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 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 conclusive that boys are more active than girls disregarding age, geographic 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 \((-0.03, \text{ns})\).

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 \((r=-0.43 \text{ and } r=-0.39, P<0.05)\). 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 \(r=-0.38 \text{ and } r=-0.34, P<0.05\). MPA displayed no such relationships \((r=-0.07 \text{ and } r=0.09, \text{both ns})\). 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 previously mentioned studies, several case-controll studies that have shown that obese children are less active compared to normal-weight control children (Trost et al., 2001; Ekelund et al., 2002; Trost et al., 2003; Metallinos-Katsaras et al., 2007).

Combining all these reports 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$_{2\text{PEAK}}$), 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$_{2\text{PEAK}}$ 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$_{2\text{PEAK}}$ (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


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


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.


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.


Reilly JJ, Jackson DM, Montgomery C, Kelly LA, Slater C, Grant S, Paton JY. 


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.


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.


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.


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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.

<table>
<thead>
<tr>
<th>Study (First author, year)</th>
<th>Population (n) boys/girls</th>
<th>Age (years)</th>
<th>GPA boys (counts/min)</th>
<th>GPA girls (counts/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jackson et al. 2003 1</td>
<td>(52/52)</td>
<td>4</td>
<td>777</td>
<td>651</td>
</tr>
<tr>
<td>Reilly et al. 2004 1</td>
<td>(40/38)</td>
<td>4</td>
<td>739</td>
<td>633</td>
</tr>
<tr>
<td>Reilly et al. 2006 2</td>
<td>(273/272)</td>
<td>4</td>
<td>773/823</td>
<td>694/794</td>
</tr>
<tr>
<td>Metallinos-Katsaras et al. 2007</td>
<td>(30/26)</td>
<td>2-5</td>
<td>803</td>
<td>688</td>
</tr>
<tr>
<td>Kelly et al. 2005</td>
<td>(20/21)</td>
<td>4-5</td>
<td>834</td>
<td>628</td>
</tr>
<tr>
<td>Janz et al. 2002</td>
<td>(203/231)</td>
<td>5</td>
<td>773</td>
<td>702</td>
</tr>
<tr>
<td>Eiberg et al. 2006</td>
<td>(291/269)</td>
<td>6-7</td>
<td>743</td>
<td>679</td>
</tr>
<tr>
<td>Trayers et al. 2006 3</td>
<td>(26/26)</td>
<td>10</td>
<td>749/743</td>
<td>580/607</td>
</tr>
<tr>
<td>Riddoch et al. 2007</td>
<td>(2662/2933)</td>
<td>11</td>
<td>644</td>
<td>529</td>
</tr>
<tr>
<td>Dencker et al. 2006</td>
<td>(128/102)</td>
<td>8-11</td>
<td>751</td>
<td>618</td>
</tr>
<tr>
<td>Tremblay et al. 2006 4</td>
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<td>8-13</td>
<td>647/646/594</td>
<td>534/523/513</td>
</tr>
<tr>
<td>Rizzo et al. 2007 5</td>
<td>(264/265)</td>
<td>9 and 15</td>
<td>801 and 561</td>
<td>663 and 484</td>
</tr>
<tr>
<td>Riddoch et al. 2004 5</td>
<td>(2185 total)</td>
<td>9 and 15</td>
<td>784 and 615</td>
<td>649 and 491</td>
</tr>
<tr>
<td>Kelly et al. 2007 6</td>
<td>(21/21)</td>
<td>4 and 6</td>
<td>696 and 884</td>
<td>642 and 753</td>
</tr>
<tr>
<td>Kristensen et al. 2007 6</td>
<td>(96/112)</td>
<td>10 and 16</td>
<td>708 and 492</td>
<td>599 and 398</td>
</tr>
</tbody>
</table>
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 (%).  
Cross-sectional data from mixed longitudinal studies.  
Data only from control group.  
Weekday and weekend values.  
Study-population consisted of Old Order Mennonites, Urban children, and Rural children.  
Average values for all age groups.  
Data for age groups 8-10, 11-13, and 14-16 years.  
Data for 9 and 15-year-olds.  
longitudinal data at age 4 and 6 year.  
longitudinal data at age 10 and 16 year.  
Data for age groups 6-8, 9-11, 12-14, and 15-18 years. Not available (NA).

<table>
<thead>
<tr>
<th>Study (First author, year)</th>
<th>Population(n) boys/girls</th>
<th>Age (yrs)</th>
<th>GPA (%)</th>
<th>MVPA (%)</th>
<th>VPA (%)</th>
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<tbody>
<tr>
<td>Metallinos-Katsaras et al. 2007</td>
<td>(30/26)</td>
<td>2-5</td>
<td>17</td>
<td>NA</td>
<td>47</td>
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<tr>
<td>Jackson et al. 2003 1</td>
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<td>19</td>
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<td>3-5</td>
<td>NA</td>
<td>13</td>
<td>24</td>
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<td>(40/38)</td>
<td>4</td>
<td>17</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Reilly et al. 2006 2</td>
<td>(145/132)</td>
<td>4</td>
<td>4</td>
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<td>Kelly et al. 2005</td>
<td>(20/21)</td>
<td>4-5</td>
<td>33</td>
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<td>Janz et al. 2002</td>
<td>(203/231)</td>
<td>5</td>
<td>10</td>
<td>5</td>
<td>29</td>
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<tr>
<td>Eiberg et al. 2006</td>
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<td>6-7</td>
<td>9</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Trayers et al. 2006 3</td>
<td>(26/26)</td>
<td>10</td>
<td>29/22</td>
<td>18/2</td>
<td>NA</td>
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<tr>
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<td>11</td>
<td>22/17</td>
<td>69/56</td>
<td>NA</td>
</tr>
<tr>
<td>Dencker et al. 2006</td>
<td>(128/102)</td>
<td>8-11</td>
<td>22</td>
<td>11</td>
<td>31</td>
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<td>Tremblay et al. 2006 4</td>
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<td>8-13</td>
<td>21/24/16</td>
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<td>22/86/36</td>
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<tr>
<td>Rizzo et al. 2007 7</td>
<td>(264/265)</td>
<td>9 and 15</td>
<td>21 and 16</td>
<td>20 and 21</td>
<td>46 and 33</td>
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<td>10 and 16</td>
<td>18 and 24</td>
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<td>NA</td>
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