Associations of body size and composition with physical activity in adolescent girls. Med Sci Sports Exerc (2006); 38: 1175-1181.

Louie L, Eston RG, Rowlands AV, Tony KK, Ingledew DK, Fu FH. Validity of heart rate, pedometry, and accelerometry for estimating the energy cost of activity in Hong Kong Chinese boys. Pediatr Exerc Sci (1999); 11: 229-239.

Lopes VP, Vasques CM, Maia JA, Ferreira JC. Habitual physical activity levels in childhood and adolescence assessed with accelerometry. J Sports Med Phys Fitness (2007); 47: 217-222.

Mårild S, Bondestam M, Bergstrom R, Ehnberg S, Hollsing A, Albertsson-Wikland K. Prevalence trends of obesity and overweight among 10-year-old children in western Sweden and relationship with parental body mass index. Acta Paediatr (2004); 93: 1588-1595.

Mattocks C, Leary S, Ness A, Deere K, Saunders J, Kirkby J, Blair SN, Tilling K, Riddoch C. Intraindividual variation of objectively measured physical activity in children. Med Sci Sports Exerc (2007a); 39: 622-629.

Mattocks C, Leary S, Ness A, Deere K, Saunders J, Tilling K, Kirkby J, Blair SN, Riddoch C. Calibration of an accelerometer during free-living activities in children. Int J Pediatr Obes (2007b); First Published Online August 29 DOI: 10.1080/17477160701408809.

Metallinos-Katsaras ES, Freedson PS, Fulton JE, Sherry B. The association between an objective measure of physical activity and weight status in preschoolers. Obesity (Silver Spring) (2007); 15: 686-694.

Miller J, Rosenbloom A, Silverstein J. Childhood obesity. J Clin Endocrinol Metab (2004); 89: 4211-4218.

Molnar D, Livingstone B. Physical activity in relation to overweight and obesity in children and adolescents. Eur J Pediatr (2000); 159 (Suppl 1): S45-S55.

Montgomery C, Reilly JJ, Jackson DM, Kelly LA, Slater C, Paton JY, Grant S. Validation of energy intake by 24-hour multiple pass recall: comparison with total energy expenditure in children aged 5-7 years. Br J Nutr (2005); 93: 671-676.

Moore LL, Gao D, Bradlee ML, Cupples LA, Sundarajan-Ramamurti A, Proctor MH, Hood MY, Singer MR, Ellison RC. Does early physical activity predict body fat change throughout childhood? Prev Med (2003); 37: 10-17.

Mossberg H-O. 40-Year Follow-up of Overweight Children. Lancet (1989); 26: 491-493.

Murphy MJ, Metcalf BS, Voss LD, Jeffery AN, Kirkby J, Mallam KM, Wilkin TJ; The EarlyBird Study (EarlyBird 6). Girls at five are intrinsically more insulin resistant than boys: The Programming Hypotheses Revisited--The EarlyBird Study (EarlyBird 6). Pediatrics (2004); 113: 82-86.

Neovius M, Janson A, Rossner S. Prevalence of obesity in Sweden. Obes Rev (2006); 7: 1-3.

Ness AR, Leary SD, Mattocks C, Blair SN, Reilly JJ, Wells J, Ingle S, Tilling K, Smith GD, Riddoch C. Objectively Measured Physical Activity and Fat Mass in a Large Cohort of Children. PLoS Med (2007); 4: e97.

Nilsson A, Ekelund U, Yngve A, Sjöström M. Assessing physical activity among children with accelerometers using different time sampling intervals and placements. Pediatr Exerc Sci (2002); 14: 87-96.

Pate RR, Freedson PS, Sallis JF, Taylor WC, Sirard J, Trost SG, Dowda M. Compliance with physical activity guidelines: prevalence in a population of children and youth. Ann Epidemiol (2002); 12: 303-308.

Pate RR, Pfeiffer KA, Trost SG, Ziegler P, Dowda M. Physical activity among children attending preschools. Pediatrics (2004); 114: 1258-1263.

Pate RR, Stevens J, Pratt C, Sallis JF, Schmitz KH, Webber LS, Welk G, Young DR. Objectively measured physical activity in sixth-grade girls. Arch Pediatr Adolesc Med (2006); 160: 1262-1268.

Puyau MR, Adolph AL, Vohra FA, Butte NF. Validation and calibration of physical activity monitors in children. Obes Res (2002); 10: 150-157.

Reilly JJ, Kelly L, Montgomery C, Williamson A, Fisher A, McColl JH, Conte RL, Paton JY, Grant S. Physical activity to prevent obesity in young children: cluster randomised controlled trial. BMJ (2006); 333: 1041-1043.

Reilly JJ, Jackson DM, Montgomery C, Kelly LA, Slater C, Grant S, Paton JY. Total energy expenditure and physical activity in young Scottish children: mixed longitudinal study. Lancet (2004); 363: 211-212.

Riddoch CJ, Andersen LB, Wedderkopp N, Harro M, Klasson-Heggebø L, Sardinha LB, Cooper A, Ekelund U. Physical activity levels and patterns of 9 and 15 year old European children. Med Sci Sports Exerc (2004); 36: 86-92.

Riddoch CJ, Mattocks C, Deere K, Saunders J, Kirkby J, Tilling K, Leary SD, Blair S, Ness A. Objective measurement of levels and patterns of physical activity. Arch Dis Child (2007); ADC Published Online First September 13 DOI:10.1136/adc.2006.112136.

Rogers IS, Ness AR, Steer CD, Wells JC, Emmett PM, Reilly JR, Tobias J, Smith GD. Associations of size at birth and dual-energy X-ray absorptiometry measures of lean and fat mass at 9 to 10 y of age. Am J Clin Nutr (2006); 84: 739-747.

Rowlands AV, Eston RG, Ingledew DK. Relationship between activity levels, aerobic fitness, and body fat in 8- to 10-yr-old children. J Appl Physiol (1999); 86: 1428-1435.

Rizzo NS, Ruiz JR, Hurtig-Wennlof A, Ortega FB, Sjostrom M. Relationship of physical activity, fitness, and fatness with clustered metabolic risk in children and adolescents: the European youth heart study. J Pediatr (2007); 150: 388-394.

Ruiz JR, Ortega FB, Warnberg J, Sjostrom M. Associations of low-grade inflammation with physical activity, fitness and fatness in prepubertal children; the European Youth Heart Study. Int J Obes (Lond) (2007); 31: 1545-1551.

Ruiz JR, Rizzo NS, Hurtig-Wennlof A, Ortega FB, Warnberg J, Sjostrom M. Relations of total physical activity and intensity to fitness and fatness in children: the European Youth Heart Study. Am J Clin Nutr (2006); 84: 299-303.

Sallis JF, Saelens BE. Assessment of physical activity by self-report. Status, limitations, and future directions. Res Q Exerc Sport (2000); 71: 1-14.

Santos P, Guerra S, Ribeiro JC, Duarte JA, Mota J. Age and gender-related physical activity. A descriptive study in children using accelerometry. J Sports Med Phys Fitness (2003); 43: 85-89.

Slyper AH. The Pediatric Obesity Epidemic: Causes and Controversies. J Clin Endocrinol Metab (2004); 89: 2540-2547.

Steinbeck KS. The importance of physical activity in the prevention of overweight and obesity in childhood: a review and an opinion. Obes Rev (2001); 2/2: 117-130.

Stevens J, Suchindran C, Ring K, Baggett CD, Jobe JB, Story M, Thompson J, Going SB, Caballero B. Physical activity as a predictor of body composition in American Indian children. Obes Res (2004); 12: 1974-1980.

Summerbell CD, Waters E, Edmunds LD, Kelly S, Brown T, Campbell KJ. Interventions for preventing obesity in children. Cochrane Database Syst Rev (2005); 20: CD001871.

Ten S, Maclaren N. Insulin resistance syndrome in children. J Clin Endocrinol Metab (2004); 89: 2526-2539.

Thompson AM, Campagna PD, Rehman LA, Murphy RJ, Rasmussen RL, Ness GW. Physical activity and body mass index in grade 3, 7, and 11 Nova Scotia students. Med Sci Sports Exerc (2005); 37: 1902-1908.

Torroni A, Achilli A, Macaulay V, Richards M, Bandelt HJ. Harvesting the fruit of the human mtDNA tree. Trends Genet (2006); 22: 339-345.

Trayers T, Cooper AR, Riddoch CJ, Ness AR, Fox KR, Deem R, Lawlor DA. Do children from an inner city British school meet the recommended levels of physical activity? Results from a cross sectional survey using objective measurements of physical activity. Arch Dis Child (2006); 91: 175-176.

Tremblay MS, Barnes JD, Copeland JL, Esliger DW. Conquering childhood inactivity: is the answer in the past? Med Sci Sports Exerc (2005); 37: 1187-1194.

Treuth MS, Hou N, Young DR, Maynard LM. Accelerometry-measured activity or sedentary time and overweight in rural boys and girls. Obes Res (2005); 13: 1606-1614.

Treuth MS, Schmitz K, Catellier DJ, McMurray RG, Murray DM, Almeida MJ, Going S, Norman JE, Pate R. Defining accelerometer thresholds for activity intensities in adolescent girls. Med Sci Sports Exerc (2004); 36: 1259-1266.

Trost SG, Kerr LM, Ward DS, Pate RR. Physical activity and determinants of physical activity in obese and non-obese children. Int J Obes Relat Metab Disord (2001); 25: 822-829.

Trost SG, McIver KL, Pate RR. Conducting accelerometer-based activity assessments in field-based research. Med Sci Sports Exerc (2005); 37 (11 Suppl): S531-S543.

Trost SG, Pate RR, Freedson PS, Sallis JF, Taylor WC. Using objective physical activity measures with youth: How many days of monitoring are needed? Med Sci Sports Exerc (2000); 32: 426-431.

Trost SG, Pate RR, Sallis JF, Freedson PS, Taylor WC, Dowda M, Sirard J. Age and gender differences in objectively measured physical activity in youth. Med Sci Sports Exerc (2002); 34: 350-355.

Trost SG, Sirard JR, Dowda M, Pfeiffer KA, Pate RR. Physical activity in overweight and nonoverweight preschool children. Int J Obes Relat Metab Disord (2003); 27: 834-839.

Trost SG, Ward DS, Moorehead SM, Watson PD, Riner W, Burke JR. Validity of the Computer Science and Applications (CSA) activity monitor in children. Med Sci Sports Exerc (1998); 30: 629-633.

Trost SG, Way R, Okely AD. Predictive Validity of Three ActiGraph Energy Expenditure Equations for Children. Med Sci Sports Exerc (2006); 38: 380-387.

Trudeau F, Shephard RJ, Arsenault F, Laurencelle L. Tracking of physical fitness from childhood to adulthood. Can J Appl Physiol (2003); 28: 257-271.

Twisk JW. Physical activity guidelines for children and adolescents: a critical review. Sports Med (2001); 31: 617-627.

Twisk JW, Kemper HC, van Mechelen W. 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. Int J Sports Med (2002); 23: Suppl 1: S8-S14.

U.S. Department of Health and Human Services (1996). Physical Activity and Health: A Report of the Surgeon General, U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Chronic Disease Prevention and Health Promotion, Atlanta, GA, USA:

Whitaker RC, Wright JA, Pepe MS, Seidel KD, Dietz WH. Predicting obesity in young adulthood from childhood and parental obesity. N Engl J Med (1997); 337: 869-873.

Winkler JT. The fundamental flaw in obesity research. Obes Rev (2005); 6: 199-202.

Table 1. Display of selected studies that have used the Actigraph and reported general physical activity (GPA) in mean counts/min.

[1] Cross-sectional data from mixed longitudinal studies. [2] intervention versus control. [3] Weekday and weekend values. [4] Study-population consisted of Old Order Mennonites, Urban children, and Rural children. [5] Values for children and adolescents aged 9 and 15 years, respectively. [6] Longitudinal studies.

Study (First author, year)	Population (n) boys/girls	Age (years)	GPA boys (counts/min)	GPA girls (counts/min)
Jackson et al. 2003 [1]	(52/52)	4	777	651
Reilly et al. 2004 [1]	(40/38)	4	739	633
Reilly et al. 2006 [2]	(273/272)	4	773/823	694/794
Metallinos-Katsaras et al. 2007	(30/26)	2-5	803	688
Kelly et al. 2005	(20/21)	4-5	834	628
Janz et al. 2002	(203/231)	5	773	702
Eiberg et al. 2006	(291/269)	6-7	743	679
Trayers et al. 2006 [3]	(26/26)	10	749/743	580/607
Riddoch et al. 2007	(2662/2933)	11	644	529
Dencker et al. 2006	(128/102)	8-11	751	618
Tremblay et al. 2006 [4]	(194/205)	8-13	647/646/594	534/523/513
Rizzo et al. 2007 [5]	(264/265)	9 and 15	801 and 561	663 and 484
Riddoch et al. 2004 [5]	(2185 total)	9 and 15	784 and 615	649 and 491
Kelly et al. 2007 [6]	(21/21)	4 and 6	696 and 884	642 and 753
Kristensen et al. 2007 [6]	(96/112)	10 and 16	708 and 492	599 and 398

Table 2 Display of selected studies that have used the Actigraph and evaluated gender differences in physical activity. Data of gender differences are reported in percent (%). [1] Cross-sectional data from mixed longitudinal studies. [2] Data only from control group. [3] Weekday and weekend values. [4] Study-population consisted of Old Order Mennonites, Urban children, and Rural children. [5] Average values for all age groups. [6] Data for age groups 8-10, 11-13, and 14-16 years. [7] Data for 9 and 15-year-olds. [8] longitudinal data at age 4 and 6 year. [9] longitudinal data at age 10 and 16 year. [10] Data for age groups 6-8, 9-11, 12-14, and 15-18 years. Not available (NA).

Study (First author, year)	Population(n) boys/girls	Age (yrs)	GPA (%)	MVPA (%)	VPA (%)
Metallinos-Katsaras et al. 2007	(30/26)	2-5	17	NA	47
Jackson et al. 2003 [1]	(52/52)	4	19	NA	NA
Pate et al. 2004	(115/132)	3-5	NA	13	24
Reilly et al. 2004 [1]	(40/38)	4	17	NA	NA
Reilly et al. 2006 [2]	(145/132)	4	4	NA	NA
Kelly et al. 2005	(20/21)	4-5	33	NA	NA
Janz et al. 2002	(203/231)	5	10	5	29
Eiberg et al. 2006	(291/269)	6-7	9	NA	NA
Trayers et al. 2006 [3]	(26/26)	10	29/22	18/2	NA
Riddoch et al. 2007 [3]	(2662/2933)	11	22/17	69/56	NA
Dencker et al. 2006	(128/102)	8-11	22	11	31
Tremblay et al. 2006 [4]	(194/205)	8-13	21/24/16	NA	NA
Trost et al. 2002 [5]	(185/190)	7-16	NA	11	45
Santos et al. 2003 [6]	(64/93)	8-16	NA	22/86/36	NA
Rizzo et al. 2007 [7]	(264/265)	9 and 15	21 and 16	20 and 21	46 and 33
Riddoch et al. 2004 [7]	(2185 total)	9 and 15	21 and 25	25 and 36	NA
Kelly et al. 2007 [8]	(21/21)	4 and 6	8 and 17	52 and 26	NA
Kristensen et al. 2007 [9]	(96/112)	10 and 16	18 and 24	NA	NA
Lopes et al. 2007 [10]	(238/265)	6-18	NA	NA	55/40/57/290