

Physical activity assessed  
by accelerometry in children



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## Abstract

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Physical activity (PA) is likely to constitute an important aspect of health-related behaviour in growing children. However, the knowledge on levels and patterns of PA in children is limited, due to the difficulty of precisely measuring this complex behaviour in normal daily living. Information on variables that significantly contributes to the variability in PA patterns is warranted as it may inform strategies for promoting physically active lifestyles in school-age youth. The overall purpose of the present studies was to increase the knowledge about the use of accelerometry when assessing PA in children, and examine sources of variability in objectively assessed PA behaviour in children. The study samples included 1954 nine- and 15-year-old children from four geographical locations in Europe (Norway, Denmark, Estonia and Portugal), and additionally 16 Swedish seven-year-old boys and girls. PA was assessed by the MTI accelerometer during free-living conditions, including both weekdays and weekend days. A part of the PA assessment was conducted using different time sampling intervals (epochs). Predictions of estimates of daily energy expenditure from accelerometer output were calculated using previously published equations. Potential correlates of PA behaviour were assessed by self-report. The main findings were; a) the epoch setting had a significant effect when interpreting time spent at higher intensities of PA in young children, b) predicted energy expenditure differed substantially between equations, c) between- and within-day differences in overall levels of PA, time spent at moderate-to-vigorous intensity physical activity and time spent sedentary differed between age, gender and geographical location, d) outdoor play and sports participation were differentially associated with objectively measured PA in 9- and 15-year-old children. It is concluded that the sporadic nature of children's physical activity require very short epoch settings for detecting high intensity PA, and that different published equations for estimations of daily energy expenditure cannot be used interchangeably. The interpretations of average energy expenditure from available equations should be made with caution. Based on a large sample of children of different ages, weekend days and leisure time during weekdays seem appropriate targets when promoting PA in order to increase the proportion of children achieving current recommendations on health enhancing PA. Further, significant correlates of PA behaviour dependent on age group are presented, which should be considered when planning interventions for promoting PA in school-age youth.

**Keywords:** activity patterns, adolescents, health promotion, activity monitor, sedentary.

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## LIST OF PUBLICATIONS

- I 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.
- II Nilsson A, Brage S, Riddoch C, Anderssen SA, Sardinha LB, Wedderkopp N, Andersen LB, Ekelund U. Comparison of equations for predicting energy expenditure from accelerometer counts in children. *Scand J Med Sci Sports*, In press.
- III Nilsson A, Anderssen SA, Andersen LB, Froberg K, Riddoch C, Sardinha LB, Ekelund U. Between- and within-day variability in physical activity and inactivity in 9- and 15-yr-old European children. *Scand J Med Sci Sports*, In press.
- IV Nilsson A, Andersen LB, Ommundsen Y, Froberg K, Sardinha LB, Piehl-Aulin K, Ekelund U. Correlates of objectively assessed physical activity and sedentary time in children. Submitted.

## LIST OF ABBREVIATIONS

|                 |   |
|-----------------|---|
| BMR             | Basal metabolic rate                                |
| DIT             | Diet-induced thermogenesis                          |
| DLW             | Doubly labelled water method                        |
| HR              | Heart rate  |
| MET             | Metabolic energy turnover                           |
| MVPA            | Moderate-to-vigorous intensity of physical activity |
| PA              | Physical activity                                   |
| PAEE            | Physical activity energy expenditure                |
| PAL             | Physical activity level                             |
| REE             | Resting energy expenditure                          |
| TEE             | Total energy expenditure                            |
| VO <sub>2</sub> | Oxygen uptake                                       |



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# 1 INTRODUCTION

## 1.1 PHYSICAL ACTIVITY – DEFINITIONS AND BASIC PRINCIPLES

In all healthy children, development and refinement of movement skills through a variety of physical activities is a normal part of growth and functional developments (Malina et al., 2004). Basic movement patterns develop during preschool ages, and with growth and maturation, these movement skills gradually becomes integrated and coordinated into more complex physical activity performances that characterize different free plays and sport games through the school years (Strong et al., 2005). Since physical activity likely constitutes an important aspect of health-related behaviour, assessing how much and how often young people participate in physical activity have become an important area of research (Fox & Riddoch, 2000). However, before assessment the variable of interest needs to be defined. Physical activity has been defined as any bodily movements produced by skeletal muscles that result in energy expenditure (Caspersen et al., 1985). Given this definition, physical activity is not synonymous to exercise, which is a subcategory of physical activity defined as planned, structured, and repetitive bodily movement done to improve or maintain one or more components of physical fitness (Caspersen et al., 1985). As energy expenditure is the core outcome, physical activity behaviour should ideally be quantified into units of energy expenditure (i.e. kcal or kJ). However, between-individual variation in total daily energy expenditure is only partly explained by differences in physical activity behaviour. To clarify this, a shorter description of human energy expenditure will be given.

Three components; basal metabolic rate (BMR), energy expenditure from physical activity (PAEE) and diet-induced energy expenditure (DIT) determine the total daily amount of energy expended (Torun et al., 1996). The greatest proportion of total energy expenditure (TEE) is BMR. The BMR is defined as the minimum of energy required to sustain normal functions of the body and accounts for approximately 55–65% of TEE (McArdle et al., 2006). Ideally, BMR should be assessed during total rest in a fasting state as no more than the body's heat production should be reflected. However, in many cases preparations necessary for a proper BMR assessment are impractical and values on BMR can instead be estimated using prediction equations, especially in larger population studies. Several published equations exist, where the equation by Schofield et al. (1985) is one of the most commonly used. This equation takes sex, age, height and weight into account, which are the main determinants of energy expenditure during rest. The diet-induced energy expenditure, accounts for about 10% of TEE (Maffei et al.,

1993), and is fairly stable. The remaining component of TEE is PAEE which could be highly variable with normal ranges from 25–35% up to 75% of TEE in extreme situations (Westerterp, 2003). PAEE can thus be calculated as  $TEE - (BMR + 10\% \text{ of } TEE)$ . Since PAEE expressed in absolute values is closely related to body mass, the energy cost of a specific activity is not identical to a certain amount of body movement when comparing individuals who differ in body weight. Therefore, expressing PAEE per kilo of body weight is suggested to take into account inter-individual differences (Westerterp, 2003). Further, since the proportions of fat mass and fat-free mass in relation to body weight normally differ between gender, adjusting PAEE for fat-free mass has also been suggested as an approach to normalize between individual differences in body size and to remove any confounding effect of gender (Ekelund et al., 2004). Another marker for physical activity based on an individual's TEE is the physical activity level (PAL). The PAL-value is obtained by dividing TEE by BMR, thus PAL is a multiple of resting energy expenditure. Both PAEE, expressed in absolute values and PAL increases with age during growth (Hoos et al., 2003; Ekelund et al., 2004). This increase with age is most likely explained by the significant intercept when regressing TEE on BMR, that is, the denominator (BMR) does not fully remove the confounding effect of body size on the numerator (TEE). Based on a review of studies assessing PAEE and PAL in 3- to 16-year-olds, Hoos et al. (2003) concluded that no relation between  $PAEE \cdot kg^{-1}$  and age exist, which indicates that the observed age difference for absolute values on PAEE is attributed to an increase in body weight with increasing age.

Three different dimensions; frequency, duration and intensity of different activities performed need to be determined when assessing patterns of physical activity. The frequency relates to how often the activity occur over a specific time period (e.g. three times per week), and the duration denotes how long the activity is sustained (e.g. 20 min per session). The intensity of the activity denotes how strenuous the activity is, often defined in terms of relative load on physiological markers in relation to maximal capacity. For example, a given percentage of maximal oxygen uptake ( $\%VO_{2max}$ ) or percentage of maximal heart rate ( $\%HR_{max}$ ) are common expressions of intensity (McArdle et al., 2006). However, when PAEE is expressed in relation to body weight, it will provide an absolute measure of the intensity for a specific activity. Another frequently used measure of intensity is the metabolic equivalent (MET) for a specific activity. A MET value represents multiples of energy expenditure during rest and approximate MET-values from many different activities have been proposed (Ainsworth et al., 1993). To translate MET-values in terms of energy expenditure, a resting meta-

bolic rate of  $3.5 \text{ mlO}_2 \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ , which approximate to  $1 \text{ kcal} \cdot \text{kg}^{-1} \cdot \text{hour}^{-1}$ , is defined as 1 MET (Ainsworth et al., 1993). Notably, while this definition of 1 MET is valid for use in adults it is not applicable to children. Harrell et al. (2005) presented data on energy costs during different activities in children and compared measured MET values based on measured resting energy expenditure against MET values based on estimated resting values, equivalent to the adult value of  $3.5 \text{ mlO}_2 \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ . They showed that estimated MET values were significantly higher than the measured MET values, due to the significantly higher resting energy expenditure in children when expressed in relation to body weight ( $\text{mlO}_2 \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ ). Hence, the authors concluded that this difference in energy expenditure during rest must be adjusted for before converting MET values into caloric cost.

## **1.2 ASSESSMENT OF PHYSICAL ACTIVITY**

Physical activity is a multidimensional exposure variable, occurring with varying frequencies and intensities, and constitutes a challenge to assess in free-living populations. An ideal method should be able to assess both the total volume of physical activity and the nature of the pattern of the activity (i.e. intensity, duration and frequency) in a valid and reliable way. The method needs to be well-designed for use in field settings (e.g. non-obtrusive), make little interference with normal living and require low compliance by the individuals, especially for use in younger age groups (Montoye et al., 1996; Livingstone et al., 2003; Lamonte & Ainsworth, 2001). Moreover, for application in larger population studies the method should preferably be low in cost. Existing assessment techniques fulfil these criteria to various degree, as feasibility for real-life settings often tend to counteract the greater accuracy usually obtained in a laboratory setting (Kohl et al, 2000; Schutz et al., 2001). Physical activity assessment methods can broadly be divided into two groups; subjective (i.e. self-report) and objective methods. A description of available assessment methods, both based on objective measurements and self-report will be given in the following chapters. As all results on physical activity presented in this thesis are based on whole-body accelerometry, special attention is given to this method in a separate chapter, although other objective assessment methods will be summarized.

### **1.2.1 Accelerometry**

The accelerometer measures body accelerations, and is currently the most widely used objective physical activity assessment method. The term acceleration is defined as a change in velocity with respect to time, often expressed in gravitational

units ( $g$ ;  $1 g = 9.8 \text{ m}\cdot\text{s}^{-2}$ ). The theoretical basis of measuring accelerations in context of physical activity assessment is that changes in body accelerations reflect changes in energy cost during locomotion. Since the accelerometer measures both the magnitude and frequency of body movement, quantification of the intensity and duration of physical activity is possible. To assess accelerations of the body during locomotion, the monitor is usually placed either at the hip or on the back of the body. Placed at the hip is likely to be more comfortable for the subjects compared to the back placement. However, an attachment as close to the centre of gravity (i.e. on the back) may intuitively seem most appropriate, and some studies have subsequently used this placement (Westerterp et al., 1999a; Ekelund et al., 2000; Ekelund et al., 2001). Therefore, controlling for a placement effect may be of importance to secure comparability between different study results.

Chan & Basset (2005) has fully described the principles and properties of the accelerometer technology. In short, the accelerometer consists of a piezoelectric sensor. The term 'piezoelectric' refers to material that generates an electric charge when mechanically deformed. For example, a piezoelectric element configured as a mechanical cantilever beam has frequently been used, which becomes deformed by bending when undergoing accelerations. The deformation by bending then generates a voltage signal that is in proportion to the applied acceleration (Chan & Basset, 2005). Although the configuration of the piezoelectric element varies between different monitors and models; the beam sensor is sensitive to tension while newer electronical chip sensors detects compressions, the presumptions for assessing accelerations are the same. Most sensors are only sensitive to vertical accelerations and these devices are therefore often called uniaxial accelerometers. Sensors measuring accelerations in multiple planes exist and may intuitively seem to be better suited to capture complex physical activity behaviours compared to uniaxial types. Non-ambulatory activities, with largest accelerations produced in other planes than vertical (i.e. mediolateral and anteroposterior), has showed to be better reflected by a multiaxial sensor compared to uniaxial types (Eston et al., 1998). However, a review of studies examining validity in multiaxial sensors compared to uniaxial ones in reflecting various physical activities, revealed that comparable results on free-living physical activity in children is obtained across sensor types (Troost et al., 2005). The reason is that acceleration in the vertical plane is dominant during ambulatory activities, which only marginally improve assessment of physical activity by measuring accelerations in additional planes. Together with the fact that a multiaxial sensor usually is more expensive, uniaxial accelerometers have become the most common type used for assessment of physical activity.

One limitation with most accelerometers, regardless of type, is that only dynamic muscular work can be detected with any reasonable reliability (Chan & Basset, 2005). Thus, static work or work against external forces will remain largely undetected. For example, Treuth et al. (2004) showed that bicycling with an intensity corresponding to about 6 METs was indicated as a less intensive activity by the accelerometer compared to a brisk walk corresponding to 4 METs. Further, contribution to energy expenditure from upper-body activities will likely be lost as changes in physiological work load for such activities are not mirrored by a change in vertical body accelerations. Using multiple uniaxial sensors (e.g. placed on the waist and the wrist), aiming to include arm movements, may increase accuracy in assessing body movements. Kumahara et al. (2004) combined data from two uniaxial sensors worn simultaneously at the wrist and waist while measuring energy costs for different activities in a respiratory chamber. Regression analysis for predicting energy cost from accelerometer output showed that the explained variance improved by 2% only when adding the wrist sensor in addition to the waist sensor. Since the contribution of upper-limb movement explaining the variance in energy expenditure seems limited, the use of multiple sensors may be questionable as it will impose a more resource-demanding procedure and also a higher compliance by the participants.

Several commercially available uniaxial accelerometers exist, where the MTI Actigraph (Manufacturing Technology Inc, Fort Walton Beach, FL, USA) accelerometer (formerly known as the Computer Science and Applications activity monitor), is currently the most frequently used for physical activity assessment. The MTI accelerometer, model 7164, is a small (4.5 X 3.5 X 1.0 cm) and relatively lightweight (43 g) monitor that measures accelerations in the vertical plane. The monitor samples voltage signals in proportion to detected accelerations (range: 0.05–2.0 g with a frequency rate of 0.25–2.5 Hz) with a sample rate of 10 measures per second. The signals first become filtered to discriminate human movement from vibration and other artefacts before converted into a digital set of numbers, called ‘counts’. Finally, all counts sampled are summarized over a user-specified time frame (epoch). A firm plastic case with a rubber lining constitutes the outer shell of the monitor protecting the piezoelectric sensor inside. The monitor is initialized for sampling by connecting the monitor to a computer program via an interface, and after measurement data from the monitor is downloaded via the interface onto a computer. When using a one-minute sampling interval the MTI monitor can sample data for 22 consecutive days. The small, lightweight and yet robust design, together with a detailed data sampling and large storage

capacity, are features that make the MTI monitor a well-adopted tool for assessing free-living physical activity in young age groups.

Recently, MTI replaced the model 7164 with a newer model, called GT1M. Although the GT1M has similar size as the older model, it weighs less (23g) and has a much larger data storage capacity. The preset ranges in detection of acceleration and its frequency are the same as for model 7164. Comparisons between model 7164 and GT1M in data output during assessment of physical activity in free-living conditions have showed that the GT1M produces slightly lower values (9%) in terms of overall physical activity level ( $\text{cnts}\cdot\text{min}^{-1}$ ) (Corder et al., 2007). However, no difference in assessing time spent at moderate or vigorous physical activity was evident. As all results on physical activity presented in this thesis are based on use of the model 7164, all further descriptions of the MTI monitor will refer to this model.

Metcalf et al. (2002) evaluated intra- and inter-instrument reliability of the MTI monitor during two different speeds using a motorized turntable. The two speeds were set to approximate accelerations applied to the monitor during walking and running. Results showed that intra-instrument variability never exceeded 2%, with no differences between monitors in terms of repeatability, and mean scores for inter-instrument variability never exceeded 5%. Eslinger & Tremblay (2006) evaluated the reliability of the monitor during three different accelerations with three different frequency rates. Intra-instrument variability was on average about 3% and inter-instrument variability was between 8–9%. Apparently, results on the technical reliability vary between these studies, depending on the testing conditions and the number of monitors tested. Notably, larger variability seems to be produced when applying accelerations with frequency rates close or equal to the maximal response rate of the monitor (i.e. 2.5 Hz), while a much improved between and within instrument variability is observed for lower frequency rates. For example, intra-instrument variability was 0.2% when a fixed acceleration with frequency of 2.0 Hz was applied, compared to 6.3% with the same acceleration but with frequency of 2.5 Hz (Eslinger & Tremblay, 2006). The difference in variability depending on frequency rates is likely explained by the signal filtering procedure of the monitor during sampling, which is most sensitive around frequencies of 2.5 Hz. When applied to humans, differences in step frequencies between individuals during high intensity running may produce between-individual variability in monitor output as the monitor filters input signals to a higher degree at higher movement frequencies (Brage et al., 2003a). These authors further showed that during lower movement frequencies, (e.g. walking), step frequency does not affect accelerometer output. Another study by Brage et al.



(2003b) showed that counts derived from the MTI monitor increase linearly with increased speed until 9 km/h and thereafter begin to level-off. The reason is likely due to a relatively constant vertical movement regardless of increased speed during running. Hence, the accelerometer is able to distinguish between different speeds of walking, between walking and running, but not between different speeds of running.

The raw outcome from the monitor (i.e. counts) reflects the total volume of physical activity performed during the given measurement period. For comparisons between individuals when assessing free-living physical activity, total sum of counts is often divided by registered time, as the latter may vary between individuals. Total counts over registered time ( $\text{cnts}\cdot\text{min}^{-1}$ ) provide an estimate of the average intensity of physical activity over a day.

Several studies have examined the strength of relationship between activity counts and components of energy expenditure during different activities.

Based on walking and running on a treadmill, Trost et al. (1998) reported that activity counts from the MTI monitor were strongly correlated ( $r = 0.87$ ) with energy cost ( $\text{kcal}\cdot\text{min}^{-1}$ ) measured with indirect calorimetry in 10-to-14-year-old children, and concluded the monitor to be valid for reflecting energy cost during treadmill walking and running. Similarly, Corder et al. (2005) compared PAEE by indirect calorimetry with activity counts during treadmill walking and running in a group of children (13 yrs), and reported a correlation of  $r = 0.71$ . In comparison to the study by Trost et al. (1998), the weaker correlation in this study is probably due to the fact that changes in work load were made by increasing both treadmill speed and grade during measurements. The accelerometer is unlikely to accurately reflect changes in workload by increased treadmill grade as it will not be followed by a subsequent increase in vertical accelerations. Another study let 8-to-11-year-olds walk and run on a treadmill, play catch, hopscotch and sit down crayoning, while simultaneously measuring oxygen consumption ( $\text{ml}\cdot\text{kg}^{-0.75}\cdot\text{min}^{-1}$ ) by indirect calorimetry and body movement by accelerometer. A correlation coefficient of  $r = 0.78$  was observed for all activities combined (Eston et al., 1998). A similar correlation coefficient was observed in a recent study by Pate et al. (2006), where 3-to-5-year-old children performed three structured activities in a laboratory setting. Correlation between activity counts and oxygen consumption ( $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ) by indirect calorimetry was  $r = 0.82$  across activities.

Ekelund et al. (2001) performed simultaneous measurements of accelerometer counts and energy expenditure by the DLW method in 26 children (9-to-10 years) in free-living conditions over a two-week period. Activity counts were significantly related to average daily PAEE ( $r = 0.54$ ) and PAL ( $r = 0.58$ ). Further ad-

justment for gender and body weight increased correlation for PAEE ( $r = 0.67$ ). Further, no significant difference between activity counts and PAL in classifying individuals in terms of 'low', 'moderate' and 'high' activity levels was evident. The authors concluded that activity counts from the MTI monitor are able to reflect the total volume of physical activity in groups of children during free-living conditions. A recent review also confirmed the MTI accelerometer as the only commercially available monitor that correlates with DLW-derived PAEE with reasonable validity (Plasqui & Westerterp, 2007).

Thresholds for activity counts corresponding to specific intensities of physical activity are useful when analysing time spent at different intensity levels of physical activity (e.g. light, moderate, vigorous) or when examining proportions of children who reach recommended levels of physical activity. Several laboratory-based prediction equations have been developed to convert activity counts to components of TEE for specific use in school-age youth (Trost et al., 2002; Puyau et al., 2002; Treuth et al., 2004; Mattocks et al., 2007), and subsequently applied in several studies to examine the amount and proportion of time spent at different intensity levels derived from activity counts (Reilly et al., 2004; Montgomery et al., 2004; Trost et al., 2002; Pate et al., 2002; Riddoch et al., 2004; Riddoch et al., 2007; Treuth et al., 2007; Ness et al., 2007). All prediction equations have been developed using respiratory gas analysis as the criterion measure. Except for the equation developed by Trost et al. (2002), additional activities besides walking and running (e.g. hopscotch, step aerobics, shooting basket balls) have been incorporated to various degrees between studies.

Walking is an example of a moderate-intensity activity where the relationship between activity counts and energy expenditure is linear. Thus, applying count thresholds corresponding to a given walking speed may be an alternative approach compared with translating activity counts into energy expenditure values. For example, a threshold of 2000 counts/min has been used in studies investigating relationship between accelerometer assessed time spent at moderate-to-vigorous intensity of physical activity (MVPA) and clustered metabolic risk in children (Ekelund et al., 2006; Andersen et al., 2006). Based on previous studies measuring activity counts during treadmill walking, this threshold roughly corresponds to a walking pace of 4 km/h (Trost et al., 1998; Eston et al., 1998; Puyau et al., 2002; Schmitz et al., 2005). In most healthy children, this represents a normal walking speed and examining all time spent above this pace would therefore include the absolute majority of brisk walking and higher intensity activities. Using an intensity threshold based on speed does not allow estimation of energy

expenditure but will provide data on time spent above specific intensity thresholds.

In addition to assess time spent above certain intensity thresholds, assessing time spent in sedentary pursuits is of interest. Two different studies measuring activity counts during sitting and playing computer games in children reported count values well below 100 cnts·min<sup>-1</sup> (Puyau et al., 2002; Treuth et al., 2004) and a threshold approximate to sedentary behaviour of <100 cnts·min<sup>-1</sup> has subsequently been used (Treuth et al., 2007).

The possibility to use accelerometry for predicting daily amounts of energy expenditure is of further interest. However, as children's habitual physical activity behaviour is complex, producing a prediction equation able to accurately reflect daily PAEE in every-day life is difficult. While laboratory-based equations may produce close estimations of energy cost for a set of structured activities in the laboratory (e.g. treadmill walking), they may be inappropriate to use in free-living conditions. The predictive power when applied to free-living conditions will be dependent on the extent to which the included activities during calibration contribute to daily PAEE (Welk et al., 2005). Several laboratory-based studies incorporated additional activities besides walking and running to widen the range of activities to which the equations could be applied (Puyau et al., 2002; Treuth et al., 2004; Mattocks et al., 2007). However, the inability of the MTI monitor (and all movement sensors based on acceleration) to fully reflect energy costs for a number of activities may produce systematic errors when applying a laboratory-based equation in every-day life settings. For example, including upper-body activities (e.g. shooting basket balls) during calibration may lead to a systematic overestimation of PAEE when applied in real life-settings. This is because the monitor would record lower activity counts during upper-body activities than would be the case for a walking speed with the same energy cost. Thus, the chosen mixture of activities during calibration will likely affect the slope and intercept of the regression line for the relationship between activity counts and energy expenditure and subsequently produce discrepancies in prediction outcome between equations. This is also indicated by different thresholds from activity counts proposed to correspond to the same intensity levels between equations. For example, in a group of 9-year-olds, the threshold for MVPA would be > 900 cnts·min<sup>-1</sup> based on the equation by Trost et al. (2002) compared with > 3200 cnts·min<sup>-1</sup> based on the equation by Puyau et al. (2002). Besides the choice of activities included when regressing activity counts on energy expenditure, the number of individuals included, the age range of individuals and the calorimetry methods used have been identified as possible causes of the observed threshold

discrepancies between equations (Freedson, et al., 2005; Welk et al., 2005; Corder et al., 2007). Taken together, prediction equations developed using specific activities in a laboratory are unlikely to be valid throughout the range of free-living activities, which in turn will affect predicted daily PAEE from these equations. Producing an equation based on multiple regression lines may improve predictive power. Crouter et al. (2006) developed an equation based on two regression lines, one based on walking and running and the other based on a set of structured life-style activities (e.g. vacuuming, raking leaves) in a group of adults. Cross-validation showed that the two-point regression model improved accuracy in estimating energy cost from activity counts compared to conventional single-regression models. However, as this equation was based on adults it may not be applicable in children.

An alternate approach when developing a PAEE prediction is to use data obtained during free-living measurements. Compared to a laboratory-derived equation, an equation based on data in free-living settings has favourable appeal as the calibration is made in the same environment in which it will be applied. As an example, Ekkelund et al. (2001) measured PAEE by the DLW method and activity counts in children during free-living conditions for two weeks. By regressing data on average daily activity counts ( $\text{cnts}\cdot\text{min}^{-1}$ ) against measured components of energy expenditure, a prediction equation could be obtained. Notably, although a free-living derived prediction equation based on daily PAEE theoretically may predict energy expenditure from activity counts most accurately, only average values of daily energy estimates can be derived. Thus it cannot be used to obtain thresholds for activity counts corresponding to a certain intensity of physical activity.

Several prediction equations exist, based on different calibration concepts (e.g. laboratory- or field-based). However, degree of agreement between different laboratory-derived and free-living derived equations for the prediction of daily TEE and PAEE is currently unclear. Clarification of comparability is important as equations producing large differences in predicted outcomes will affect data interpretation between studies.

### **1.2.2 Other objective methods**

Several additional objective assessment techniques exist, whereas some have limitations regarding their ability to measure volume and/or different dimensions of physical activity in free-living conditions.

Respiratory gas analysis (indirect calorimetry) is valid for measuring energy expenditure with a high time resolution but it is inapplicable in field settings (Kohl et al., 2000; Schutz et al., 2001). Behavioural observation can be included among objective methods as the outcome does not rely on self-report. However, the time- and labour-consuming procedure make direct observations confined to relatively short periods, which seriously limit the ability to capture patterns of habitual physical activity or estimate daily energy expenditure (Sallis & Owen, 1999). Further, because of the time-consuming procedure observational studies will be limited to smaller samples (Lagerros & Lagiou, 2007; Livingstone et al., 2003). The presence of observers may also influence the behaviour of the observed individuals, and they may not allow to be observed with the required intrusiveness (Sallis & Owen, 1999). Because of the detailed information on physical activity behaviour that can be obtained during shorter time periods, direct observation has been suggested as a suitable criterion measurement against which other methods aiming to assess patterns of physical activity can be validated (Welk et al., 2000).

Another existing objective method is the pedometer, a device measuring step frequency by sensing vertical movement of the body. The pedometer is a relatively cheap and feasible tool for field studies and can provide a rough picture of total volume of physical activity by the accumulated number of steps taken during the measurement period. The pedometer is limited to measure only vertical body movements, which make upper-body activities or work against external forces to remain undetected. Another limitation is that the pedometer cannot record the magnitude of movement, thus it cannot assess changes in the intensity of movement (Trost et al., 2001). Crouter et al. (2003) evaluated ten pedometer models in their ability in assessing steps, distance walked and energy cost during treadmill walking at different speeds. The authors concluded that pedometers in general are most accurate for assessment of steps, less accurate for assessing distance and not reliable for assessing energy cost. Another study has showed that pedometer steps are moderately correlated against whole-body accelerometry ( $r = 0.47$ ) during assessment of physical activity in children in free-living conditions (Treuth et al., 2003). The lacking ability of assessing intensities of movement have produced different conclusions about number of steps that supposedly correspond to time spent in physical activities above certain thresholds of intensity in children. For example, 8000 steps have been concluded to estimate 33 minutes (Tudor-Locke et al., 2002) or 60 minutes (Jago et al., 2006) of physical activity of at least moderate intensity.

Besides accelerometry, two objective assessment techniques; measurement of TEE by the doubly labelled water technique and measurement based on heart rate recording are applicable in field settings and have the proven ability to assess energy expenditure and/or reflect habitual patterns of activity (i.e. intensity, duration and frequency) with accepted accuracy and reliability. Furthermore, an integrated approach by combining movement registration by accelerometry and heart rate recording could be used as one method.

**The doubly labelled water method (DLW).** The DLW method is regarded as the most accurate method to assess energy expenditure outside the laboratory environment (Westerterp, 1999b; Müller & Bosy-Westphal, 2003). The method estimates energy expenditure on group level within 1–3% of reference values measured by respiratory gas analysis in the laboratory (Schoeller et al., 1986; Speakman et al., 1993; Racette et al., 1994) and the repeatability is about 4–10% depending on reviewed studies (Murgatroyd et al., 1993; Montoye et al., 1996; Speakman, 1998).

The theory and principle of the method has previously been presented (Speakman, 1998). In short, the individual ingest a dose of labelled water ( $^2\text{H}_2^{18}\text{O}$ ) with known concentration of stable isotopes of hydrogen ( $^2\text{H}$ ) and oxygen ( $^{18}\text{O}$ ). The labelled hydrogen and oxygen will then gradually leave the body, hydrogen as water ( $^2\text{H}_2\text{O}$ ), principally as urine and sweat, and the oxygen as water ( $\text{H}_2^{18}\text{O}$ ) but also as carbon dioxide ( $\text{C}^{18}\text{O}_2$ ). Since the elimination rate of the isotopes is directly related to the carbon dioxide production, measuring the divergence of isotope enrichment between different time points the carbon dioxide production can be estimated. Finally, by using information on the macronutrient composition of the diet (the food quotient), TEE during the measurement period can be estimated. A measurement period is usually between 1–3 weeks. The isotopes can be sampled from any body fluid although urine samples are most commonly used.

The method do not interfere with normal living and low participant burden, makes the DLW method feasible to use even in young age groups. Furthermore, information about an individual's total body water is provided from either of the isotopes and from this information body composition can be estimated. This is clearly an advantage since information about body composition can be of interest as potential predictors of TEE when evaluating other methods for assessment of TEE (Montoye et al., 1996). However, the high costs for the isotopes, combined with expensive analysis procedure, limits the use to studies based on smaller samples. Another disadvantage is that no more than the TEE for the whole measure-

ment period is provided, and no information on pattern (intensities, duration and frequency) of physical activity is given, which further limit its application in assessment of physical activity behaviour (Kohl et al., 2000). The DLW method is frequently used as a criterion when validating other physical assessment methods during free living conditions.

**Heart rate monitoring.** The basic principle when assessing physical activity using heart rate (HR) monitoring is the close relationship between HR and  $\text{VO}_2$ , hence energy expenditure, during a wide range of exercise intensities (McArdle et al., 2006). HR is an indirect measure of physical activity as it measures the physiological response to activity and not body movement. Notably, the fact that the HR response tends to lag behind changes in movement and also may remain elevated a time after cessation of movement may limit its ability to capture sporadic activity patterns, especially occurring in children (Troost, 2001). HR is recorded using a transmitter fixed in a belt around the chest and a receiver worn as a wristwatch. The small size of the instrument and storage capabilities sufficient to record heart rates over weeks at a time makes it a well-adopted tool for assessing habitual physical activity in field settings. The method is feasible for use in epidemiological studies for assessing level and pattern of energy expenditure (Wareham et al., 1997). Because of the linear relationship between HR and  $\text{VO}_2$ , a proxy measure of energy expenditure can be predicted from HR values as well as information on time spent at different intensities of physical activity. However, using absolute HR values (e.g. 140 or 160 beats per min) for defining time spent at different intensity levels may be biased as HR at a certain workload vary between individuals (Epstein et al., 2001; Ekelund et al., 2001). Age, gender, body size and training status are examples of factors that influence the HR- $\text{VO}_2$  relationship (Freedson & Miller, 2000; Troost, 2001). Therefore, to be able to translate HR into a measure of energy expenditure in each individual, regression equations for the relationship between HR and  $\text{VO}_2$  must be determined individually. Walking and running at different speeds on a treadmill while simultaneously measuring HR and  $\text{VO}_2$  is commonly used for this purpose (Lamonte & Ainsworth, 2001; Freedson & Miller, 2000). Individually calibrated HR monitoring provide close estimations of TEE on groups level when validated against the DLW method and whole body calorimetry (Ceesay et al., 1989; Livingstone et al., 1992; Ekelund et al., 2002). The method has been reported to lack validity on an individual level, with an error of approximately 20% (Davidson et al., 1997). It should be noted that the predicted linear relationship between HR and  $\text{VO}_2$  is dependent on the chosen activities during calibration and it is unlikely that activities used during calibra-

tion in the laboratory can represent all kinds of activities causing cardio-respiratory responses during free living conditions (Livingstone, 1997). Further, the calibration curves obtained in the laboratory is most valid for moderate-to-vigorous activities and thus less reliable during lower levels of physical activity. Emotional stress, changes in ambient temperature and humidity affects HR (Livingstone et al., 2003; Freedson & Miller, 2000; Lamonte & Ainsworth, 2001). Moreover, HR responses are depending on the relative size of the working muscle mass. For example, arm exercise elicits a higher HR compared to leg exercise at the same  $VO_2$  because of the smaller muscle mass in the arms (McArdle et al., 2006; Freedson & Miller, 2000). Although the method is regarded to be feasible in relatively large population studies (Wareham et al., 1997), it requires high compliance by the participants which may limit its use in younger children.

**Combination of HR recording and movement sensors.** When aiming to quantify daily measures of energy expenditure, both HR recording and movement registration by accelerometry are associated with limitations as described in previous chapters. For example, relationship between HR and oxygen uptake is weaker for low-intensity activities compare to more vigorous intensity levels, while high intensity running or load-bearing activities are underestimated by accelerometry. Since measurement error associated with each method are uncorrelated, using a combination of HR recording and movement sensing would theoretically reduce limitations inherent with each method used alone, and produce a more accurate estimation of energy expenditure (Brage et al., 2004; Strath et al., 2002, Rennie et al., 2000). One example of a combined HR and movement sensor is the Actiheart. Two versions of the Actiheart currently exist, one developed in the U.K (Cambridge Neurotechnology, Cambridge, UK) and one in the U.S. (Mini Mitter, Sunriver, OR, USA). The Actiheart (U.K model) has been validated in a laboratory setting in adults (Brage et al., 2005) and children (Corder et al., 2005), where highest correlation with energy cost measured by indirect calorimetry during walking and running was obtained when using a combined HR and movement regression model compared to single HR or movement models. Crouter et al. (2007) evaluated the Actiheart (U.S. model) in adults during a large set of activities in a field setting. Comparisons of predicted PAEE against measured PAEE by indirect calorimetry revealed that a combined activity and HR algorithm provided similar estimates of PAEE as when using a HR algorithm on both a group and individual basis. While the Actiheart has showed promising result based on activities in the laboratory, further studies of the ability of combined HR and movement sensors in predicting estimates of PAEE on child groups in free-living set-



tings are needed. Developing prediction equations for estimating daily PAEE has been warranted, preferably performed in free-living settings with the DLW method as criterion (Corder et al., 2007).

### **1.2.3 Subjective methods**

Data from subjective methods rely on the validity of the reported response by the respondent or from a spokesperson of the respondent. Subjective methods include self-administered or interview-administered recall questionnaires, activity logs and proxy-reports (Sallis and Saelens, 2000; Lagerros & Lagiou, 2007), where proxy-reports provided by parents or teachers are more common when assessing physical activity behaviour in young children (Sallis and Saelens, 2000). Depending on type of method, information on patterns on physical activity can be obtained (i.e. frequency, duration and intensity), as well as type of activity (e.g. weight-bearing) and in which context the activity occurs (e.g. occupational- or leisure-related). Further, if activities are ranked in relation to their intensity, estimates of total volume of physical activity can be obtained by assigning a MET value to each activity (Westerterp, 1999b; Lagerros & Lagiou, 2007). The latter information is typically derived from self-reported activity logs (also called diaries), where the respondents are told to record all their activities within specified time blocks (e.g. every 15 minutes). Apart from the activity log, which requires high compliance from the respondents (Lamonte & Ainsworth, 2001), questionnaires are often acceptable by most individuals, low in cost and feasible to use in large study populations (Sallis & Owen, 1999). Among the different self-report methods, self-administered questionnaires are most common in children and adolescents. This because activity logs is regarded as too demanding and proxy-reports often provide a very crude measure of children's activity behaviour as parents or teachers are unable to observe children all day (Sallis & Owen, 1999). However, it has been argued that considerably cognitive demands are placed on the respondent when asked to recall specific events that may have occurred in the past (Baranowski 1988), which would impose questionnaires as a generally crude method for use in younger children. This argument is supported by the belief that children's activity behaviour is sporadic and intermittent (Baily et al., 1995; Welk et al., 2000), making it difficult to accurately recall. Compared to adults, children are less able to accurately recall activities and tend to make poor estimations about the actual time of activities performed (Welk et al., 2000). Because of the expected loss of validity when applying self-report methods in younger ages, it has been stated that self-report methods should be used with caution in ages 10 to

15 years, and be avoided in children under the age of 10 years (Sallis & Owen, 1999; Kohl et al., 2000). Although the validity of self-report may be questioned in younger age groups, it should be noted that other information from self-report in young age groups may still provide important data as supplement to objective measures of physical activity behaviour. For example, asking children about participation in organized sports or mode of transportation to school may provide possibilities to identify mediators of objectively assessed physical activity behaviours.

### **1.3 PHYSICAL ACTIVITY, INACTIVITY AND HEALTH EFFECTS**

Cardiovascular diseases (CVD), including coronary heart diseases and stroke, are the number one cause of premature death and are responsible for a large portion of health care costs throughout Europe (McKay & Mensah, 2004). Other chronic disorders or morbidities typical for our affluent society includes accumulation of adiposity to an obese state, elevated levels of low density lipoproteins and total cholesterol in the blood, and glucose intolerance by insulin resistance of the muscle cells. These chronic disorders often act together as a cluster of risk factors, termed ‘the metabolic syndrome’, exerting a strong increased risk for CVD and diabetes mellitus (U.S. Department of Health and Human Services, 1996; National Institutes of Health, 1997; McArdle et al., 2006).

The high prevalence of degenerative diseases in our time may be explained by our dramatic change in lifestyle pattern over a relatively short period of time. Human cardio-respiratory and musculoskeletal systems were developed in a foraging environment where our ancestors lived as hunter-gatherers (Eaton & Eaton, 2003). Although our industrialised society has changed considerably during the last 100 years, the contemporary human genome has only changed minimally from the one selected in a stone-age environment many thousands of years ago (Cordain et al., 1998). During the majority of human existence the basis of survival has been dependent on individual physical activity, where availability of food and energy expenditure from physical activity has been closely linked (Eaton & Eaton, 2003). Daily energy expenditure from physical activity in ancestral humans living in foraging environments has been estimated to about 1000 kcal-day<sup>-1</sup>, with daily food intake around 3000 kcal-day<sup>-1</sup> (Cordain et al., 1998). The subsistence efficiency; reflecting how much food energy that can be acquired for a given volume of physical activity, would for our ancestors thus have been about 3 : 1. In comparison, sedentary adults in modern societies may have a food intake of about 2500 kcal-day<sup>-1</sup> and energy expenditure from physical activity of about 500

kcal-day<sup>-1</sup>, yielding a subsistence efficacy of 5 : 1. The obvious change of the ancient relationship between intake of food energy and level of physical activity likely reflects the diminished demand for being physical active for survival in our modern society. Unfortunately, as the necessity to be physically active becomes degraded, an excessive food intake in relation to the energy expenditure may easily results in unfavourable accumulation of body fat and related co-morbidities. Hence, our contemporary lifestyle with typically less physically demanding tasks in our everyday lives, together with an abundant access to food energy, likely facilitate the occurrence of adverse health effects.

Over the latest decades, prevalence of overweight and obesity has increased at a rate considered to be of epidemic proportions (World Health Organization, 1998; James et al., 2001; Mokdad et al., 2003). Since obesity is a strong predictor for the development of insulin resistance (Mokdad et al., 2003; American Heart Association, 2003), it is not unexpected that the prevalence of diabetes has increased globally (Amos et al., 1997; Wild et al., 2004) and is projected to further increase during the coming two decades (Wild et al., 2004). Although the development of the morbidity is multi-factorial, a large body of evidence exists for the relationship between sedentariness and increased risk for CVD and related risk factors in adults. In short, physical activity is negatively related to development of CVD, with coronary heart disease in particular, where those who change from being inactive to at least moderately active significantly reduce their CVD risk (Berlin et al., 1990; Paffenbarger et al., 1993; Sesso et al., 2000; Lee et al., 2001). Further, significant influences of physical activity for the prevention and treatment of diabetes and factors related to the metabolic syndrome, including obesity, have frequently been reported (Tuomilehto et al., 2001; Erlichman et al., 2002; Hu et al., 2005; Wareham et al., 2005; Ekelund et al., 2007; Jeon et al., 2007).

In children and adolescents the prevalence of manifest diagnosis of CVD or diabetes is for natural reasons very low compared to the adult population. However, prevalence of overweight in youth have increased globally over the last decades (Mårild et al., 2004; Andersen et al., 2005; Lobstein et al., 2003; Lobstein et al., 2007; Kimm & Obarzanek, 2002). Similarly, the prevalence of type 2 diabetes, which normally is regarded as a middle-age disease, has reported to increase in children and adolescents (American Heart Association, 2003; Alberti et al., 2004). The strong link between obesity and diabetes in young people is evident as about 85% of the children and adolescents diagnosed with diabetes are reported to be overweight or obese (American Diabetes Association, 2000). The pathological processes and risk factors associated with typically adult-related morbidities (e.g. atherosclerosis) have been reported to be evident already in childhood

(McGill et al., 2000). Further, overweight in childhood increases the risk of overweight in adulthood (Whitaker et al., 1997; Field et al., 2005; Deshmukh-Taskar et al., 2006), and being overweight during growth years has showed to increase risk of adverse health effects and premature death in adulthood (Must et al., 1992; Dietz, 1998; Maffei & Tataru, 2001; Field et al., 2005). Taken together, these findings provide a rationale for the need of prevention efforts, including promotion of physical activity, to begin already in early ages.

Despite the recently increased prevalence of unhealthy weight gain and related morbidities in the young population, no firm evidence for a casual link between higher levels of physical activity and positive health effects in youth exists (Riddoch, 1998; Livingstone et al., 2003; Biddle et al., 2004). The reason for this is likely multi-factorial. Children are the healthiest group in the population and markers of health outcomes, supposedly linked to a physically active lifestyle, may be hard to sufficiently detect in childhood (Biddle, et al. 2004). That is, the occurrence of certain disease risk factors may not show until later in life, although they may be a consequence of a sedentary lifestyle during childhood. Further, studies based on cross-sectional design allow detection of associations between exposures and outcomes but prohibits conclusions about the direction of the association. To determine causality and the existence of a dose-response relationship between physical activity and health outcomes, controlled randomised trials and longitudinal prospective studies, starting from an early age are needed. Furthermore, the assessment of physical activity is a challenge and methodologically difficult. The choice of assessment method will therefore influence the ability to make valid conclusions about habitual physical activity and its effects on health (Riddoch, 1998).

Although relationship between physical activity and health outcomes observed in children is weaker compared to adults, recent studies have in fact been able to demonstrate beneficial associations between physical activity and an array of health-related outcomes, such as markers for obesity (Rowlands et al., 2000, Berkey et al., 2003; Ness et al., 2007), insulin resistance (Brage et al., 2004; Imperatore et al., 2006), and clustered metabolic risk (Andersen et al., 2006; Ekelund et al., 2006).

Promoting physical activity during childhood should not purely be seen as a preventive measure in order to decrease risk for developing diseases later in life. For example, involvement in various forms of physical activities, including weight-bearing activities, facilitates development of muscular strength and flexibility, increase in bone mineral density and cardio-respiratory functioning during growth (Payne et al., 1997; Bailey et al., 1999; Biddle et al., 1998; Malina et al.,

2004; Strong et al., 2005; Tobias et al., 2007). Establishing a physically active lifestyle in early ages may increase the likelihood of being physically active as an adult. Although a low to moderate tracking of physical activity behaviour has been observed in earlier studies, it has been suggested that patterns in young ages will influence on activity levels in later life (Corbin, 2001). Recent studies have also indicated tracking of physical activity level during years in childhood (Janz et al., 2005), from childhood through adolescents (Kristensen et al., 2007; McMurray et al., 2003), and from childhood into adulthood (Telama et al., 2005). Therefore, a physically active lifestyle is likely beneficial for optimal health development during growth and also for establishing long-term physical activity habits and decrease the risk of adverse health effects later in life.

#### **1.4 PHYSICAL ACTIVITY RECOMMENDATIONS**

Over the last decades, numerous recommendations stating appropriate amounts of physical activity for the adult population have been proposed (Blair et al., 2004). The basis for current recommendations about health-related physical activity is the compelling evidence that even relatively small amounts of moderate-intensity physical activity can substantially decrease CVD risk in previously sedentary individuals (Blair et al., 2004; Livingstone et al., 2003). Examples of recommendations on amounts of health-related physical activity aiming at adult populations can be found in Pate et al. (1995) and Haskell et al. (2007). Fewer recommendations exist aimed specifically at children and adolescents compared to adults. One likely explanation is that the relationship between physical activity and health is less consistent in youth compared to adults, thus making a firm evidence-based recommendation difficult. Therefore, the basis for recommendations for youth has borrowed much from the evidence of health effects in adult groups. Blair et al. (1989) suggested a minimum level of physical activity of 3 kcal·kg<sup>-1</sup> per day, an energy expenditure known to be associated with reduced mortality in adults. The focus of the recommendation would primarily be to promote an active lifestyle in early age to persist throughout the lifespan. The amount of physical activity proposed would approximately translate to about 20–40 minutes of daily moderate-intensity physical activity (Cureton, 1994). As a result of an international consensus conference, Sallis & Patrick (1994) presented a set of physical activity guidelines for adolescents (defined as 11 to 21 years). The first guideline stated that all adolescents should be physically active daily as part of the every-day life. No particular intensity or duration was specified. The second guideline stated that all adolescents should engage in at least three sessions per week of physical

activity of moderate-to-vigorous exertion (50% of  $VO_{2max}$ ), with every session lasting 20 minutes or longer. This recommendation is very similar to the current ACSM/AHA recommendation for adults (Haskell et al. 2007).

As the result of a more recent international consensus conference, Biddle et al. (1998) updated the physical activity guidelines. These guidelines now included both children and adolescents (defined as 5 to 18 years) and suggested that all young people should participate in physical activity of at least moderate intensity for one hour per day. The term moderate intensity was defined as approximately 40-60% of  $VO_{2max}$ , and examples of activities of this level would be brisk walking, bicycling and playing outdoors (Pate et al., 1998). A secondary recommendation stated that twice a week some of the activities performed should help to enhance and maintain muscular strength, flexibility and bone health (i.e. weight-bearing activities). Critique against the recommendations may be that the underlying scientific evidence of the proposed amounts (i.e. intensity and duration) and types of activity and its effect on health status during youth remain yet unclear (Epstein et al., 2001; Twisk, 2001). Further, given the high prevalence of childhood obesity, a clearer recommendation stating amounts of physical activity, in terms of energy expenditure, needed to prevent unhealthy weight gain has been warranted (Livingstone et al., 2003). Despite the limited evidence, the recommendation presented by Biddle et al. (1998), stating 60 minutes of daily physical activity of at least moderate intensity, has gained acceptance as the current recommendation to use in the work of promoting health during growth years (Boreham & Riddoch, 2001; Livingstone et al., 2003; Strong et al., 2005).

### **1.5 LEVELS AND PATTERNS OF PHYSICAL ACTIVITY IN YOUTH**

A popular public perception, often emphasized by media, is that of increasingly sedentary lifestyles of contemporary children and adolescents consequently with less time spent at active pursuits compared to previous generations. This perception may be indirectly supported by the observed decline in daily energy intakes in British adolescents from the 1930s to the 1980s, without a concomitant decrease in body mass (Durnin, 1992). However, no firm evidence for a decline in physical activity levels in youth exists. In fact, the exact amount of activity youth engage in is yet undecided. The large number of various studies presenting prevalence rates of physical activity in youth has been characterized more by its quantity than its quality (Livingstone et al., 2003). Previous reviews based on self-report methods have come to different conclusions. For example, it has been suggested that children rarely participate in amounts of activity sufficient to have health

benefits (Cale & Almond, 1992), while others concluded that children spend enough amounts of activity to achieve health benefits (Sallis, 1993). Boreham & Riddoch (1995) reviewed 36 studies, including studies based on self-report and objective monitoring by HR recording and concluded that studies using self-report methods in general report higher levels of physical activity compared to studies using heart rate monitoring. This discrepancy was explained by that children tend to overestimate actual time spent in physical activity, which therefore should be taken into account when interpreting self-report data. Based on studies using HR monitoring, children spent between 15 to 60 minutes at moderate-to-vigorous intensity of physical activity (MVPA) per day. Further, physical activity levels seemed to decline by age and boys were generally more active than girls (Boreham & Riddoch, 1995). Another review by Armstrong & van Mechelen (1998) confirmed the observation that boys are more active than girls and that amount of physical activity decline by age. They also reported that while most children seem to accumulate at least 30 daily minutes at MVPA, very few children are able to sustain a 20-minute period of physical activity of at least moderate intensity, as recommended (Sallis & Patrick, 1994). Finally, the authors concluded that accurate information on habitual physical activity is limited due to the lack of valid objective assessment methods suitable to use in larger representative samples (Armstrong & van Mechelen, 1998).

Epstein et al. (2001) reviewed 26 studies based on HR monitoring and concluded that young people accumulate about 50 minutes of health-related physical activity, meaning that they fulfil the adult recommendation of 30 daily minutes of physical activity, while falling short of the 60-minute recommendation proposed by Biddle et al. (1998). Similar to the previous review by Armstrong & van Mechelen (1998), the authors concluded that children's activity patterns are best described as sporadic and intermittent, as they seem to engage in MVPA in very brief periods rather than in continuous bouts.

The main issue when comparing results from various studies using HR monitoring is that relatively few studies have performed individual calibration for the relationship between HR and  $VO_2$  during different work loads, which is necessary to obtain heart rates corresponding to a specific intensity for each individual. Instead, analysis of time spent above arbitrary values (e.g. 140 and 160 beats per min) have been used in several studies, which limits the ability of making valid conclusions about the actual amount of physical activity performed (Boreham & Riddoch, 1995; Epstein et al., 2001; Ekelund et al. 2001). Given the need of determination of the individual relationship between HR and  $VO_2$ , the use of HR monitoring has often become limited to smaller non-random study populations.

To date, a large number of studies including accelerometer-assessed physical activity have been published. Only those with the specific aim to examine prevalence of physical activity levels in youth are included in the following summary.

Trost et al. (2002) measured daily time spent at MVPA in 375 seven- to 15-year-olds American children. Overall, children spend 50–200 minutes at MVPA depending on age and gender. Physical activity declined significantly with increasing age and boys were more active than girls in all age groups. Based on the same study population, Pate et al. (2002) reported how the observed levels of physical activity complied to recommended amounts of activity previously presented (Sallis & Patrick, 1994; Biddle et al., 1998). Across age and gender groups, about 90% achieved 30 daily minutes of at least moderately-intense physical activity, around 70% achieved 60 daily minutes, and less than 3% showed at least three weekly 20-min bouts of MVPA.

Riddoch et al. (2004) reported time spent at MVPA in 2185 nine- and 15-year-olds from four European countries. The results suggested that children and adolescents spend between 70 to 200 minutes per day at MVPA depending on age, gender and geographical location, which is in agreement with the results previously reported by Trost et al. (2002). Boys were more active than girls, and 9-year-olds more active than 15-year-olds. Almost all 9-year-olds accumulated at least 60 daily minutes at MVPA, and the corresponding results for 15-year-olds were 80% and 62% for boys and girls, respectively. Although a subgroup of adolescents failed to achieve recommended amounts of activity, a large majority seem to accumulate substantial amounts of physical activity sufficient to achieve health effects. In contrast, two recent studies provide a different picture of children's activity levels. Pate et al. (2006) assessed physical activity in 1578 twelve-year-old girls and reported that girls in this age group accumulated in average 24 minutes per day of at least moderately-intense physical activity, and hardly any of the girls (0.6%) achieved the 60-minute recommendation. Similarly, Riddoch et al. (2007), reported that 11-year-old British children (n=5595), only spend about 20 minutes per day of at least moderately-intense physical activity, making the absolute majority (97%) of children to fall short of the 60-minute recommendation. Moreover, only 40% of the boys and 20% of the girls averaged at least one daily bout of activity lasting more than 5 minutes, and less than 1% averaged one daily 20-min bout of activity, regardless of gender (Riddoch et al., 2007). The most likely reason for the obvious discrepancy in proportions achieving the 60-minute recommendation between these studies is the use of different accelerometer count cut-points for defining time spent at MVPA. The result from the studies by Trost et al. (2002) and Riddoch et al. (2004) was based on identical count cut-points,



which is lower compared to those used by Pate et al. (2006) and Riddoch et al. (2007), respectively.

In conclusion, these accelerometer-based studies, together with more recent reviews discussing children's levels of habitual physical activity (Livingstone et al., 2003; Biddle et al., 2004; Strong et al., 2005; Armstrong & Welshman, 2006), confirm a number of conclusions made in earlier reviews. First, the level of physical activity seems to decline by age. This decline is especially observed when comparing age groups before and after puberty. Secondly, boys are generally more active than girls in all age groups. The gender difference seems more pronounced for higher-intensity physical activity. Thirdly, children's activity patterns are intermittent, as they rarely engage in continuous bouts of activity lasting more than a few minutes at a time, although they may accumulate a substantial amount of time in physical activity over a day. Therefore, the number of children classified as achieving sufficient amounts of health-related physical activity will vary dependent on whether recommendations describe continuous bouts of physical activity or accumulated time in physical activity per day. Accumulated time rather than continuous time in physical activity has recently been emphasized as the appropriate measure when evaluating levels of activity in youth (Strong et al., 2005). Finally, while a portion of children and adolescents appear to perform little physical activity, no definite conclusion about levels of daily physical activity among children can currently be made. Nor can it be concluded whether children have become increasingly sedentary over time. Lack of temporal trend data, diversities in methods used and data handling procedures, together with different operational definitions for what is health-related physical activity have made interpretations and comparisons of results between studies difficult. (Welk et al., 2000; Livingstone et al., 2003; Biddle et al., 2004; Armstrong & Welshman, 2006).

## **1.6 VARIABILITY IN PHYSICAL ACTIVITY PATTERNS**

Assessing physical activity with regard to different seasons, type of days and time periods within a day is of interest to increase our understanding about physical activity variability. Identifying type of days or periods within a day typically related to lower levels of physical activity and increased time in sedentary is of interest as such information may facilitate the planning of interventions aiming to promote increased amounts of physical activity.

First it can be hypothesised that variability in physical activity patterns is likely to be observed between seasons, especially in the northern hemisphere where outside temperatures and weather conditions differ substantially between summer and

winter time. Therefore, it has been argued that seasonal variations should be taken into account when interpreting results on levels of physical activity between studies (Livingstone et al., 2003). Recent studies assessing activity levels in children and adolescents have also confirmed an effect of season on physical activity behaviour (Plasqui & Westerterp, 2004; Kristensen et al., 2007; Mattocks et al., 2007).

School days and weekend days are likely to provide different opportunities for being active, and differences in physical activity behaviour are likely to be observed. However, a recent study hypothesised that the variation in physical activity lies within the child and not his environment (Wilkin et al., 2006), which would imply a consistent activity level between days. On the other hand, Jago et al. (2005) reported a significant increase in time spent sedentary (e.g. TV/electronic games) during weekend days compared to weekdays in 13-year-old children, which may indicate that these sedentary activities displace time spent at moderate and vigorous levels of activity. Earlier studies examining differences in the amount of physical activity between weekdays and weekend days are not conclusive. For example, one recent study showed that adolescent girls spend more time at MVPA during weekdays compared to weekends (Treuth et al., 2007). Another study showed contrasting results, where young children spent more time at MVPA during weekends compared to weekdays, while the opposite was observed in adolescents (Trost et al., 2000). Others have shown that time spent at MVPA was greater during weekdays compared to weekend days in primary school children while no clear difference was indicated in high school students (Gavarry et al., 2003). Additionally, one study reported no differences between weekend days versus weekdays in amount of physical activity in first-grade school children (Sallo & Silla, 1997).

Patterns of physical activity and time spent sedentary has previously been shown to vary significantly between different time blocks of a day, and this variability seems to be modified by gender, (Jago et al., 2005). In youth, school time and leisure time are the two major time domains of a weekday and likely provide different opportunities for accumulating physical activity. Physical activity patterns in children have also been reported to be more consistent in the school environment compared to leisure time periods after school (Fairclough et al., 2007). However, there is limited knowledge about the actual amount of time spent physically active during different time blocks within a day, and thus its contribution to the total amount of physical activity. Mallam et al. (2003) and Dale et al. (2000) have reported on physical activity levels stratified by school time and leisure time in 9-year-olds. Mallam et al. (2003) concluded that the total daily amount of physical activity is mainly determined by leisure time activity whereas

Dale et al. (2000), concluded that school time physical activity is the most important contributor to the totality of daily physical activity. No information about differences in time spent in health-related physical activity between time periods was given in these two studies.

In conclusion, information on differences in physical activity pattern with regard type of day (i.e. school day and free day) and within days (i.e. school time and leisure time) is currently inconclusive. Similar to studies examining the prevalence of health-related physical activity, differences in assessment methods and data reduction procedures between studies combined with relatively small sample sizes have made conclusions elusive. Further, information about variability in time spent sedentary is often lacking. Clarifying differences in patterns of physical activity and time spent sedentary, and the effect of those differences for ability to reach recommended levels of physical activity, is of interest as it would provide possibilities to identify appropriate time periods for promotion of physical activity and a subsequent reduction in sedentary behaviour.

## **1.7 BEHAVIOURAL INFLUENCES ON PHYSICAL ACTIVITY**

It has been argued that interventions aiming to promote physical activity should target consistent modifiable correlates of physical activity to be most effective (Baranowski et al., 1998). Age, gender, ethnicity and socio-economic status represent determinants for physical activity (Sallis & Owen, 1999; Wold & Hendry, 1998), however they are not modifiable and more suitable for identifying groups at risk of being inactive. Data from cross-sectional studies of associations can identify behavioural mediators of physical activity and thereby provide a base for selection of appropriate targets for change when planning future interventions (Sallis et al., 2000). Examining determinants on physical activity in children is complicated by the rapid physical, social and psychological development during growth years (Sallis & Owen, 1999). That is, influences on physical activity identified to be important in childhood may change and be irrelevant during adolescence.

Participation in different types of leisure time activities such as organized sports is likely to influence on overall daily levels of physical activity. For example, different rates of enrolment in organized sports between genders has been suggested as one variable explaining gender differences in daily physical activity levels (Vilhjalmsson & Kristjansdottir, 2003). This is supported by studies indicating involvement in organized sports as a determinant for overall levels of physical activity (Spinks et al., 2006), and also a predictor of stability of activity levels through adolescence (Aarnio et al., 2002) and from adolescents into adult-

hood (Telama et al., 2006). Further, two different reviews of correlates of physical activity in children have concluded that time spent outdoors is associated with physical activity in children younger than 13 years (Sallis et al., 2000; Ferreira et al., 2006), suggesting that children's play outdoor incorporate more health-related physical activity compared to indoor activities at home.

Active transportation (e.g. walking or cycling) to and from school has recently gained attention as being a potential mediator of physical activity among youth. Tudor-Locke et al. (2002) reported a significant decrease in proportions of 10-year-old children achieving recommendations of daily physical activity if active commuting was omitted from the analysis, indicating that mode of transportation is an important contributor to daily amount of physical activity. In contrast, Cooper et al. (2003) reported physical activity data based on accelerometer measurements in 10-year-old children and observed no difference in proportions achieving physical activity recommendations between commuting groups, and suggested that any influence of active commuting on overall physical activity was observed in boys only. Sirard et al. (2005) assessed physical activity by accelerometers in 10-year-olds and reported that walking to and from school were associated with 24 additional minutes spent at MVPA. However, only 10 of those 24 minutes were directly related to active commuting (Sirard et al., 2005). Saksvig et al. (2007) assessed physical activity by accelerometer in a large population (n=1596) 12-year-old girls and estimated the contribution to daily time spent at MVPA from active commuting of about 5 minutes.

Sedentary activities such as TV-viewing may potentially have a negative impact on daily levels of physical activity as excessive media use may displace more active pursuits, resulting in low levels of physical activity (Fox and Riddoch, 2000). Some have suggested that TV-viewing and computer use are positively related to overweight in youth (Gortmaker et al., 1996; Robinson, 1999; Marshall et al., 2004; Andersen et al., 2005). Based on this association, limiting TV-viewing among youth to less than two hours per day has been recommended (American Academy of Pediatrics, 2001). A large-scale (n=7982) cross-sectional study examining sedentary behaviours and physical inactivity in 15-year-olds reported TV-viewing to be associated with physical inactivity (Koezuka et al., 2006). It has been suggested that TV may displace time in physical activity in 9 to 12-year-olds, especially in the afternoon time after school (Hager, 2006), while others have reported no association between TV-viewing and time spent in active play in the same age group (Vandewater et al., 2006). One meta-analysis based on a compilation of studies examining associations between TV viewing and physical activity behaviour in youth have concluded associations to be either small or close

to zero, depending on age groups studied (Marshall et al., 2004). Further, a recent longitudinal study reported no associations between changes in TV viewing and changes in leisure time MVPA in 10 to 15-year-olds (Taveras et al., 2007).

Several previous studies evaluating impact of different behavioural influences on physical activity and time spent sedentary have been based on self-report methods (Sallis et al., 2000; Tudor-Locke et al., 2002; Vilhjalmsson et al., 2003; Spinks et al., 2006; Koezuka et al., 2006; Vandewater et al., 2006; Taveras et al., 2007). Given the fact that children's activity pattern seems to be characterized by intermittent episodes of physical activity with short durations and varying intensities (Baily et al., 1995; Armstrong & van Mechelen, 1998; Epstein et al., 2001), it is unlikely to be captured accurately by self-report. Therefore, self-report methods may limit the detailed description of physical activity behaviour in youth and the true associations between different behavioural variables and physical activity is less likely to be observed. Therefore, examining influence of potential correlates of physical activity and time spent sedentary based on an objective assessment technique is much more likely to detect existing associations and its actual strength. Moreover, as the effectiveness of any promotion effort aiming to increase physical activity levels and reduce sedentary behaviour is likely dependent on selecting appropriate mediators of habitual physical activity, further investigations clarifying such mediators for different age groups is warranted.



## 2 PURPOSE

The overall purpose of the studies summarised in this thesis was to increase the knowledge about the use of accelerometry when assessing physical activity in children, and examine sources of variability in objectively assessed physical activity behaviour in children. Specific aims were to:

1. examine how different time sampling intervals (epochs), and the influence of placement of the monitor, would affect the outcome from the MTI accelerometer (**Study I**).
2. examine the degree of agreement between three different equations, developed to predict energy expenditure from accelerometry, when applied to a large sample of children (**Study II**).
3. examine differences in level of physical activity, time spent at MVPA and time spent sedentary between- and within-days with regard to age, gender and geographical location in 9- and 15-year olds from four European countries (**Study III**).
4. examine associations of potential correlates (mode of transportation, outdoor play after school, participation in exercise in clubs, and TV viewing) on objectively assessed physical activity and sedentary behaviour in a large sample of 9- and 15-year-olds from three different geographical regions in Europe (**Study IV**).





## 3 MATERIALS AND METHODS

### 3.1 STUDY DESIGN AND SAMPLING

The children in **Study I** were recruited by a convenience-sampling procedure from a local elementary school in the Örebro area of Sweden. A total of 16 seven-year-old children (10 boys and 6 girls) participated. The children and their parents signed a written consent form prior to the study.

Children included in **Study II** to **IV** were all participants in the European Youth Heart Study (EYHS). The EYHS is a multi-centre cross-sectional study aimed to study the nature, strength and interactions between personal, environmental and lifestyle influences on CVD risk factors in a large population of children from different European countries. The EYHS comprises data from Norway (Oslo), Denmark (Odense), Estonia (Tartu) and Portugal (Madeira) and have been pooled into one database for analysis. To ascertain comparable data, all participating countries followed a standardized protocol on sampling procedure and data variable assessment. A pre-study training program for all researchers involved in variable assessment was carried out, and standardization and calibration of all instruments and equipments were made across study locations. A complete description of rationale, aims, study design and assessed variables in the EYHS has been presented previously (Riddoch et al., 2005).

The study sample was recruited using a two-stage cluster procedure in each study location. First, all public schools within each local area was identified and stratified by school grade and mean income level of the local area; below or over the mean income in the municipality. Schools were then randomly selected within each stratified group and invited to participate. Secondly, groups of children aged 9 and 15 years were randomly selected from each school in proportion to school size and invited to participate. Written informed consent was obtained from parent or legal guardian to each participant and the study was approved locally in each country. A total of 4072 children agreed to participate. Of those, 2739 children completed assessment of PA (67%). Due to inclusion criteria to ascertain quality of PA data, the final sample with complete PA data was 1184 nine-year-olds (Denmark: 301 [141 boys]; Portugal: 292 [151 boys]; Estonia: 299 [151 boys]; Norway: 292 [152 boys]) and 770 fifteen-year-olds (Denmark: 198 [86 boys]; Portugal: 162 [79 boys]; Estonia: 272 [100 boys]; Norway: 138 [58 boys]). In both ages, no difference between the final sample and those excluded was evident in height, weight or body mass index, with the exception of height among 15-year-old boys (included vs. excluded:  $174 \pm 8$  cm vs.  $172 \pm 8$  cm;  $P < 0.05$ ).

### **3.2 ANTHROPOMETRICS**

In all studies (I to IV), height was measured to the nearest 0.5 cm with a portable Harpenden stadiometer and weight was measured to the nearest 0.1 kg with a beam balance scale. Body mass index was additionally calculated as weight (kg) / height<sup>2</sup> (m) (Study II).

### **3.3 ASSESSMENT OF PHYSICAL ACTIVITY**

In all four studies, data on physical activity (PA) was assessed using the MTI accelerometer, model 7164 (Manufacturing Technology Inc., Fort Walton Beach, FL). The children were told to wear the monitors during all waking hours, except when bathing or swimming.

In Study I, activity registration was conducted over a 4-day period, three weekdays and one weekend day. All children wore two monitors, one on the lower back (i.e. as close as possible to the centre of gravity) and the other on the right side of the hip. The monitors were tightly strapped to the body using an elastic belt. The monitors were initialized to measure with a 5-second epoch. The monitors were switched between hip and back placement after half of the measurement period to control for potential inter-instrument differences. Because of the limited memory capacity of the monitor when using the 5-second epoch, data was downloaded after two days and then reinitialized to measure the two remaining days.

In Study II to IV, the children wore the accelerometer using an elastic belt attached on the hip during all waking hours for four consecutive days, including two weekdays and two weekend days. Four days of measurement was selected to balance activity recording time to be fairly representative for average PA behaviours on group level, and yet being logistically feasible for administration in a larger study population, and also to minimize demand on subjects. Previous studies have shown that four days of measurement provide a reliable picture of habitual PA in children (Janz et al., 1995; Trost et al., 2000).

The accelerometer was set to record PA data every minute (60s epoch). The administration of accelerometers was conducted in collaboration with the schools and therefore the measurement period followed the school year, with the majority of measurements performed between September and May. Inclusion criteria were a minimum of three days of registration, including at least one weekend day and at least 600 registered minutes per day. Although 10 hours do not cover all wak-

ing hours it was yet considered to provide a sufficient picture of daily PA. A recent study has also shown that reliability in assessing daily habitual PA increases with increased monitored time, but only up to 600 min per day (Penpraze et al., 2006).

### 3.4 PHYSICAL ACTIVITY DATA REDUCTION AND ANALYSIS

In all four studies, sequences of 10 or more consecutive zero counts were defined as missing data. This to ensure that only wear-time of the monitor was calculated as registered time. In **Study I**, the activity counts were reintegrated from 5-second epochs into 10-, 20-, 40- and 60-second epochs.

In all four studies, total number of counts over registered time (cnts·min<sup>-1</sup>) was calculated and expressed as overall level of PA. Time spent at different intensities of PA was additionally expressed (**Study I, III, IV**). In **Study I**, cut-off limits for activity counts defined as moderate (1952–5724 cnts·min<sup>-1</sup>), high (5725–9498 cnts·min<sup>-1</sup>) and very high intensity ( $\geq 9499$  cnts·min<sup>-1</sup>) levels were used based on a previously published prediction equation (Freedson et al., 1998). These limits correspond to 3–5.99, 6–8.99 and  $\geq 9$  METs, respectively based on measurements in adults. However, they were slightly modified in order to make them divisible into exact numbers. Thus, the cut-off limits used were 1956–5759, 5760–9479 and  $\geq 9480$  cnts·min<sup>-1</sup>. Since these limits are only useful with a 60-second measurement period, they were divided to correspond to the outcome of 5-second (163-479, 480-789,  $\geq 790$  cnts·epoch<sup>-1</sup>), 10-second (326-959, 960-1579,  $\geq 1580$  cnts·epoch<sup>-1</sup>), 20-second (652-1919, 1920-3159,  $\geq 3160$  cnts·epoch<sup>-1</sup>) and 40-second epoch (1304-3839, 3840-6319,  $\geq 6320$  cnts·epoch<sup>-1</sup>) measurements (**Study I**). The number of minutes in each intensity level was summarized over all four measurement days. In addition, total number of 10-minute periods where activity counts exceeded the moderate intensity threshold was calculated over the four-day measurement.

In **Study III** and **IV**, all minutes above 2000 counts during a day was summarized and expressed as time spent at MVPA. This threshold roughly estimates a walking pace of 4 km/h (Eston et al. 1998; Brage et al., 2003; Puyau et al., 2002; Schmitz et al., 2005), and has been used in previous studies for defining time spent at MVPA in children (Ekelund et al., 2004; Andersen et al., 2006). In addition, time spent sedentary was defined as  $< 100$  cnts·min<sup>-1</sup>. Measurements during sitting and playing video games in children have showed count values well below 100 cnts·min<sup>-1</sup> (Puyau et al., 2002; Treuth et al., 2004) and this threshold has

been also used to define time spent sedentary in similar studies (Treuth et al., 2007).

In **Study III**, all data was calculated separately for weekdays and weekend days. Further, all data from weekdays were divided into two time blocks. In 9-year-olds, the two time blocks were set from 8 AM to 2 PM and 2 PM to midnight. Corresponding values for the 15-year-olds were 8 AM to 3 PM and 3 PM to midnight, respectively. These two time blocks were selected representing an average school day based on personal knowledge about schooling times obtained during the data collection in the participating schools. Finally, proportions accumulating at least 60 minutes of MVPA was calculated and separated for weekdays and weekend days, and school time and leisure time (**Study III**).

### **3.5 PREDICTIONS OF ENERGY EXPENDITURE ESTIMATES**

TEE and its components (PAEE and PAL) were calculated from accelerometer counts based on three different prediction equations (**Study III**).

The first set of estimates was based on an equation developed by simultaneous measurement of accelerometer counts, expressed as  $\text{cnts}\cdot\text{min}^{-1}$ , and PAEE ( $\text{kcal}\cdot\text{day}^{-1}$ ) by the DLW method in 26 children (9 yr-olds) in free-living conditions (Ekelund et al., 2001). The second set of energy expenditure estimates was based on an equation developed during treadmill locomotion in 80 children with an age range of 6-17 years, where oxygen uptake by indirect calorimetry and accelerometer counts were simultaneously measured during the test (Troost et al., 2002). The third set of energy expenditure estimates was based on an equation developed during different structured activities in a metabolic chamber where PAEE (by indirect calorimetry) and accelerometer counts were simultaneously measured in 26 children with an age range of 6-16 years (Puyau et al., 2002). Energy expenditure estimates from the free-living derived equation (Ekelund et al., 2001) were compared with estimations from the two laboratory-based equations developed for use in children (Troost et al., 2002; Puyau et al., 2002). All three equations are shown in **Table 1**.

TEE was predicted by recalculating 1 MET defined as  $3.5\text{mlO}_2\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$  to units of energy expenditure ( $\text{kcal}\cdot\text{day}^{-1}$ ) by assuming a conversion factor of 4.825 kcal per litre of oxygen consumed, and a resting respiratory quotient equivalent to 0.82 (Weir, 1949) from the equation developed by Troost et al. (2002). This value was then multiplied with the predicted MET value to express TEE. Predicted resting energy expenditure (REE) according to Schofield et al. (1985) was subtracted from TEE to predict PAEE.

Similarly, TEE was calculated by summing PAEE and predicted REE estimated according to Schofield et al. (1985) when estimated from the equation developed by Puyau et al (2002).

When calculating TEE from PAEE and REE (or vice versa) from the laboratory-based equations, the diet induced thermogenesis was assumed to account for 10% of TEE (Maffeis et al., 1993).

**Table 1.** The three equations used for predicting TEE and its components from accelerometer measurement.

|                       | Prediction Equation  |
|-----------------------|--|
| Ekelund et al. (2001) | $PAEE \text{ (kcal}\cdot\text{day}^{-1}) = 66.847 + (\text{cnts}\cdot\text{min}^{-1} \cdot 0.953) - (176.91 \cdot \text{Gender})$                                |
| Puyau et al. (2002)   | $PAEE \text{ (kcal}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}) = 0.0183 + (\text{cnts}\cdot\text{min}^{-1} \cdot 0.00001)$  |
| Trost et al. (2002)   | $METs = 2.757 + (\text{cnts}\cdot\text{min}^{-1} \cdot 0.0015) - (0.08957 \cdot \text{Age}) - (0.000038 \cdot \text{cnts}\cdot\text{min}^{-1} \cdot \text{Age})$ |

Gender: boys = 0, girls = 1. Age in years.

Average energy expenditure estimates per day were calculated in two ways from the laboratory-derived equations. The first approach was calculated by multiplying the predicted outcome per minute by 1440 (24 hours). The second approach was calculated by multiplying the predicted outcome per minute by measured accelerometer time, assumed to correspond to awake time. The remaining time of the day was assumed as sleep, and energy expenditure was defined as REE according to Schofield et al. (1985).

### 3.6 SELF-REPORTED MEASURES

In Study IV, all participants completed a structured computerized questionnaire on numerous items related to health behaviour. The questionnaire was adapted from previously validated self-report instruments (Edmundson et al., 1996; Kowalski et al., 1997) and developed specifically for the EYHS. All children comple-

ted the questionnaire individually and a researcher was available at all time to assist the child understanding the questions if needed. Otherwise the researcher was instructed not to interfere during the completion of the questionnaire. Questions were asked individually and had to be answered before proceeding to the next question. Four items acting as potential correlates of objectively measured time spent sedentary, time spent at MVPA and overall level of PA was chosen as follows; a) usual mode of travel to and from school including average time of travel, b) frequency in taking part in outdoor play after school, c) participation in exercise within sport clubs, and d) daily time spent watching television.

Mode of travel to school was a closed question with three possible answers (motorized transport, bicycling and walking). However only motorized transport (non-active) and walking (active) was included in the analysis since vertical accelerometry is unable to reflect PA intensity during bicycling (Treuth et al., 2004). Only three 9-year-olds and eleven 15-year olds reported bicycling to school. Those who reported motorized transport in one direction and walking in the opposite direction were classified as active commuters. Time length of travel had five possible answers ('less than 5 min', '5 to 15 min', '15 to 30 min', '30 min to 1 hour', 'more than 1 hour'). Data on frequency of outdoor play during leisure time ('how often do you play games outside after school?') had four possible answers ('never/hardly ever', 'once or twice a week', 'most days', 'every day'). Before analysis, data were combined into two outcomes ('twice a week or less' or 'most days/every day'). Data on participation in exercise in clubs ('how often do you take part in exercise in clubs?') had four possible answers ('never/hardly ever', 'once or twice a week', 'most days', 'every day') and was also combined into two outcomes ('never/hardly ever' or 'at least once a week'). Data on time watching television was based on two questions ('how many hours of TV do you usually watch before school?' and 'how many hours of TV do you usually watch after school?') with five possible answers ('none', 'less than 1 hour', '1–2 hours', '2–3 hours, more than 3 hours') for each question. Data on TV viewing before and after school were summarized and combined into two outcomes ('less than 2 hours per day' or '2 hours or more per day'). In addition, data on parental socio-economic status (SES) were collected by parental report, assessed as a combination of the highest income and education in both parents. A detailed description of how parental SES was calculated has been described elsewhere (Lawlor et al., 2005).

### 3.7 STATISTICS

Mean  $\pm$  SD are used to describe physical characteristics of the individuals, data on PA and estimates of energy expenditure components. One-way analysis of variance (ANOVA) was used to examine differences in anthropometrics between gender groups (**Study II, III, IV**), and differences between the epoch settings with regard to registered number of 10-minute periods of MVPA (**Study I**). To examine effects of epoch setting and monitor placement, a three-way ANOVA with epoch setting and body placement considered as fixed factors and subjects as a random factor was performed in **Study I**. Tukey's *post hoc* test was subsequently performed to investigate differences between the epoch settings (**Study I**). Linear regression analyzes were performed to study a potential relationship between the difference in time spent at high and very high intensities with regard to epoch setting (between the 5- and 60-second epoch measurements) in relation to overall level of PA ( $\text{cnts}\cdot\text{min}^{-1}$ ) (**Study I**).

Degrees of agreement were studied according to the method described by Bland & Altman (1986), where the difference between methods is plotted against the mean of the methods. Degree of agreement was studied for difference in overall level of PA ( $\text{cnts}\cdot\text{min}^{-1}$ ) between the hip and low back placement (**Study I**), and for difference in PAEE between the free-living derived equation and the two laboratory-derived equations (**Study II**). Estimation differences in overall level of PA ( $\text{cnts}\cdot\text{min}^{-1}$ ) for different placements (**Study I**), and different PAEE between equations (**Study II**) were tested by paired t-test.

Systematic differences between PAEE derived from the three different equations (**Study II**), were calculated as the Pearson correlation coefficients between the difference of the methods and the mean of the methods displayed in the Bland-Altman plots.

ANOVA for repeated measures was used to investigate differences in overall PA level, time spent at MVPA and time spent sedentary between weekdays and weekends, and between school time and leisure time within a weekday (**Study III**). First a possible interaction between age and country with the dependent variables, day (weekday vs. weekend day) and time period (school time vs. leisure time) was examined. In the second step, the analysis was repeated stratified by age and country including gender as between-subject factor. Reanalyses including measurement period as a covariate, and adjustment for registered time for between-day differences were made but did not change the results and were not included in the final model (**Study III**). Differences in proportions who reached recom-

mended levels of PA (60 min) between days was analysed by sign tests based on two related samples (**Study III**).

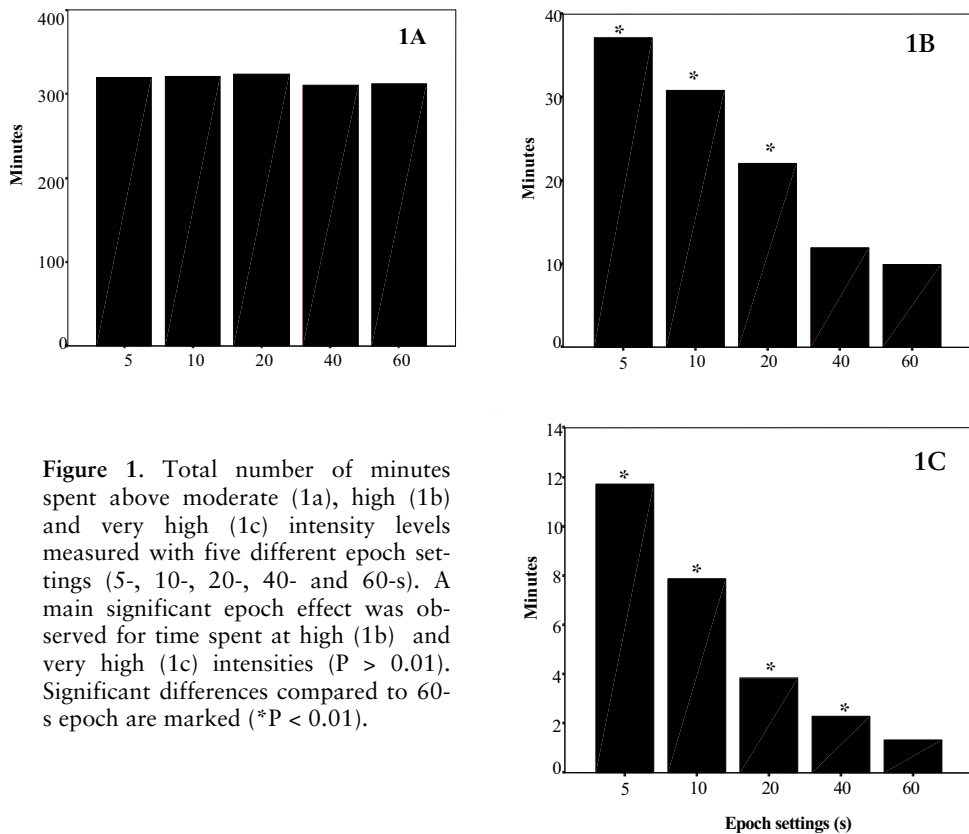
In **Study IV**, univariate general linear models were used to examine the influence of different correlates on overall level of PA, time spent at MVPA and time spent sedentary, respectively. Data on time spent sedentary and at MVPA per day were expressed in relation to monitor wear time per day. Time period of data collection was summarized into three defined seasons; autumn (Sep-Nov), winter (Dec-Feb) and spring (Mar-Jun) and included as a covariate. All analyses were performed stratified by age and with gender, study location, season and parental SES as covariates. An interaction term (gender x study location x correlate) was included in each model. When investigating the associations with transportation mode to and from school, time length of travel was added as a covariate. Impact of each correlate on the dependent variables was analyzed separately (**Study IV**). In all studies alpha was set at 0.05.



## 4 RESULTS AND COMMENTS

### 4.1 EFFECT OF EPOCH SETTING AND MONITOR PLACEMENT (STUDY I)

The sum of minutes spent at different intensity levels of PA over four days of measurement are shown in **Figure 1A – 1C** (data from hip placement only). Significant epoch effects were observed for sum of minutes above the high ( $P < 0.01$ ) and very high ( $P < 0.01$ ) intensity cut-points. In contrast, no effect of epoch setting was observed for sum of time above the moderate intensity cut-point. No interaction effect of epoch setting and placement was observed. A combination of the monitor's sampling procedure and the children's activity behaviour, with very short bouts of time in higher intensity activities, is probably related to the magnitude of the epoch effect.



**Figure 1.** Total number of minutes spent above moderate (1a), high (1b) and very high (1c) intensity levels measured with five different epoch settings (5-, 10-, 20-, 40- and 60-s). A main significant epoch effect was observed for time spent at high (1b) and very high (1c) intensities ( $P > 0.01$ ). Significant differences compared to 60-s epoch are marked (\* $P < 0.01$ ).

When comparing number of 10-minute bouts of at least moderate intensity between epoch settings, using a 60-second epoch setting resulted in a significantly higher number of 10-minute bouts compared to all other settings ( $P < 0.01$ ). Even if the majority of activities performed are intermittent, several shorter bouts of higher intensity activities combined with periods of low intensity activities may produce a count value above the cut point for moderate intensity when summed over a minute. In contrast, using a shorter epoch (e.g., 5- or 10-seconds) the short periods where the intensity drop below the actual cut-off value will be captured. Thus, only “true” steady state activities are judged as continuous activities when measured with a shorter sampling interval.

Further, no significant relationship for the difference between the 5s- and 60s-epoch setting in time spent at high ( $r = .24$ ;  $P = 0.36$ ) and very high intensity ( $r = .46$ ;  $P = 0.07$ ) was observed when plotted against overall level of PA (cnts·min<sup>-1</sup>). These analyses were made to examine whether the magnitude of the epoch effect would be amplified among highly active individuals. However, such a hypothesis could not be verified.

There was no significant difference between the two monitor placements for overall level of PA (cnts·min<sup>-1</sup>). The mean difference was 22 cnts·min<sup>-1</sup>,  $P = 0.20$  (limits of agreement [ $\pm 2SD$ ]: -110 to 154). A graphical presentation of the degree of agreement between placements is showed in Appendix (Study I). Overall, no placement effect was found for time spent at different intensities of PA. The only exception was for time spent at moderate intensity when measured with the 5-second epoch setting. However, when measuring PA using such a short epoch (i.e., 5-seconds) even very small differences in body site movements could be captured. These differences, though, could be considered as inevitable, without practical relevance and do not affect the general conclusions from the study. Taken together, these findings suggest that the two placements are comparable for use in free living children.

#### **4.2 COMPARISON OF ENERGY EXPENDITURE PREDICTION EQUATIONS (STUDY II)**

Predicted estimates of energy expenditure from the three different prediction equations are shown in Table 2. The equation by Trost et al. (2002) overestimated PAEE by 17% ( $P < 0.001$ ) when based on 24 hours compared with DLW-predicted PAEE. In contrast, when based on measured time it underestimated PAEE by 46% ( $P < 0.001$ ).

**Table 2.** Mean values ( $\pm$  SD) of TEE, PAEE and PAL based upon different prediction equations when applied on the same accelerometer data.

|                                  | TEE<br>(kcal·d <sup>-1</sup> ) | PAEE<br>(kcal·d <sup>-1</sup> ) | PAL<br>(TEE/REE)  |
|----------------------------------|--------------------------------|---------------------------------|-------------------|
| <u>Equations</u>                 |                                |                                 |                   |
| Ekelund et al.                   | 2049 $\pm$ 348                 | 663 $\pm$ 274                   | 1.74 $\pm$ 0.26   |
| <sup>a</sup> Trost et al. (2002) | 1709 $\pm$ 347**               | 357 $\pm$ 216**                 | 1.44 $\pm$ 0.17** |
| <sup>b</sup> Trost et al. (2002) | 2170 $\pm$ 473**               | 773 $\pm$ 318**                 | 1.82 $\pm$ 0.23** |
| <sup>a</sup> Puyau et al. (2002) | 2029 $\pm$ 356*                | 646 $\pm$ 227*                  | 1.71 $\pm$ 0.17** |
| <sup>b</sup> Puyau et al. (2002) | 2657 $\pm$ 427**               | 1211 $\pm$ 264**                | 2.24 $\pm$ 0.14** |

<sup>a</sup>Based on assumption that average counts per registered minute reflect measured time only, whereas remaining time is assumed to be sleep.

<sup>b</sup>Based on assumption that average counts per registered minute reflect all minutes of the day (24 hours).

\*\*significantly different from Ekelund et al. (2001) equation estimate ( $P < 0.01$ )

\*significantly different from Ekelund et al. (2001) equation estimate ( $P < 0.05$ )

Similarly, the equation by Puyau et al. (2002) overestimated PAEE by 83% ( $P < 0.001$ ) when based on 24 hours, and underestimated PAEE by 3% ( $P < 0.05$ ) when based on measured time, compared with free-living predicted PAEE. The observed differences in predicted PAEE between equations remained similar when the equations were used to estimate TEE and PAL (Table 2). In comparison to the DLW-based equation, both laboratory-derived equations significantly overestimated TEE and PAL when based on 24-hour measurement, and significantly underestimated TEE and PAL when based on measured time.

Regarding agreement between predicted PAEE from the Trost et al. (2002) equation and the DLW-based equation (Ekelund et al., 2001), a significant positive correlation between the difference of the methods and the mean of the methods was observed when predictions were based on 24 hours ( $r = -0.17$ ;  $P < 0.001$ ). When predicted PAEE was based on measured time, a significant and positive correlation was observed ( $r = 0.26$ ;  $P < 0.001$ ), indicating a systematic bias for this equation regardless of the time factor used. Correspondingly, the observed error variance in PAEE between predicted PAEE from the Puyau et al. (2002) equation and the DLW-based equation (Ekelund et al., 2001) was randomly distributed ( $r = 0.04$ ;  $P = 0.12$ ) when based on 24 hours. In contrast, a sys-

tematic error was indicated when PAEE was based on measured time ( $r = 0.20$ ;  $P < 0.001$ ). The degree of agreement between laboratory- and DLW-based equations is graphically shown in Appendix (Study II).

Overall, individual differences were substantial, with standard deviations around  $\pm 290$  kcal-day<sup>-1</sup>, when comparing the laboratory-based equations with the DLW derived equation.

Theoretically, predicted PAEE based on awake time is likely to provide the best prediction, since no PAEE per definition occurs during sleep. If this assumption holds true, predicted PAEE from the equation by Puyau et al. (2002) were similar to the DLW-derived equation (Ekelund et al., 2001) and also in good agreement with measured PAEE reported elsewhere (Hoos et al., 2003). However, even if this equation produces a similar mean value of PAEE as the DLW-based equation, a systematic trend of the differences was evident which may still limit to the comparability between equations to predict PAEE in free-living children. The equation by Trost et al. (2002) clearly underestimated PAEE when based on awake time. The underestimation in predicted PAEE is also reflected in a predicted PAL value of 1.44 from this equation (Table 2), which is considerably lower than previously reported (Hoos et al., 2003). The equation by Trost et al. (2002) estimated EE within the normal range when based on 24 hour time factor. However, these values were estimated assuming that 1 MET is equal to 3.5 ml O<sub>2</sub>·kg<sup>-1</sup>·min<sup>-1</sup>, which do not reflect multiples of true REE in children. We chose not to present data on PAEE based on age-adjusted REE when using the equation by Trost et al. (2002) since we believe that the METs predicted by the equation reflect oxygen uptake in relation to 3.5ml O<sub>2</sub>·kg<sup>-1</sup>·min<sup>-1</sup>. It should be emphasized that, if adjustment for children's higher metabolic rate when expressed per kilogram of body mass are made, the equation would substantially overestimate PAEE compared to the DLW-based equation. This is likely explained by the assumption that 1 MET was defined as 3.5ml O<sub>2</sub>·kg<sup>-1</sup>·min<sup>-1</sup> (i.e. the adult value) when the equation was developed.

### **4.3 VARIABILITY IN PHYSICAL ACTIVITY AND SEDENTARY TIME (STUDY III)**

Variability between weekdays and weekend days for overall level of PA (cnts·min<sup>-1</sup>), time spent at MVPA and time spent sedentary is illustrated in Table 3. In both age groups, consistent between-day differences for time spent at MVPA and time spent sedentary was evident, indicating that weekdays are associated with higher amounts of time spent at MVPA and time spent sedentary. Further, more time spent at MVPA during weekdays was generally reflected in higher

overall levels of PA (cnts·min<sup>-1</sup>) across age and country groups, with exceptions for Estonia (9-yrs only) and Portugal (both ages). Gender interactions for between-day differences when analysing the three variables on PA and sedentary time were occasionally indicated within country groups. A description of gender stratified analyses is presented in Appendix (Study III). In both age groups, more time spent at MVPA during weekdays was reflected by a significantly higher proportion ( $P < 0.01$ ) of children achieving the 60-min recommendation on weekdays compared to weekends in all countries, except for 15-year-old Danes (Appendix, Study III).

**Table 3.** Overall level of PA, time spent sedentary and time spent at MVPA averaged over weekday and weekend days among 9- and 15-year-olds stratified by country.

|   | <u>9-year-olds (n = 1184)</u> |              | <u>15-year-olds (n = 770)</u> |             |
|---|-------------------------------|--------------|-------------------------------|-------------|
|   | Weekday                       | Weekend day  | Weekday                       | Weekend day |
| <u>Level of PA</u><br>(cnts·min <sup>-1</sup> ) |                               |              |                               |             |
| Denmark   | 670 ± 254                     | 628 ± 289**† | 432 ± 169                     | 396 ± 177** |
| Portugal  | 658 ± 216                     | 702 ± 256**  | 535 ± 197                     | 544 ± 209   |
| Estonia   | 723 ± 252                     | 736 ± 300    | 568 ± 224                     | 530 ± 254** |
| Norway  | 827 ± 274                     | 751 ± 358**  | 628 ± 219                     | 530 ± 248** |
| <u>Sedentary</u><br>(min·d <sup>-1</sup> )      |                               |              |                               |             |
| Denmark   | 310 ± 76                      | 289 ± 88**   | 455 ± 86                      | 412 ± 94**  |
| Portugal  | 331 ± 79                      | 274 ± 92**   | 423 ± 87                      | 347 ± 87**  |
| Estonia   | 292 ± 77                      | 248 ± 88**   | 423 ± 95                      | 354 ± 94**  |
| Norway  | 306 ± 67                      | 285 ± 78**†  | 457 ± 87                      | 395 ± 84**  |
| <u>MVPA</u><br>(min·d <sup>-1</sup> )           |                               |              |                               |             |
| Denmark   | 74 ± 43                       | 58 ± 44**†   | 46 ± 29                       | 37 ± 31**   |
| Portugal  | 81 ± 40                       | 78 ± 45*     | 69 ± 36                       | 56 ± 38**   |
| Estonia   | 90 ± 48                       | 81 ± 54**    | 76 ± 42                       | 56 ± 42**   |
| Norway  | 107 ± 39                      | 79 ± 45**†   | 83 ± 34                       | 55 ± 36**   |

\*\* difference between days ( $P < 0.01$ )

\* difference between days ( $P < 0.05$ )

† difference between days by gender interaction ( $P < 0.05$ )

**Table 4.** Level of PA, time spent sedentary and time spent at MVPA averaged for school time and leisure time among 9- and 15-year-olds and stratified by country.

|   | <u>9-year-olds (n = 1184)</u> |              | <u>15-year-olds (n = 770)</u> |              |
|---|-------------------------------|--------------|-------------------------------|--------------|
|   | School time                   | Leisure time | School time                   | Leisure time |
| <u>Level of PA</u><br>(cnts·min <sup>-1</sup> ) |                               |              |                               |              |
| Denmark   | 755 ± 326                     | 619 ± 274**† | 438 ± 198                     | 444 ± 232†   |
| Portugal  | 618 ± 240                     | 702 ± 260**  | 527 ± 216                     | 542 ± 249    |
| Estonia   | 722 ± 262                     | 744 ± 348    | 536 ± 226                     | 602 ± 336*   |
| Norway  | 859 ± 375                     | 824 ± 388    | 571 ± 215                     | 663 ± 390    |
| <u>Sedentary</u><br>(min·d <sup>-1</sup> )      |                               |              |                               |              |
| Denmark   | 122 ± 38                      | 144 ± 43**†  | 212 ± 48                      | 198 ± 53**†  |
| Portugal  | 149 ± 41                      | 161 ± 49**   | 212 ± 44                      | 186 ± 55**   |
| Estonia   | 130 ± 39                      | 139 ± 50*    | 212 ± 54                      | 180 ± 56**†  |
| Norway  | 134 ± 32                      | 138 ± 44     | 218 ± 42                      | 189 ± 57**   |
| <u>MVPA</u><br>(min·d <sup>-1</sup> )           |                               |              |                               |              |
| Denmark   | 38 ± 24                       | 28 ± 21**†   | 23 ± 16                       | 19 ± 16**†   |
| Portugal  | 32 ± 19                       | 44 ± 25**    | 34 ± 20                       | 30 ± 22*     |
| Estonia   | 40 ± 21                       | 45 ± 33      | 35 ± 19                       | 36 ± 30      |
| Norway  | 51 ± 24                       | 46 ± 26**    | 36 ± 16                       | 35 ± 26      |

\*\*difference between time periods ( $P < 0.01$ )

\* difference between time periods ( $P < 0.05$ )

† difference between time periods by gender interaction ( $P < 0.05$ )

Variability between school time and leisure time within a weekday for overall level of PA, time spent at MVPA and time spent sedentary is illustrated in Table 4. In both age groups, PA variability with regard to time period was highly inconsistent across country groups. Furthermore, a gender by time period interaction was frequently observed within country groups. A description of gender stratified analyses is presented in Appendix (Study III). Opportunities to be physically active during a school day are likely to differ by country. Differences in school environments, total time in recess and frequency and contents of physical education lessons between the present countries included in this study likely influence on the differences observed in PA levels between school and leisure time. Overall, between 4% and 31% of children accumulated at least 60 minutes of MVPA during either school time or leisure time within a weekday.

#### **4.4 CORRELATES OF PHYSICAL ACTIVITY AND SEDENTARY TIME (STUDY IV)**

In 9-year-olds, outdoor play after school on most days/every day of the week was significantly related to higher overall levels of PA ( $F = 6.247$ ;  $P < 0.05$ ) and more time spent at MVPA ( $F = 6.843$ ;  $P < 0.01$ ). No other correlate was significantly associated with PA behaviour. In 15-year-olds, only participation in sport clubs was related to higher overall levels of PA ( $F = 4.684$ ;  $P < 0.05$ ) and more time spent at MVPA ( $F = 10.841$ ;  $P < 0.01$ ).

Three way interaction terms (gender x study location x correlate) were observed when modelling the association between TV viewing and time spent at MVPA in both age groups (9-year-olds:  $F = 3.344$ ,  $P < 0.01$ ; 15-year-olds:  $F = 2.213$ ,  $P < 0.05$ ), and for overall PA in 9-year-olds ( $F = 4.039$ ;  $P < 0.01$ ). An interaction term was also observed for the association between sport club participation and time spent at MVPA in 15-year-olds ( $F = 2.834$ ;  $P < 0.01$ ), and for the association between participation in sport clubs ( $F = 2.050$ ;  $P > 0.05$ ) with time spent sedentary in 9-year-olds. Stratified analyses revealed that depending on age, gender and study location, the results on the associations between correlates and dependent variables could deviate from that indicated by the main effects. A complete description of associations between correlates and dependent variables when stratified by gender and study location is presented in Appendix (Study IV).

Overall, walking to school seem not to influence on overall PA and time spent sedentary in children. Children who reported walking in one direction and motorized transport in the other direction were classified as 'walkers'. Since inclusion of these children in the 'walking group' hypothetically may dilute an influence from active commuting, we reanalysed our data excluding these children, and the re-

sults were unchanged (data not shown). Similarly, time spent watching TV was generally not associated with any dependent variable. Thus, the hypothesis suggesting that TV viewing should displace time for activities of at least moderate intensity is not supported by the results from the present study.



## **5 GENERAL DISCUSSION AND IMPLICATIONS**

### **5.1 ASSESSING TIME SPENT AT DIFFERENT INTENSITIES OF ACTIVITY**

The epoch setting can be of significant importance when interpreting the output of the MTI accelerometer when used in children. A more detailed picture of the PA intensity pattern is achieved when using a shorter epoch (e.g. 5s) compared with using a longer (e.g. 60s) epoch. This is explained by the ability of a shorter epoch to detect a highly sporadic mixture of high and low intensity activities, while these intensity variations will be reflected as an intermediate intensity activity if summed over a longer epoch. Further, when analysing time spent above a certain intensity level of PA, the effect of epoch setting depends on the intensity threshold, and the nature of the activities performed by the individuals. For example, when measuring time spent at vigorous or very vigorous intensity activity, usually performed in short intervals, a significant difference is observed between different epoch settings. In contrast, if the activity is performed in a steady-state manner for a continuous time period the effect of epoch setting is diminished. Furthermore, the epoch setting do not seem to influence on measured time spent at moderate intensity levels in children. Thus, the effect of epoch setting observed for vigorous and very vigorous intensity levels is likely explained by limited amount of continuous time spent at these intensity levels in children.

When examining the total amount of time spent at MVPA, the effect of epoch setting is attenuated since the majority of time spent at MVPA is due to moderately intense activities. Based on these results, average daily time spent at MVPA range approximately between 80 and 90 minutes per day depending on epoch setting. Therefore, the children in the present study would be considered to achieve PA in accordance with published recommendations regardless of the epoch setting.

When determining the number of continuous bouts of PA (e.g. 10-min bouts) both the selected epoch setting and the operational definition of a continuous bout will determine the outcome. For example, when using a shorter epoch (e.g. 5 sec) it is necessary to accept several brief second-intervals of intensities below the intensity cut point of interest if any bouts should be recorded.

A shorter epoch setting is strongly recommended when detailed analysis of PA patterns is required. For example, assessing time spent at higher intensity PA during school recess, higher resolution of PA assessment is required in order to capture even short bursts of high intensity PA.

Levels of PA and time spent at different intensity levels of PA seem comparable regardless of the placement of the monitor (hip or back placement) during free living conditions. Placed at the hip may be recommended as it is likely to be more comfortable for the subjects compared to the back placement.

## 5.2 ASSESSING DAILY ENERGY EXPENDITURE FROM ACTIVITY COUNTS

Estimated energy expenditure (e.g. PAEE) based on accelerometer counts may differ substantially depending on the equation used and the integration period from laboratory-based equations. Therefore, these equations can not be used interchangeably when predicting PAEE and interpretations of average levels of PAEE in children should be made with caution.

Since the different mixture of activities during calibration in the laboratory affect the slope and intercept of the regression line, it is unlikely that prediction equations developed using specific activities in a laboratory are valid throughout the range of free-living activities, which in turn will affect predicted daily PAEE from these equations.

Among the equations compared, the Puyau et al. (2002) equation included a more extensive calibration, including a scheduled set of activities besides treadmill walking and running compared to the Trost et al. (2002) equation. The Puyau et al. (2002) equation also agreed better with the criterion equation compared to the Trost et al. (2002) equation, even though a systematic error was evident.

Data on measured TEE and its derivatives were not available in the study population. Hoos et al. (2003) recently published data on TEE and its derivatives from a compilation of studies using the DLW method. Average gender-combined values on TEE and PAEE were approximately 2000 kcal·d<sup>-1</sup> and 650 kcal·d<sup>-1</sup>, respectively, in 9–10 year-old children. In comparison, predicted TEE and PAEE from the DLW-derived equation (Ekelund et al., 2001), were 2049 kcal·d<sup>-1</sup> and 663 kcal·d<sup>-1</sup>, respectively (Table 2). When developing the DLW-equation (Ekelund et al., 2001), it showed no mean bias against measured PAEE and seems to reflect average daily PAEE with reasonable validity on group level. Further, no systematic bias was indicated against measured PAEE, which indicate the unbiased ability of the equation to predict average values on PAEE in 9 to 10 year old children. However, as the standard error was large and the limits of agreement were wide, the equation is not valid on an individual level. Nonetheless, as the aim was to compare group values, lack of systematic bias should be regarded as more important than any large individual variation per se. It can also be noted that this equation was derived from a relatively small sample of children which is likely to limit

its external validity. Therefore, for the purpose of predicting group values of daily PAEE, further development of equations applicable to free-living scenarios is needed. Such work should be based on larger and more heterogeneous samples and assessed during diverse activity scenarios, including free-living.

### **5.3 PHYSICAL ACTIVITY AND INACTIVITY BETWEEN AND WITHIN DAYS**

This is the first study investigating between-day and within-day differences in objectively assessed PA patterns in children from different geographical locations in Europe. The data showed that between- and within-day differences in overall level of PA, time spent at MVPA and sedentary exist and may differ by age, gender and geographical location.

Differences in PA patterns between weekdays and weekend days were overall consistent across different geographical locations. Increased time spent sedentary (e.g. TV/electronic games) during weekend days compared to weekdays have previously been reported (Jago et al., 2005), which may indicate that these sedentary activities displace time spent at moderate and vigorous levels of activity. In contrast, present results suggested a greater amount of time spent sedentary during weekdays in combination with a greater amount of time spent at MVPA. Hence, an overall lower level of PA during weekend days compared to weekdays is explained by less accumulated time spent at MVPA and not by an increase in time spent sedentary. Although weekend days are likely to offer more free time than school days, surprisingly small proportions of children were able to reach the current recommendation for health enhancing PA in youth (Biddle et al., 1998). For example, only a minority of 15-year-olds reached this recommendation during weekend days, regardless of country (Appendix, Study III). Initiatives aiming to promote PA during weekend days seem especially important if the majority of children are expected to achieve the basic 60-min recommendation of daily PA.

Within-day differences in PA patterns and time spent sedentary were inconsistent between countries. Total recess time in school and physical education offer opportunities to being active, however, school time is likely to be more restricted compared with leisure time in terms of opportunities to participate in PA. Further, leisure time could be expected to be the major contributor to time spent at MVPA given the relatively low levels of PA during recess (Ridgers et al., 2005; Mota et al., 2005) and PE lessons (Fairclough et al., 2005; Nader et al., 2005) previously reported. However, observed differences for time spent at MVPA between time blocks of the day were fairly modest in the present study. It was also obvious that only a small proportion of children in both age groups are able to

accumulate 60 minutes of MVPA during leisure time alone. PA during school time seems to contribute, perhaps more than expected, to the total daily amount of time spent at MVPA and subsequently for achieving the current PA recommendation. Given that school time offers less potential time for PA compared to leisure time, PA promoting efforts including increased opportunities for being active during leisure time seem warranted to increase the proportion of school-age youth to meet the current PA recommendations.

#### **5.4 INFLUENCES ON PATTERNS OF PHYSICAL ACTIVITY AND INACTIVITY**

Outdoor play and sports participation seem differentially associated with objectively measured PA in 9- and 15-year-old children. Apparently, the occurrence of outdoor play after school is more influential on PA levels in younger children compared with sport club participation. Occurrence of unorganized outdoor play during leisure time, incorporating PA of different intensities, is likely more prominent in younger compared with older children. A shift in choice of unstructured physical activities towards less intensive pursuits during free time would then make sport club participation a more important contributor to daily PA level with increasing age. The consistent observation that total PA decreases by age is in accordance with such change in behaviour.

Although the local environment is likely to differ substantially between study locations in the present study, no interaction by study location was observed, which further accentuates the importance of outdoor play for increasing young children's PA levels across different geographical settings. Besides recess time at school, opportunities to outdoor play is predominantly given in the afternoon and early evening, indicated by the difference in hourly PA patterns between 'play groups' (Appendix, Study IV). Therefore, afternoon time becomes a key period for accumulation of time spent at MVPA, and subsequently a target when promoting PA in younger children.

Although walking to school may offer a possibility to contribute to the overall levels of PA and time spent at MVPA, no such association was observed. Given the results from the present study, targeting only active commuting as a PA promoting strategy in order to increase daily PA levels in children may not have the expected effect.

Overall, associations between self-reported TV-viewing and PA variables or time spent sedentary was non-significant and seem to support previous findings (Sallis et al., 2000; Marshall et al., 2004; Marshall et al., 2006; Taveras et al., 2007). Apparently, determinants influencing PA behaviours (e.g. organized sports

or outdoor play) may not be directly related to reduced time spent sedentary. Hence, children may accumulate substantial amounts of sedentary time, in combination with participation in activities of moderate and vigorous intensity activities. This does not mean that reducing sedentary time is irrelevant from a health point of view. Reducing television time in children has showed to reduce meals eaten in front of the TV, following a relative decrease in body mass index and waist circumference over a six-month period (Robinson, 1999), and eating frequency while viewing TV may be associated with adiposity independent of PA (Ekelund et al., 2006).

The findings of this study should be considered when planning physical activity interventions in school-age youth.

## **5.5 STUDY STRENGTHS AND LIMITATIONS**

Overall, study strengths include the use of a validated objective method for assessing PA; the MTI accelerometer (**Study I, II, III, IV**), and the large sample of randomly selected children representing various geographical and economic locations in Europe (**Study II, III, IV**). The sample size was fairly small in **Study I**. However, it is highly unlikely that the conclusions regarding presence of an epoch effect or lack of placement effect would be altered had the sample size been larger.

Sample sizes for the EYHS were initially estimated for assessing pre-specified target differences in risk factors for CVD, including energy expenditure. It was estimated that about 200 children in each age/sex group (total  $n = 800$ ) in each country would provide a statistical power sufficient to detect a difference of  $0.5 \text{ kcal}\cdot\text{kg}^{-1}\cdot\text{d}^{-1}$  between subgroups (Riddoch et al., 2005). Although the sample size used in the present thesis is lower due to incomplete variable assessments, the conclusions from **Study III** and **IV** were not dependent on the ability to detect such small variations in predicted energy expenditure. It seems unlikely that the main findings from Study III and IV are biased by insufficient sample size.

The choice of a 60s epoch in the EYHS protocol was decided before the impact of different epoch settings was fully clarified. However, epoch choice is irrelevant for the composite measure of PA used in **Study II**. Although a potential underestimation of time spent in higher intensities of PA would be present when using a one minute epoch in **Study III** and **IV**, likely to be more pronounced in the younger age group, any potential effect on the outcomes is considered to be minor due to the specific aims of these studies. In **Study III**, the outcome was based on repeated-measurement ANOVA, where a potential underestimation of measured time will be equal in both variables compared (e.g. weekday vs. weekend

day) and will not affect the outcome of analysis. In **Study IV**, the association between correlates and accumulated time spent at MVPA are likely to be detected even if the absolute values of MVPA are underestimated. This is because the ranking of individuals will remain the same regardless of the absolute levels of PA.

Finally, due to the cross-sectional design, causality between correlates and PA behaviour cannot be concluded (**Study IV**). Further, it is possible that unmeasured confounding factors other than age, gender, study location, season and parental SES may affect the observed relations between correlates and dependent variables. As all correlates were assessed by self-report, misclassification of correlate exposures may be present. While such misclassifications are likely to be non-differential, a dilution of the magnitude of associations between correlates and outcomes may be present.

## **5.6 FUTURE DIRECTIONS**

Obviously, one single assessment technique that can produce valid data on free-living daily energy expenditure and assess PA patterns, including detailed information on time spent at different intensities of PA is currently not available. The choice of method is largely dependent on the specific research questions, study population and economic resources. While the accelerometer has inherent limitations when estimating daily energy expenditure, particularly on individual level, it is a feasible instrument for assessing patterns of PA in free-living conditions with high time resolution. Perhaps the best application of the accelerometer for future studies lies in monitoring variability in PA patterns in individuals over time to assess temporal trend data, which currently are limited. The recent advances in combined HR and movement sensing (e.g. the Actiheart), with the ability to reduce measurement errors related to each method when used alone, seem to be a promising tool for future assessment of minute-by-minute energy expenditure during free-living conditions.

Although the epoch effect was evident in the present study of seven-year-old children, the importance of epoch setting for assessing time at higher intensities in older children or adults remain elusive, as no corresponding study has been performed in other age groups. Whether high intensity PA lasting for a few seconds, and captured by a short epoch setting, are related to health outcomes may be a scope for future research as the health-related effects of short durations of high intensity PA in comparison to longer continuous bouts of PA at lower intensities or simply daily accumulated time in MVPA is currently not known. The ongoing

debate on the importance of different dimensions of PA on health in growing children may influence the choice of epoch settings among researchers.

Future work of examining significant mediators of PA behaviours in youth is important. This will increase our understanding about determinants of PA and may inform the planning of successful interventions aimed to promote PA in children. Future studies using a longitudinal design following individuals from an early age throughout school years is warranted, as these studies may inform on causality. These studies should also include potential correlates of PA not available in the present thesis, e.g. physical education and total recess time in school.





## 6 CONCLUSIONS

- The epoch setting will influence on the interpretation of the output from the MTI accelerometer when used in young children. A more detailed picture of the physical activity intensity pattern will be achieved when using a shorter time sampling interval than when using a 60-second setting.
- Predicted PAEE differ substantially between equations, also depending on time frame assumptions. These equations can not be used interchangeably and interpretations of average levels of PAEE in children from available equations should be made with caution.
- Between- and within-day differences in overall level of physical activity, time spent at MVPA and sedentary exist and may differ by age, gender and geographical location. Differences in physical activity patterns between weekdays and weekend days are explained by less accumulated time spent at MVPA, without increased time spent sedentary, during weekend days. Overall, weekend days and leisure time during weekdays seem appropriate targets when promoting physical activity in order to increase the proportion of children achieving current recommendations on health enhancing physical activity.
- Outdoor play after school on most days of the week is a significant correlate for increased PA level and time spent at MVPA in 9-year-old children, while participation in sport clubs significantly contributes to increased levels of PA in 15-year-olds. Overall, walking to school and time spent watching TV seem not to influence on overall PA and time spent sedentary in children. These findings should be considered when planning physical activity interventions in children.



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## REFERENCES

1. Aarnio M, Winter T, Peltonen J, Kujala UM, Kaprio J. Stability of leisure-time physical activity during adolescence – a longitudinal study among 16-, 17- and 18-year-old Finnish youth. *Scan J Med Sci Sports*, 2002; 12: 179-185.
2. Ainsworth BE, Haskell WL, Leon AS, Jacobs DR Jr, Montoye HJ, Sallis JF, Paffenbarger RS Jr. Compendium of physical activities: classification of energy costs of human physical activities. *Med Sci Sports Exerc*, 1993; 25: 71-80.
3. 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.
4. Andersen LF, Lillegaard IT, Overby N, Lytle L, Klepp KI, Johansson L. Overweight and obesity among Norwegian schoolchildren: changes from 1993 to 2000. *Scan J Public Health*, 2005; 33: 99-106.
5. Alberti G, Zimmet P, Shaw J, Bloomgarden Z, Kaufman F, Silink M; Consensus Workshop Group. Type 2 diabetes in the young: the evolving epidemic: the international diabetes federation consensus workshop. *Diabetes care*, 2004; 27: 1798-1811.
6. American Academy of Pediatrics. Children, adolescents, and television. *Pediatrics*, 2001; 107: 423-6.
7. American Diabetes Association. Type 2 diabetes in children and adolescents. *Diabetes Care*, 2000; 23: 381-89.
8. American Heart Association. Obesity, insulin resistance, diabetes and cardiovascular risk in children – AHA scientific statement. *Circulation*, 2003; 107: 1448-53.
9. Amos AF, McCarty DJ, Zimmet P. The rising global burden of diabetes and its complications: estimates and projections to the year 2010. *Diabet Med*, 1997; 14 (Suppl 5): 1-85.
10. Armstrong N, Welshman JR. The physical activity patterns of European youth with reference to methods of assessment. *Sports Med*, 2006; 36: 1067-86.
11. Bailey DA, McKay HA, Mirwald RL, Crocker PR, Faulkner RA. A six-year longitudinal study of the relationship of physical activity to bone mineral accrual in growing children: the university of Sas-

- katchewan bone mineral accrual study. *J Bone Miner Res*, 1999; 14: 1672-9.
12. Baily R, Olson J, Pepper S, Porszasz J, Barstow T, Cooper D. The level and tempo of children's physical activities: an observational study. *Med Sci Sports Exerc*, 1995; 27: 1033-41.
  13. Baranowski T. Validity and reliability of self-report measures of physical activity: an information-processing perspective. *Res Q Exerc Sport*, 1988; 59: 314-27.
  14. Baranowski T, Anderson C, Carmack C. Mediating variable framework in physical activity interventions: how we doing? How might we do better? *Am J Prev Med*, 1998; 15: 266-297.
  15. Berlin JA, Colditz GA. A meta-analysis of physical activity in the prevention of coronary heart disease. *Am J Epidemiol*, 1990; 4: 612-28.
  16. Berkey CS, Rockett HR, Gillman MW, Colditz GA. One-year changes in activity and in inactivity among 10- to 15-year-old boys and girls: relationship to change in body mass index. *Pediatrics*, 2003; 111: 836-43.
  17. Biddle JH, Gorely T, Stensel DJ. Health-enhancing physical activity and sedentary behaviour in children and adolescents. *J Sports Sci*, 2004; 22: 679-701.
  18. Biddle S, Sallis J, Cavill N (eds.). *Young and active? Young people and health-enhancing physical activity – evidence and implications*. London: Health Education Authority, 1998.
  19. Blair S, Clark D, Cureton K, Powell K. Exercise and fitness in childhood: implications for a lifetime of health. In C. Gisolfi and D. Lamb (eds.) *Perspectives in exercise science and sports medicine: youth exercise and sport*, pp. 401-30. Indianapolis: Benchmark Press, 1989.
  20. Blair SN, LaMonte MJ, Nichaman MZ. The evolution of physical activity recommendations: how much is enough? *Am J Clin Nutr*, 2004; 79: 913-20.
  21. Bland J, Altman D. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet*, 1986; 8476: 307-10.
  22. Boreham C, Riddoch C. The physical activity, fitness and health of children. *J Sports Sci*, 2001; 19: 915-929.

23. Brage S, Brage N, Franks PW, Ekelund U, Wareham NJ. Reliability and validity of the combined heart rate and movement sensor Acti-heart. *Eur J Clin Nutr*, 2005; 59: 561-70.
24. 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*, 2004; 96: 343-51.
25. 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: 277-87.
26. Brage S, Wedderkopp N, Franks PW, Andersen LB, Froberg K. Re-examination of validity and reliability of the CSA monitor in walking and running. *Med Sci Sports Exerc*, 2003b: 35: 1447-54.
27. Caspersen C, Powell K, Christenson G. Physical activity, exercise and physical fitness: Definitions and distinctions for health-related research. *Public Health Rep*, 1985; 100: 126-31.
28. Ceesay SM, Prentice AM, Day KC, Murgatroyd PR, Goldberg GR, Scott W, Spurr GB. The use of heart rate monitoring in the estimation of energy expenditure: a validation study using indirect whole-body calorimetry. *Br J Nutr*, 1989; 61: 175-86.
29. Chen KY, Bassett JR. The technology of accelerometry-based activity monitors: current and future. *Med Sci Sports Exerc*, 2005; 11: 490-500.
30. Cooper AR, Page AS, Foster LJ, Qahwaji D. Commuting to school – are children who walk more physically active? *Am J Prev Med*, 2003; 25: 273–6.
31. Corbin CB. The “untracking” of sedentary living: a call for action. *Pediatr Exerc Sci*, 2001; 13: 347-56.
32. Cordain R, Gotshall RW, Eaton SB, Eaton III SB. Physical activity, energy expenditure and fitness: An evolutionary perspective. *Int J Sports Med*, 1998; 19: 328-35.
33. Corder K, Brage S, Ekelund U. Accelerometers and pedometers: methodology and clinical application. *Curr Opin Clin Nutr Metab Care*, 2007; 10: 597-603.
34. Corder K, Brage S, Ramachandran A, Snehalatha C, Wareham N, Ekelund U. Comparison of two Actigraph models for assessing free-

- living physical activity in Indian adolescents. *J Sports Sci*, 2007: 25: 1607-11.
35. Corder K, Brage S, Wareham N, Ekelund U. Comparison of PAEE from combined and separate heart rate and movement models in children. *Med Sci Sports Exerc*, 2005: 37: 1761-67.
  36. Crouter SE, Churilla JR, Bassett DR Jr. Accuracy of the Actiheart for the assessment of energy expenditure in adults. *Eur J Clin Nutr*, 2007 (ahead of print).
  37. Crouter SE, Clowers KG, Basset Jr DR. A novel method for using accelerometer data to predict energy expenditure. *J Appl Physiol*, 2006: 100: 1324-31.
  38. Crouter SE, Schneider PL, Karabulut M, Bassett DR Jr. Validity of 10 electronic pedometers for measuring steps, distance, and energy cost. *Med Sci Sports Exerc*, 2003: 35: 1455-60.
  39. Cureton KJ. Physical fitness and activity standards for youth. In R.R. Pate and R.C. Hohn (eds.). *Health and fitness through physical education*, pp. 129-36. Champaign: Human Kinetics Inc, 1994.
  40. Dale D, Corbin CB, Dale KS. Restricting opportunities to be active during school time: do children compensate by increasing physical activity levels after school? *Res Q Exerc Sport*, 2000: 71: 240-8.
  41. Davidson L, McNeill G, Haggarty P, Smith JS, Franklin MF. Free-living energy expenditure of adult men assessed by continuous heart-rate monitoring and doubly-labelled water. *Br J Nutr*, 1997: 78: 695-708.
  42. Dietz WH. Childhood weight affects adult morbidity and mortality. *J Nutr*, 1998: 128: 411-14
  43. Durnin JVGA. Physical activity levels – past and present. In: Norgan NG (Ed.). *Physical activity and health*, pp 20-27. Cambridge: Cambridge University Press, 1992.
  44. Eaton SB, Eaton III SB. An evolutionary perspective on human physical activity: implications for health. *Comp Biochem Physiol A Mol Integr Physiol*, 2003: 136: 153-9.
  45. Edmundson E, Parcel GS, Perry CL, Feldman HA, Smyth M, Johnson CC, Layman A, Bachman K, Perkins T, Smith K, Stone E. The effect of the child and adolescent trial for cardiovascular health intervention on psychosocial determinants of cardiovascular disease risk behavior among third-grade students. *Am J Health Promot*, 1996: 10: 217-25.



46. Ekelund U, Brage S, Froberg K, Harro M, Anderssen SA, Sardinha LB, Riddoch C, Andersen LB. TV viewing and physical activity are independently associated with metabolic risk in children: The European Youth Heart Study. *PLoS Med*, 2006; 3: 2449-57.
47. Ekelund U, Franks PW, Sharp S, Brage S, Wareham NJ. Increase in physical activity energy expenditure is associated with reduced metabolic risk independent of change in fatness and fitness. *Diabetes Care*, 2007; 30: 2101-6.
48. Ekelund U, Poortvliet E, Yngve A, Hurtig-Wennlöv A, Nilsson A, Sjöström M. Heart rate as an indicator of the intensity of physical activity in human adolescents. *Eur J Appl Physiol*, 2001; 85: 244-9.
49. Ekelund U, Sjöström 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: 275-81.
50. Ekelund U, Yngve A, Brage S, Westerterp K, Sjöström M. Body movement and physical activity energy expenditure in children and adolescents: how to adjust for differences in body size and age. *Am J Clin Nutr*, 2004; 79: 851-6.
51. Ekelund U, Yngve A, Sjöström M, Westerterp K. Field evaluation of the Computer Science and Applications Inc. Activity monitor during running and skating training in adolescent athletes. *Int J Sports Med*, 2000; 21: 586-92.
52. Ekelund U, Yngve A, Westerterp K, Sjöström M. Energy expenditure assessed by heart rate and doubly labeled water in young athletes. *Med Sci Sports Exerc*, 2002; 34:1360-6.
53. Epstein L, Paluch R, Kalakanis L, Goldfield G, Cerny F, Roemmich J. How much activity do youth get? A quantitative review of heart-rate measured activity. *Pediatrics*, 2001; 108: e44.
54. Erlichman J, Kerbey AL, James WPT. Physical activity and its impact on health outcomes. Paper 2: prevention of unhealthy weight gain and obesity by physical activity: an analysis of the evidence. *Obes Rev*, 2002; 3: 273-287.
55. Esliger DW, Tremblay MS. Technical reliability assessment of three accelerometer models in a mechanical setup. *Med Sci Exerc Sci*, 2006; 38: 2173-81.

56. Eston RG, Rowlands AV, Ingledeu DK. Validity of heart rate, pedometry and accelerometry for predicting energy cost of children's activities. *J Appl Physiol*, 1998; 84: 362-71.
57. Fairclough SJ, Butcher ZH, Stratton G. Whole-day and segmented-day physical activity variability of northwest England school children. *Prev Med*, 2007; 44: 421-5.
58. Fairclough S, Stratton G. 'Physical education makes you fit and healthy'. Physical education's contribution to young people's physical activity levels. *Health Educ Res*, 2005; 20: 14-23.
59. Ferreira I, van der Horst K, Wendel-Vos W, Kremers S, van Lenthe FJ, Brug J. Environmental correlates of physical activity in youth – a review and update. *Obes Rev*, 2006; 8: 129-54.
60. Field AE, Cook NR, Gillman MW. Weight status in childhood as a predictor of becoming overweight or hypertensive in early adulthood. *Obes Res*, 2005; 13: 163-9.
61. Fox KR, Riddoch C. Charting the physical activity patterns of contemporary children and adolescents. *Proc Nutr Soc*, 2000; 59: 497-504.
62. Freedson PS, Melanson E, Sirard J. Calibration of the Computer Science and Applications, Inc. accelerometer. *Med Sci Sports Exerc*, 1998; 30: 777-81.
63. Freedson P, Pober D, Janz KF. Calibration of accelerometer output for children. *Med Sci Sports Exerc*, 2005; 37: 523-30.
64. Gavarry O, Giacomoni M, Bernard T, Seymat M, Falgairette G. Habitual physical activity in children and adolescents during school and free days. *Med Sci Sports Exerc*, 2003; 35: 525-531.
65. Gortmaker SI, Must A, Sobol AM, Peterson K, Colditz GA, Dietz WH. Television viewing as a cause of increasing obesity among children in the United States, 1986-1990. *Arch Pediatr Adolesc Med*, 1996; 150: 356-62.
66. Hager RL. Television viewing and physical activity in children. *J Adolesc Health*, 2006; 39: 656-61.
67. Hoos M, Gerver W, Kester A, Westerterp K. Physical activity levels in children and adolescents. *Int J Obes*, 2003; 27: 605-9.
68. Hu G, Jousilahti P, Barengo N, Qiao Q, Lakka T, Tuomilehto J. Physical activity, cardiovascular risk factors, and mortality among Finnish adults with diabetes. *Diabetes Care*, 2005; 28: 799-805.

69. Imperatore G, Cheng Y, Williams D, Fulton J, Gregg E. Physical activity, cardiovascular fitness, and insulin sensitivity among U.S. adolescents. *Diabetes Care*, 2006; 29: 1567-72.
70. Jago R, Anderson C, Baranowski T, Watson K. Adolescent patterns of physical activity. Differences by gender, day, and time of day. *Am J Prev Med*, 2005; 28: 447-52.
71. Jago R, Watson K, Baranowski T, Zakeri I, Yoo S, Baranowski J, Conry K. Pedometer reliability, validity and daily activity targets among 10- to 15-year-old boys. *J Sports Sci*, 2006; 24: 241-51.
72. James PT, Leach R, Kalamara E, Shayeghi. The worldwide obesity epidemic. *Obes Res*, 2001; 9: 228-233.
73. Janz KF, Burns TL, Levy SM. Tracking of activity and sedentary behaviors in childhood – the Iowa bone development study. *Am J Prev Med*, 2005; 29: 171-8.
74. Janz KF, Witt J, Mahoney LT. The stability of children’s physical activity as measured by accelerometry and self-report. *Med Sci Sports Exerc*, 1995; 27: 1326-32.
75. Jeon CY, Lokken PR, Hu FB, van Dam RM. Physical activity of moderate intensity and risk of type 2 diabetes. *Diabetes Care*, 2007; 30: 744-52.
76. Kimm SYS, Obarzanek E. Childhood obesity: A new pandemic of the new millenium. *Pediatrics*, 2002; 110: 1003-7.
77. Kohl HW, Fulton JE, Caspersen CJ. Assessment of physical activity among children and adolescents: a review and synthesis. *Prev Med*, 2000; 31: 54-76.
78. Koezuka N, Koo M, Allison KR, Adlaf EM, Dwyer JJM, Faulkner G, Goodman J. The relationship between sedentary activities and physical inactivity among adolescents: results from the Canadian community health survey. *J Adolesc Health*, 2006; 39: 515-22.
79. Kowalski KC, Crocker PRE, Faulkner RA. Validation of the physical activity questionnaire for older children. *Pediatr Exerc Sci*, 1997; 9: 174-86.
80. Kristensen PL, Møller 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 (ahead of print).
81. Kristensen PL, Korsholm L, Møller NC, Wedderkopp N, Andersen LB, Froberg K. Sources of variation in habitual physical activity of

- children and adolescents: the European Youth Heart Study. *Scan J Med Sci Sports*, 2007 (ahead of print).
82. Kumahara H, Tanaka H, Schutz Y. Daily physical activity assessment: what is the importance of upper limb movements vs whole body movements? *Int J Obes Relat Metab Disord*, 2004; 28: 1105-10.
  83. Lagerros YT, Ligiou P. Assessment of physical activity and energy expenditure in epidemiological research of chronic diseases. *Eur J Epidemiol*, 2007; 22: 353-62.
  84. Lamonte MJ, Ainsworth BE. Quantifying energy expenditure and physical activity in the context of dose response. *Med Sci Sports Exerc*, 2001; 33: 370-8.
  85. Lawlor DA, Harro M, Wedderkopp N, Andersen LB, Sardinha LB, Riddoch CJ, Page AS, Anderssen SA, Froberg K, Stansbie D, Davey Smith G. Association of socioeconomic position with insulin resistance among children from Denmark, Estonia, and Portugal: cross sectional study. *BMJ*, 2005; 331:183-7.
  86. Lee IM, Rexrode KM, Cook NR, Manson JE, Buring JE. Physical activity and coronary heart disease in women – Is “no pain, no gain” passé? *JAMA*, 2001; 285: 1447-54.
  87. Livingstone MB. Heart-rate monitoring: the answer for assessing energy expenditure and physical activity in population studies? *Br J Nutr*, 1997; 78: 869-71.
  88. Livingstone MB, Coward WA, Prentice AM, Davies PS, Strain JJ, McKenna PG, Mahoney CA, White JA, Stewart CM, Kerr MJ. Daily energy expenditure in free-living children: comparison of heart-rate monitoring with the doubly labeled water (2H2(18)O) method. *Am J Clin Nutr*, 1992; 56: 345-52.
  89. Livingstone MBE, Robson PJ, Wallace JMW, McKinley MC. How active are we? Levels of routine physical activity in children and adults. *Proc Nutr Soc*, 2003; 62: 681-701.
  90. Lobstein T, Jackson-Leach R. Child overweight and obesity in the USA: prevalence rates according to IOTF definitions. *Int J Pediatr Obes*, 2007; 2: 62-4.
  91. Lobstein T, James W, Cole T. Increasing levels of excess weight among children in England. *Int J Obes*, 2003; 27: 1136-8.

92. Maffei C, Schutz Y, Zocante L, Micciolo L, Pinelli L. Meal-induced thermogenesis in lean and obese prepubertal children. *Am J Clin Nutr*, 1993; 57: 481-5.
93. Maffei C, Tatò L. Long-term effects of childhood obesity on morbidity and mortality. *Horm Res*, 2001; 55: 42-5.
94. Malina RM, Bouchard C, Bar-Or O. *Growth, maturation, and physical activity*. Second edition. Champaign: Human Kinetics Inc, 2004.
95. Mallam KM, Metcalf BS, Kirkby J, Voss LD, Wilkin TJ. Contribution of timetabled physical education to total physical activity in primary school children: cross sectional study. *BMJ*, 2003; 327: 592-3.
96. Marshall SJ, Biddle SJH, Gorely T, Cameron N, Murdey I. Relationships between media use, body fatness and physical activity in children and youth: a meta-analysis. *Int J Obes Relat Metab Disord*, 2004; 28: 1238-46.
97. Marshall SJ, Gorely T, Biddle SJH. A descriptive epidemiology of screen-based media use in youth: a review and critique. *J Adolesc*, 2006; 29: 333-49.
98. 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*, 2007; 39: 622-9.
99. 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*, 2007; 29: 1-9.
100. McArdle WD, Katch FI, Katch VL. *Essentials of Exercise Physiology – energy, nutrition, and human performance*. Third edition. Baltimore: Lippincott Williams & Wilkins, 2006.
101. McGill HC, McMahan CA, Herderick EE, Malcom GT, Tracy RE, Strong JP. Origin of atherosclerosis in childhood and adolescence. *Am J Clin Nutr*, 2000; 72: 1307-15.
102. McKay J, Mensah GA. *The atlas of heart disease and stroke*. Geneva: World Health Organization, 2004.
103. McMurray RG, Harrel JS, Bangdiwala S, Hu J. Tracking of physical activity and aerobic power from childhood through adolescence. *Med Sci Sports Exerc*, 2003; 35: 1914-22.

104. Metcalf BS, Curnow JSH, Evans C, Voss LD, Wilkin TJ. Technical reliability of the CSA activity monitor: The early bird study. *Med Sci Sports Exerc*, 2002; 34: 1533-37.
105. Mokdad AH, Ford ES, Bowman BA, Dietz WH, Vinicor F, Bales VS, Marks JS. Prevalence of obesity, diabetes and obesity-related health risk factors, 2001. *JAMA*, 2003; 289: 76-9.
106. Montgomery C, Reilly J, Jackson D, Kelly L, Slater C, Paton J, Grant S. Relation between physical activity and energy expenditure in a representative sample of young children. *Am J Clin Nutr*, 2004; 80: 591-6.
107. Montoye HJ, Kemper HCG, Saris WHM, Wahsburn RA. *Measuring physical activity and energy expenditure*. Champaign: Human Kinetics Inc, 1996.
108. Mota J, Silva P, Santos MP, Ribeiro JC, Oliveira J, Duarte JA. Physical activity and school recess time: differences between the sexes and the relationship between children's playground physical activity and habitual physical activity. *J Sports Sci*, 2005; 23: 269-75.
109. Murgatroyd PR, Shetty PS, Prentice AM. The techniques for the measurements of human energy expenditure: a practical guide. *Int J Obes*, 1993; 17: 549-68.
110. Must A, Jacques PF, Dallal GE, Bajema CJ, Dietz WH. Long-term morbidity and mortality of overweight adolescents. A follow-up at the Harvard growth study of 1922 to 1935. *New Engl J Med*, 1992; 327: 1350-55.
111. Müller MJ, Bösby-Westphal A. Assessment of energy expenditure in children and adolescents. *Curr Opin Clin Nutr Metab Care*, 2003; 6: 519-30.
112. Mårild S, Bondestam M, Bergström 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: 1588-95.
113. Nader PR, National Institute of Child Health and Human Development Study of Early Child Care and Youth Development Network. Frequency and intensity of activity of third-grade children in physical education. *Arch Pediatr Adolesc Med*, 2005; 157: 185-90.
114. National Institute of Health. *Physical activity and cardiovascular health – a national consensus*. Champaign: Human Kinetics Inc, 1997.

115. 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.
116. Paffenbarger RD, Hyde RT, Wing AL, Lee IM, Jung DL, Kampert JB. The association of changes in physical activity level and other lifestyle characteristics with mortality among men. *N Engl J Med*, 1993; 328: 538-45.
117. Pate RR, Almeida MJ, McIver KL, Pfeiffer KA, Dowda M. Validation and calibration of an accelerometer in preschool children. *Obesity (Silver spring)*, 2006; 14: 2000-6.
118. 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: 303-8.
119. 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: 1262-8.
120. Pate R, Trost S, Williams C. Critique of existing guidelines for physical activity in young people. In S. Biddle, J Sallis, N Cavill (Eds.) *Young and active? Young people and health-enhancing physical activity – evidence and implications*, pp 162-176. London: Health Education Authority, 1998.
121. Payne VG, Morrow JR Jr, Johnson L, Dalton SN. Resistance training in children and youth: a meta-analysis. *Res Q Exerc Sport*, 1997; 68: 80-8.
122. Penpraze V, Reilly JJ, McLean CM, Montgomery C, Kelly LA, Paton JY, Aitchison T, Grant S. Monitoring of physical activity in young children: how much is enough? *Pediatr Exerc Sci*, 2006; 18: 483-91.
123. Plasqui G, Westerterp KR. Seasonal variation in total energy expenditure and physical activity in Dutch young adults. *Obes Res*, 2004; 12: 688-94.
124. Plasqui G, Westerterp KR. Physical activity assessment with accelerometers: an evaluation against doubly labeled water. *Obesity (Silver Spring)*, 2007; 15: 2371-9.
125. Puyau M, Adolph A, Firoz V and Butte N. Validation and calibration of physical activity monitors in children. *Obes Res*, 2002; 10: 150-7.

126. Racette SB, Schoeller DA, Luke AH, Shay K, Hnilicka J, Kushner RF. Relative dilution spaces of  $^2\text{H}$ - and  $^{18}\text{O}$ -labeled water in humans. *Am J Physiol*, 1994; 30: 585-90.
127. Reilly J, Jackson D, Montgomery C, Kelly L, Slater C, Grant S, Paton J. Total energy expenditure and physical activity in young Scottish children: mixed longitudinal study. *Lancet*, 2004; 363: 211-2.
128. Rennie K, Rowsell T, Jebb SA, Holburn D, Wareham NJ. A combined heart rate and movement sensor: proof of concept and preliminary testing study. *Eur J Clin Nutr*, 2000; 54: 409-14.
129. Riddoch C. Relationships between physical activity and physical health in young people. In: Biddle S, Sallis J, Cavill N (Eds.) *Young and active? Young people and health-enhancing physical activity – evidence and implications*, pp 17-48. London: Health Education Authority, 1998.
130. Riddoch C, Andersen LB, Wedderkopp N, Harro M, Klasson-Heggebo L, Sardinha L, 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.
131. Riddoch C, Edwards D, Page A, Froberg K, Anderssen SA, Wedderkopp N, Brage S, Cooper AR, Sardinha LB, Harro L, Klasson-Heggebo L, van Mechelen W, Boreham C, Ekelund U, Andersen LB, and the European Youth Heart Study team. The European Youth Heart Study – Cardiovascular disease risk factors in children: rationale, aims, study design, and validation of methods. *JPAH*, 2005; 2: 115-29.
132. Riddoch C, Mattocks C, Deere K, Saunders J, Kirkby J, Tilling K, Leary S, Blair S, Ness A. Objective measurement of levels and patterns of physical activity. *Arch Dis Child*, 2007; 00: 1-8.
133. Ridgers N, Stratton G, Fairclough S. Assessing physical activity during recess using accelerometry. *Prev Med*, 2005; 41: 102-7.
134. Robinson TN. Reducing children's television viewing to prevent obesity: a randomized controlled trial. *JAMA*, 1999; 27: 1561-7.
135. Rowlands AV, Ingledeu DK, Eston RG. The effect of type of physical activity measure on the relationship between body fatness and habitual physical activity in children: a meta-analysis. *Ann Hum Biol*, 2000; 27: 479-97.



136. Saksvig BI, et al. Travel by walking before and after school and physical activity among adolescent girls. *Arch Pediatr Adolesc Med*, 2007; 161: 153-8.
137. Sallis JF, Owen N. *Physical activity and behavioral medicine*. Thousand Oaks: SAGE publications Inc, 1999.
138. Sallis J, Patrick K. Physical activity guidelines for adolescents: consensus statement. *Pediatr Exerc Sci*, 1994; 6: 302-14.
139. Sallis JF, Prochaska JJ, Taylor WC. A review of correlates of physical activity of children and adolescents. *Med Sci Sports Exerc*, 2000; 32: 963-75.
140. Sallis JF, Saelens BE. Assessment of physical activity by self-report: status, limitations and future directions. *Res Q Exerc Sport*, 2000; 71: 1-14.
141. Sallo M, Silla R. Physical activity with moderate to vigorous intensity in preeschool and first-grade schoolchildren. *Pediatr Exerc Sci*, 1997; 9: 44-54.
142. Schmitz KH, Treuth M, Hannan P, McMurray R, Ring KB, Catellier D, Pate R. Predicting energy expenditure from accelerometry counts in adolescent girls. *Med Sci Sports Exerc*, 2005; 37: 155-61.
143. Schoeller DA, Ravussin E, Schultz Y, Acheson KJ, Baertschi P, Jequier E. Energy expenditure by doubly labelled water: validation in humans and proposed calculation. *Am J Physiol*, 1986; 250: 823-30.
144. Schofield W, Schofield C, James P. Predicting basal metabolic rate. New standards and review of previous work. *Hum Nutr Clin Nutr*, 1985; 39: 5-41.
145. Schutz Y, Weinsier RL, Hunter GR. Assessment of free-living physical activity in humans: an overview of currently available and proposed new measures. *Obes Res*, 2001; 9: 368-79.
146. Sesso HD, Paffenbarger RS, Lee IM. Physical activity and coronary heart disease in men: The harvard alumni health study. *Circulation*, 2000; 102: 975-80.
147. Sirard JR, Riner WF, McIver KL, Pate RR. Physical activity and active commuting to elementary school. *Med Sci Sports Exerc*, 2005; 37: 2062-69.
148. Speakman JR. The history and theory of the doubly labeled water technique. *Am J Clin Nutr*, 1998; 68: 932-8.

149. Speakman JR, Nair KS, Goran MI. Revised equations for calculating CO<sub>2</sub> production from doubly labelled water in humans. *Am J Physiol*, 1993; 264: 912-7.
150. Spinks A, MacPherson A, Bain C, McClure R. Determinants of sufficient daily activity in Australian primary school children. *J Paediatr Child Health*, 2006; 42: 674-9.
151. Strath SJ, Bassett DR Jr, Thompson DL, Swartz AM. Validity of the simultaneous heart rate-motion sensor technique for measuring energy expenditure. *Med Sci Sports Exerc*, 2002; 34: 888-94.
152. Strong WB, Malina RM, Cameron JR, et al. Evidence based physical activity for school-aged youth. *J Pediatr*, 2005; 146: 732-7.
153. Taveras EM, Field AE, Berkey CS, Rifas-Shiman SL, Frazier AI, Colditz GA, Gillman MW. Longitudinal relationship between television viewing and leisure-time physical activity during adolescence. *Pediatrics*, 2007; 119: e314-19.
154. Telama R, Yang X, Hirvensalo M, Raitakari O. Participation in Organized Youth Sport as a Predictor of Adult Physical Activity: A 21-Year Longitudinal Study. *Pediatr Exerc Sci*, 2006; 18: 76-88.
155. Telama R, Yang X, Viikari J, Välimäki I, Wanne O, Raitakari O. Physical activity from childhood to adulthood – a 21-year tracking study. *Am J Prev Med*, 2005; 28: 267-73.
156. Tobias JH, Steer CD, Mattocks CG, Riddoch C, Ness AR. Habitual levels of physical activity influence bone mass in 11-year-old children from the United Kingdom: findings from a large population-based cohort. *J Bone Miner Res*, 2007; 22: 101-9.
157. Torun B, Davies PSW, Livingstone MBE, Paolisso M, Sackett R, Spurr GB. Energy requirements and dietary energy recommendations for children and adolescents 1 to 18 years old. *Am J Clin Nutr*, 1996; 50: 37-81.
158. Treuth MS, Catellier DJ, Schmitz K, Pate RR, Elder JP, McMurray RG, Blew RM, Yang S, Webber L. Weekend and weekday patterns of physical activity in overweight and normal-weight adolescent girls. *Obesity (Silver Spring)*, 2007; 15: 1782-88.
159. 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: 1259-66.

160. Treuth MS, Sherwood NE, Butte NF, McClanahan B, Obarzanek E, Zhou A, Ayers C, Adolph A, Jordan J, Jacobs DR, Rochon J. Validity and reliability of activity measures in African-American girls for GEMS. *Med Sci Sports Exerc*, 2003; 35: 532-9.
161. Trost SG. Objective measurement of physical activity in youth: current issues, future directions. *Exerc Sport Sci Rev*, 2001; 29: 32-6.
162. Trost SG, McIver KL, Pater RR. Conducting accelerometer-based activity assessments in field-based research. *Med Sci Sports Exerc*, 2005; 37: 531-43.
163. 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: 426-31.
164. 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: 350-55.
165. Trost S, Ward D, Moorehead S, Watson P, Riner W, Burke J. Validity of the computer science and applications (CSA) activity monitor in children. *Med Sci Sports Exerc*, 1998; 30: 629-633.
166. Tudor-Locke C, Ainsworth BE, Thompson RW, Matthews CE. Comparison of pedometer and accelerometer measures of free-living physical activity. *Med Sci Sports Exerc*, 2002; 34: 2045-51.
167. Tudor-Locke C, Neff LJ, Ainsworth BE, Addy CL, Popkin BM. Omission of active commuting to school and the prevalence of children's health-related physical activity levels: the russian longitudinal monitoring study. *Child Care Health Dev*, 2002; 28: 507-12.
168. Tuomilehto J, Lindström J, Eriksson J, et al. Prevention of Type 2 diabetes mellitus by changes in lifestyle among subjects with impaired glucose tolerance. *New Engl J Med*, 2001; 344: 1343-50.
169. Twisk J. Physical activity guidelines for children and adolescents: a critical review. *Sports Med*, 2001; 31: 617-27.
170. US Department of Health and Human Services. *Physical activity and health: a report of the Surgeon General*. Atlanta: US Department of Health and Human Services, Centers for disease control and prevention, 1996.
171. Vandewater EA, Bickham DS, Lee JH. Time well spent? Relating television use to children's free-time activities. *Pediatrics*, 2006; 117: e181-91.

172. Vilhjalmsson R, Kristjansdottir G. Gender differences in physical activity in older children and adolescents: the central role of organized sport. *Soc Sci Med*, 2003; 56: 363-74.
173. Wareham NJ, Hennings SJ, Prentice AM, Day NE. Feasibility of heart-rate monitoring to estimate total level and pattern of energy expenditure in a population-based epidemiological study: the Ely Young Cohort Feasibility Study 1994-5. *Br J Nutr*, 1997; 78: 889-900.
174. Wareham NJ, van Sluijs EM, Ekelund U. Physical activity and obesity prevention: a review of the current evidence. *Proc Nutr Soc*, 2005; 64: 229-47.
175. Weir, JB. New methods for calculating metabolic rate with special reference to protein metabolism. *J Physiol*, 1949: 109:1-9.
176. Welk GJ, Corbin CB, Dale D. Measurement issues in the assessment of physical activity in children. *Res Q Exerc Sport*, 2000; 71: 59-73.
177. Westerterp KR. Physical activity assessment with accelerometers. *Int J Obes Relat Metab Disord*, 1999a; 23: 45-9.
178. Westerterp KR. Assessment of physical activity level in relation to obesity: current evidence and research issues. *Med Sci Sports Exerc*, 1999b; 11: 522-5.
179. Westerterp KR. Impacts of vigorous and non-vigorous activity on daily energy expenditure. *Proc Nutr Soc*, 2003; 62: 645-50.
180. Wilkin TJ, Mallam KM, Metcalf BS, Voss LD. Variation in physical activity lies with the child, not his environment: evidence for an 'activitystat' in young children (EarlyBird 16). *Int J Obes Relat Metab Disord*, 2006; 30: 1050-55.
181. 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: 869-73.
182. Wild S, Roglic G, Green A, Sicree R, King H. Global prevalence of diabetes – estimates for the year 2000 and projections for 2030. *Diabetes care*, 2004; 27: 1047-53.
183. Wold B, Hendry L. Social and environmental factors associated with physical activity in young people. In: Biddle S, Sallis J, Cavill N (Eds.) *Young and active? Young people and health-enhancing physical activity – evidence and implications*, pp 119-132. London: Health Education Authority, 1998.