From THE DEPARTMENT OF MEDICAL NUTRITION
Karolinska Institutet, Stockholm, Sweden

ASSESSMENT OF PHYSICAL ACTIVITY AND ENERGY EXPENDITURE IN ADOLESCENTS

Ulf Ekelund

Stockholm 2002

Published and printed by Karolinska University Press
Box 200, SE-171 77 Stockholm, Sweden

ISBN 91-7349-186-1

"Men vem besitter förmågan av och veta vad som ryms i en ny individ och vem kan säga till nån annan hur lyckan ser ut, vem kan säga vad nån annan vill bli?
Låt dina blommor slå rot där det finns jordmån, låt dina växter få leva där dom trivs, lås inte in dina plantor i ett drivhus, låt dom få slippa ett onaturligt liv.
Låt den du älskar få pröva sina vingar, en dag så flyger din älskade rätt, vill du bli respekterad av din avbild får du visa din avbild respekt"

(Björn Afzelius, Ikaros, 1984)

Till Rasmus och Emil

ABSTRACT

Physical activity (PA) is a complex, multidimensional human behaviour that includes all bodily movement from fidgeting to participation in marathon running. The detailed relationship (i.e. dose – response) between the type and degree of PA and its effects on various aspects of health remains to be elucidated, not least in young people. The development and evaluation of different PA assessment methods is therefore of high priority. Methods of physical activity assessment include both self-report methods, such as activity diaries, questionnaires and activity recalls, and objective assessment techniques. Objective assessment of free-living physical activity can be based on physiological (energy expenditure, heart rate [HR] monitoring) and biomechanical (accelerometry) principles.

The overall purpose with the present studies was to increase our understanding of the suitability of different PA assessment methods for use in normally active adolescents and in young athletes, and to gain further knowledge about the amount and pattern of physical activity among adolescents. One hundred and fifty-seven randomly selected boys and girls and eight volunteer young athletes participated in the studies. One self-report method (activity diary) and three objective methods (HR monitoring, accelerometry and the doubly labelled water method, [DLW]) were applied in the studies. All measurements of PA and total energy expenditure (TEE) were performed under free-living conditions. In addition, the relationship between HR and energy expenditure was individually measured during rest and standardised exercises in the laboratory. In the group of eight young athletes all measurements were performed under two different training conditions.

The main findings were that: 1) there was no significant difference for the data on TEE and time spent at PA of moderate intensity or higher between the HR monitoring method and the activity diary; 2) the fitness level of the subjects affected the use of absolute HR when defining PA intensity levels; 3) in a random sample of 14-to-15-year-old adolescents, approximately 30% of the boys and girls did not achieve appropriate levels of PA according to published recommendations; and 4) the relationship between TEE and its derivatives measured by DLW, on the one hand, and the total amount of physical activity measured with an accelerometer, on the other, was influenced by the different training condition, whereas TEE estimated by minute-by-minute HR monitoring seem to be unaffected both by the definition of the FLEX HR and by the training condition.

It is concluded that the activity diary method is a valid method for estimating TEE and time spent at PA of moderate intensity or higher in groups of adolescents. With the HR monitoring method, use of absolute heart rates for defining intensity levels reduces the validity of the data interpretation. Individual calibration for the heart rate – oxygen uptake relationship is therefore necessary. A relatively large group of adolescents does not achieve the amounts of physical activity recommended beneficial for health. This seems to be a public health concern. The HR monitoring method is not affected by different training regimens and is therefore a more favourable way of assessing physical activity in young athletes as compared to accelerometry.

LIST OF PUBLICATIONS

I Ekelund U, Yngve A, Sjöström M. (1999) Total daily energy expenditure and patterns of physical activity assessed by two different methods in adolescents. *Scand J Med Sci Sports*, 9; 257-264

II Ekelund U, Poortvliet E, Yngve A, Hurtig-Wennlöv A, Nilsson A, Sjöström M. (2001) Heart rate as an indicator of the intensity of physical activity in human adolescents. *Euro J Appl Physiol*. 85; 244-249

III Ekelund U, Sjöström M, Yngve A, Nilsson A. (2000) Total daily energy expenditure and pattern of physical activity measured by minute-by-minute heart rate monitoring in 14-15 year old Swedish adolescents. *Eur J Clin Nutr*, 54; 195-202

IV Ekelund U, Yngve A, Westerterp K, Sjöström M. (2002) Energy expenditure assessed by heart rate and doubly labeled water in young athletes. *Med Sci Sports Exerc,* 34(8) (in press)

V Ekelund U, Yngve A, Sjöström M, Westerterp K. (2000) Field evaluation of the Computer Science and Application's Inc. activity monitor during running and skating training in adolescent athletes. *Int J Sports Med*, 21; 586-592

CONTENTS

1 INTRODUCTION 1
1.1 Quantifying physical activity and energy expenditure 1
1.1.1 Dimensions of physical activity and energy expenditure 2
1.1.2 Intensity of physical activity 2
1.1.3 Total energy expenditure 3
1.2 Accurate and consistent assessments of physical activity 4
1.3 Assessment methods 5
1.3.1 Self-report methods 6
1.3.2 Heart rate monitoring 7
1.3.3 The doubly labelled water method 10
1.3.4 Accelerometry 11
1.4 The epidemiology of young people's physical activity 14
1.4.1 Prevalence of habitual physical activity 14
1.4.2 Recommendations for physical activity in young people 16
1.4.3 Total energy expenditure and physical activity level 18
2 PURPOSE 20
3 MATERIALS AND METHODS 21
3.1 Subjects and study designs 21
3.2 Anthropometrics and body composition 23
3.2.1 Skinfold measurements 23
3.2.2 Total body water, fat mass and fat-free mass 23
3.3 Laboratory energy expenditure measurements 23
3.3.1 Individual calibration 23
3.3.2 Resting energy expenditure 24
3.3.3 Resting metabolic rate 25
3.3.4 Peak oxygen uptake 25
3.4 TEE measurements under free-living conditions 26
3.4.1 The Activity diary method 26
3.4.2 The FLEX HR method 26
3.4.3 The Doubly labelled water method 27
3.4.4 Calculation of basal metabolic rate 27
3.4.5 Calculation of PAL and AEE 28
3.5 Measurements of patterns of physical activity 28
3.5.1 Activity diary 28
3.5.2 Heart rate monitoring 28
3.5.3 Accelerometry 28
3.6 Energy intake 28
3.7 Training diary 29
3.8 Ethics 29
3.9 Statistics 29
4 RESULTS AND COMMENTS 31
4.1 Validity of a self-reported activity diary (STUDY I) 31
4.2 The definition of intensity from heart rate (STUDY II) 33
4.3 Physical activity in relation to guidelines (STUDY III) 35
4.4 TEE measured by HR and DLW in young athletes (STUDY IV) 37

4.5 The validity of the CSA accelerometer (STUDY V) 39
5 GENERAL DISCUSSION 41
5.1 Calculation of TEE and AEE from self-reports 41
5.2 HR monitoring – the definition of intensity thresholds 42
5.3 Assessment of the total volume of physical activity 43
5.4 Future directions 45
6 CONCLUSIONS 47
7 ACKNOWLEDGEMENTS 48
8 REFERENCES 50

LIST OF ABBREVIATIONS

AD	Activity diary
ADMR	Average daily metabolic rate, synonymous to TEE and TDEE
AEE	Activity energy expenditure
BMR	Basal metabolic rate
CSA	Computer Science and Application's (activity monitor)
DIT	Diet induced thermogenesis
DLW	Doubly labelled water
EE	Energy expenditure
FFM	Fat free mass
FQ	Food quotient
HR	Heart rate
HRR	Heart rate reserve
LTPA	Leisure-time physical activity
MET	Metabolic energy turnover
MPA	Moderate intensity of physical activity
MVPA	Moderate and vigorous intensity of physical activity
PA	Physical activity
PAL	Physical activity level
PVO_2	Peak oxygen uptake
RMR	Resting metabolic rate
REE	Resting energy expenditure, synonymous to SEE
RQ	Respiratory quotient
SEE	Sedentary energy expenditure, synonymous to REE
TBW	Total body water
TDEE	Total daily energy expenditure, synonymous to TEE and ADMR
TEE	Total energy expenditure, synonymous to TDEE and ADMR
VO_2	Oxygen uptake
VO_{2max}	Maximal oxygen uptake
VO_2R	Oxygen uptake reserve
VPA	Vigorous intensity of physical activity

1 INTRODUCTION

Apart from the very first year, the adolescence period is the most revolutionary part of the life of a human being when it comes to growth, and to physical, social, and mental development.

The normal somatic development during adolescence is characterised by rapid growth in weight and height, and remarkable changes in body composition, including changes in fat mass, fat-free mass and skeletal growth, changes in hormonal regulatory systems and in primary and secondary sexual characteristics (Kreipe, 1992). Physical activity (PA) together with nutritional intake, socio-economic status, family size, history of illness and climate, is often seen as an environmental factor, which influences growth and maturation (Malina and Bouchard, 1991). However, even if physical activity is presumably important for supporting normal growth and maturation, the amount of activity needed is unknown (Malina and Bouchard, 1991; Parizkova, 1996).

Moreover, young people of today are living in an environment, that has been described as full of 'sedentary alternatives' (Epstein *et al*, 1995) and there is general concern about low levels of physical activity in youth. However, scientific evidence pointing to a gradual decline in physical activity over the last decades is limited, as also is evidence supporting a close relationship between physical activity and health in the young population. This has been said to be largely due to the lack of accurate assessment methods, and to the difficulties associated with the measurement of habitual physical activity in young people (Boreham and Riddoch, 2001; Rowland, 2001).

Thus, there seems to be a current need for developing, evaluating and testing different techniques for assessing physical activity in young people. The overall aim of the studies described in the present thesis was to gain further knowledge about the assessment of physical activity and energy expenditure in adolescents.

The terms adolescents, young people and youth are often used interchangeably. In The 'Physical activity guidelines for adolescents', Sallis and Patrick (1994) define adolescence as the ages from 11 to 21 years. In 'Young and active? Young people and health enhancing physical activity – evidence and implications' (Health Education Authority, 1998) young people are defined as those of ages from 5 to 18 years.

The present thesis focuses on the adolescent age group, i.e. 14 to 20 years, although some of the cited literature, when appropriate, refers to adults as well as to children.

1.1 QUANTIFYING PHYSICAL ACTIVITY AND ENERGY EXPENDITURE

Physical activity is a complex multidimensional form of human behaviour that theoretically includes all bodily movement from fidgeting to participation in extreme sport activities such as marathon running or triathlon (Sallis and Owen, 1999). Although physical activity is behavioural, it has physiological consequences, for example it is associated with an increase in energy expenditure (EE) above a basal level. Usually, physical activity refers to the use of large muscle groups, such as movements of the arms and legs, but it has been defined as *"any bodily movement produced by skeletal muscles that results in energy expenditure"* (Caspersen *et al*, 1985). However, physical activity and energy expenditure are not synonymous. Physical activity is a form of behaviour, whereas energy expenditure is an outcome of that behaviour. Physical activity is most commonly quantified in terms of intensity, frequency and duration (see below), whereas energy expenditure is measured as the energy cost of a given form of physical activity or as the energy cost associated with physical activity performed for a specific period of time. Available assessment methods include direct and indirect measurements of both physical activity and energy expenditure.

1.1.1 Dimensions of physical activity and energy expenditure

In assessments of physical activity, at least four main dimensions are of interest, namely its type, frequency, duration and intensity, all of which are important both for descriptive and analytical purposes.

The **type** or **mode** of physical activity refers to the different specific activities in which the subjects are engaged. Leisure-time physical activity (LTPA) is a broad term covering those activities carried out during free time. These include both structured exercise programmes and non-structured exercise such as walking, hiking, cycling, jogging etc. All these activities result in a substantial increase in energy expenditure even though their intensity and duration may vary considerably (Howley, 2001). **Exercise** is thus a subcategory of LTPA, which has been defined as "*a subset of physical activity that is planned, structured, and repetitive bodily movement done to improve or maintain one or more components of physical fitness.*" (Casperson *et al*, 1985). Another subcategory of LTPA includes those activities associated with household chores such as cleaning, washing, cooking and so on. Occupational physical activity refers to activities associated with a job or schoolwork, and transportation physical activity concerns physical activity for transportation, such as walking or cycling.

The **frequency** of physical activity refers to the number of sessions of physical activity per unit of time (i.e. day, week, or month), and the **duration** is the length of time in each session.

1.1.2 Intensity of physical activity

The dose of physical activity can be described in terms of both absolute and relative intensities, but also as the total volume of physical activity or as the energy expenditure associated with physical activity over a specific period of time. The intensity of physical activity is commonly described as low or light, moderate, vigorous or hard, or very vigorous or strenuous (US Department of Health and Human Services, 1996).

Absolute intensity. This is defined as the actual rate of energy expenditure during a specific time period and is usually expressed as: oxygen uptake (VO_2; $l \cdot min^{-1}$), oxygen uptake relative to body mass ($ml \cdot kg^{-1} \cdot min^{-1}$; $ml \cdot kg^{-0.67} \cdot min^{-1}$), energy expenditure ($kcal \cdot min^{-1}$ or $kJ \cdot min^{-1}$), or as multiples of resting metabolic rate (RMR), the metabolic energy turnover (MET) classification. One MET corresponds to the energy expenditure during rest, about 3.5 ml O_2 $kg^{-1} \cdot min^{-1}$ or broadly equivalent to 1 $kcal \cdot kg^{-1} \cdot min^{-1}$ in adult subjects (Mc Ardle *et al*, 2001; US Department of Health and Human Services, 1996). The MET classification can be a useful tool when calculating energy expenditure from self-report assessment methods such as questionnaires and activity diaries. For adults, more than 600 specific activities have been classified according to their respective MET values (Ainsworth *et al*, 1993; Ainsworth *et al*, 2000).

Absolute intensity levels corresponding to specific MET values have been suggested for young people (Pate, 1998; Riddoch and Boreham, 1995). Riddoch and Boreham (1995) suggested the following intensity levels based on data from young adults (Swain *et al*, 1994): light intensity 2 to 4 METs, moderate as 5 to 7.5 METs and vigorous as > 7.5 METs. Similarly, Pate *et al*, (1998) suggested the following MET values for various intensity levels of physical activity: < 5 MET light intensity, 5 to 8 METs, moderate intensity and > 8 METs, vigorous intensity of physical activity.

Relative intensity. To take into account differences in age, sex, body composition and aerobic fitness level between subjects, the intensity of physical activity can be categorised in relative terms (Howley, 2001; Mc Ardle *et al*, 2001; US Department of Health and Human Services, 1996); that is, in relation to a person's maximal aerobic capacity for a specific activity. The relative intensity of aerobic activities can be described in terms of percentage of maximal aerobic capacity (% VO_{2max}) (American College of Sports Medicine [ACSM], 1995; Mc Ardle *et al*, 2001), percentage of maximal heart rate (% HR_{max}) (ACSM, 1995), percentage of heart rate reserve (% HRR) (Karvonen *et al*, 1957) and percentage of oxygen uptake reserve (% VO_2R) (Swain *et al*, 1997). The % VO_2R corresponds to the heart rate response when it is expressed as a percentage of HRR across the fitness continuum, at least in adults (Swain *et al*, 1997; Swain *et al*, 1998).

1.1.3 Total energy expenditure

The product of absolute intensity, frequency and duration yields the energy expenditure associated with total physical activity during a given period, or the **total volume** of activity. The total volume of physical activity can be quantified in MET-minutes or MET-hours per day or week. This is the intensity of all different activities performed during the assessment period expressed in MET equivalents multiplied by time spent in all activities. This is a common way to express the total volume of physical activity when using self-report assessment methods (Montoye *et al*, 1996; Kriska and Casperson, 1997).

If an assessment method is designed to quantify the total energy expenditure over a specific period of time, it is possible to calculate the **total energy expenditure** (TEE), which is synonymous to **total daily energy expenditure** (TDEE) and **average daily metabolic rate** (ADMR). TEE consists of **resting metabolic rate** (RMR), **diet-induced thermogenesis** (DIT), and energy expenditure devoted to physical activity, the **activity energy expenditure** (AEE). In normally active subjects consuming a normal diet, the basal or resting energy expenditure consitutes 60 to 70% of TEE and the diet-induced thermogenesis constitutes about 10% of the total energy expended per day (Belko *et al*, 1986). DIT seems to be unaffected by body composition in young people (Maffeis *et al*, 1993).

Energy expenditure from physical activity is by far the most variable component of TEE. By subtracting estimated or measured RMR from TEE, AEE can be calculated. AEE is the total amount of energy expended in association with physical activity. The calculation of AEE usually takes into account DIT, assuming that 10% of TEE is due to DIT (i.e. TEE * 0.9 minus resting metabolic rate [RMR]) (Maffeis *et al*, 1993). In extreme cases, the energy expended in physical activity (i.e. AEE) is about three to four times the resting metabolic rate (RMR) (Sjödin *et al*, 1994; Trappe *et al*, 1997; Westerterp *et al*, 1986).

Although the calculation of AEE provides an estimate of energy expenditure due to physical activity, it may not differentiate between subjects or groups of subjects with physical activity of different levels. Comparisons of activity levels between individuals require correction of energy expenditure for body size. In attempts to adjust for differences in body size, several options are available. TEE and AEE can be divided by body weight or by body weight scaled, using an exponent between 0.5 and 1.0

(Westerterp, 1999). The rationale for scaling body weight is that physical activity includes both weight-bearing and non-weight-bearing activities. The use of ratios (e.g. $TEE \cdot kg^{-1}$) for expressing energy expenditure data has been questioned on the grounds of the variability of the non-zero intercept between the numerator and denominator, which is necessary if a ratio is to remove the confounding effect of the denominator (Allison *et al*, 1995; Carpenter *et al*, 1995). There is unfortunately no generalisable scaling coefficient for adjusting activity energy expenditure for differences in body size (Prentice *et al*. 1996). However, it was recently suggested that normalisation of energy expenditure from physical activity by division by body weight is an appropriate means for comparing the volume of physical activity between individuals of different body size (Schoeller and Jefford, 2002).

The **physical activity level** (PAL) is calculated as the ratio of TEE to RMR and provides a way to adjust for inter-individual differences in age, gender, body weight, and body composition (Prentice *et al*, 1996; Shetty *et al*, 1996). PAL may be the most useful indicator of the total volume of physical activity, although it assumes that the variation in TEE is dependent on body size and physical activity (Westerterp, 1999). PAL values have been estimated for different life-styles and activity levels in adults (Black *et al*, 1996), and for low, moderate and vigorous habitual levels of physical activity in children and adolescents (Torun *et al*, 1996). Generally, PAL values vary between 1.2 and 2.5 (Black *et al*, 1996). It has been suggested that a PAL value of 1.2 is the lowest 'survival' level in a free-living individual (Black *et al*, 1996), although lower values for PAL have been reported from wheel chair dependent children (van den Berg-Emons *et al*, 1996). The suggested upper limit in the general population is about 2.2 to 2.5 and about twice as high in extreme endurance athletes (Westerterp, 2001).

When physical activity is assessed by means of accelerometry, the total volume of physical activity over a prolonged period of time (i.e. days) can also be quantified as total counts or total counts corrected for monitoring time (Bouten *et al*, 1996; Ekelund *et al*, 2001b).

1.2 ACCURATE AND CONSISTENT ASSESSMENTS OF PHYSICAL ACTIVITY

There is a substantial body of evidence, pointing to clear associations between a sedentary life-style and mortality and morbidity in the adult population (US Department of Health and Human Services, 1996). This is most pronounced for all-cause mortality (Paffenbarger *et al*, 1986), coronary heart disease (CHD) (Paffenbarger *et al*, 1978), cardiovascular disease (CVD) (Kannel and Sorlie, 1979; Paffenbarger *et al*, 1984), stroke (Wannamethee and Sharper, 1992; Lee and Paffenbarger, 1998), non-insulin-dependent diabetes mellitus (NIDDM) (Manson *et al*, 1991; Manson *et al*, 1992), colon cancer (Giovannucci *et al*, 1995; Martinez *et al*, 1997) and hip fracture (Cummings *et al*, 1995; Dragent-Molina *et al*, 1996). Much of this evidence comes from epidemiological studies, where the methods used to assess physical activity have been relatively crude (Wareham and Rennie, 1998).

Surprisingly, and in contrast to the data in adults, the empirical evidence supporting the hypothesis that physical activity is beneficial for health in young people is limited (Alpert and Wilmore, 1994; Armstrong and Simons-Morton, 1994; Boreham and Riddoch, 2001; Leonard 2001; Riddoch 1998; Rowland, 2001). Nevertheless, there is increasing awareness of the potential health benefits of physical activity in young people. Blair *et al*, (1989) have suggested three main benefits of adequate amounts of physical activity in young people (although the appropriate amounts of physical activity beneficial for health in young people are not very well defined). First, a direct relationship between physical activity and the health status in young people is suggested. Secondly, there is a relationship between physical activity during young ages and adult health status. Thirdly, it is likely that physically active young people will maintain adequate levels of physical activity into adulthood, generally referred to as tracking of physical activity (Blair *et al*, 1989).

Although there is some evidence supporting all these three relationships, it is relatively weak and no prospective study has unquestionable linked the health status of adults with the amount and patterns of physical activity during childhood or adolescence. One of the major reasons for this is the difficulties in accurately measuring habitual physical activity in young people (Riddoch, 1998; Boreham and Riddoch, 2001; Rowland, 2001), not least during the adolescence period, when potential relationships between activity and health may be confounded by natural changes in the body composition, and hormone levels and a natural decline in physical activity (Malina and Bouchard, 1991).

Thus, there are a number of reasons, justifying the research aimed to improve the methods used to assess physical activity in young people (as well as in adults). First, to determine what dimension or combination of dimensions of physical activity is of most importance for a particular health outcome and how much of the exposure is likely to have an effect. This, in turn, will provide a rationale for developing physical activity guidelines for public health purposes (Kohl III *et al*, 2000; Wareham and Rennie, 1998). Secondly, valid instruments that can assess either the absolute amount of physical activity spent at different intensity levels or the total amount of physical activity are needed to be able to characterise dose-response relationships between physical activity and health outcomes, or to be able to define a physical activity threshold for a specific health outcome (Wareham and Rennie, 1998; Lamonte and Ainsworth, 2001). Thirdly, cross-cultural comparisons and the monitoring of temporal trends of physical activity require accurate and consistent, preferably objective assessment methods (Kohl III *et al*, 2000; Wareham and Rennie, 1998). Finally, accurate objective methods of assessment would be of value for determine the effects of interventions and to be able to control for the amount of habitual physical activity in randomised controlled trials.

1.3 ASSESSMENT METHODS

The different assessment methods used for quantifying physical activity and energy expenditure can broadly be divided into objective and self-report methods. The self-report methods are questionnaires, activity diaries, interviews, and proxy reports (Montoye *et al*, 1996). Objective measurement techniques include the doubly labelled water (DLW) method, heart rate monitoring, and use of motion sensors based on accelerometry (Schutz *et al*, 2001).

Pedometers are instruments for objective assessment, designed to measure the number of steps taken, but they do not provide any information about the intensity, frequency, duration and total volume of activity (Montoye *et al*, 1996; Schutz *et al*, 2001). Direct observation is regarded as a valid and reliable method for assessment of physical activity (Epstein *et al*, 1984; McKenzie *et al*, 1991; Puhl *et al*, 1990), but is both time- and labour consuming and may interfere with the normal activity pattern of the subject under observation. The strengths, limitations, reliability and validity of different assessment methods when used in children and adolescents have been reviewed elsewhere (Freedson, 1991; Kohl III *et al*, 2000; Montoye *et al*, 1996; Pate, 1993; Rowlands *et al,* 1997; Sallis, 1991; Sallis and Saelens, 2000; Saris, 1986; Sirard and Pate, 2001, Trost, 2001).

It is beyond the scope and intention of this thesis to describe and discuss all the different assessment techniques. Thus, the primary focus will be the methods used in **Studies I** to **V**.

1.3.1 Self-report methods

Self-report methods, including self-administered and interview-based recall questionnaires, activity logs and activity diaries (AD), are probably still the most commonly used methods for assessing physical activity in both young people and adults and have been extensively reviewed elsewhere (Ainsworth *et al*, 1994; Kriska and Caspersen, 1997; Montoye *et al*, 1996; Sallis, 1991; Sallis and Saelens 2000; Sirard and Pate, 2001).

The reliability and validity of self-report methods for use in children and adolescents have been discussed in previous reviews (Kohl III *et al*, 2000; Pate, 1993; Sallis, 1991; Sallis and Saelens, 2000; Sirard and Pate, 2001). Self-report instruments, also known as subjective methods because they rely on the responses from the subjects under investigation, are considered to be less accurate when used in children as compared to adults (Kohl III *et al*. 2000; Sallis and Owen, 1999). This is partly due to the limited ability of children to recall their physical activity, which has been categorised as a highly complex cognitive task (Baranowski, 1988). Moreover, the nature of children's physical activity is intermittent and characterised by rapid changes from rest to physical activity of vigorous intensity (Bailey *et al*, 1995), which make these activities even more difficult to recall and quantify, especially in terms of the intensity and duration. It has been suggested that the use of self-report methods in children under the age of 10 years should not be recommended (Kohl III *et al*, 2000; Sallis, 1991; Sallis and Owen, 1999).

In two recent reviews of the use of self-report instruments in young people, those instruments that have been validated against an objective criterion method have been identified (Sallis and Saelens, 2000; Sirard and Pate, 2001). Correlations between the self-report methods and the criterion methods vary considerably between the studies surveyed in both reviews. The wide variability was said to be indicative of the many different self-report instruments and criterion measures used (Sirard and Pate, 2001).

In twenty out of twenty-three studies reviewed by Sirard and Pate (2001), correlation coefficients were reported for the relationship between the self-report instrument and the criterion measure. In the review by Sallis and Saelens (2000) seventeen instruments were identified as having been validated against an objective criterion method, but for only two of these instruments the absolute validity had been assessed. Thus, in the great majority of previous studies addressing the validity of self-report instruments for use in children and adolescents the relative validity (i.e. correlation coefficients) of the instrument has been reported. This type of validity is useful if the instrument is going to be used in studies of associations between physical activity and health outcomes. However, to be able to characterise the dose-response relationships between physical activity and health outcomes, valid self-report instruments that can assess either the absolute amount of physical activity spent at different intensity levels or the total amount of physical activity are needed (Lamonte and Ainsworth, 2001).

1.3.1.1 The activity diary

The activity diary is a subjective instrument, which can be used for assessing both the time spent at physical activity of different intensity levels and the energy expenditure associated with physical activity, and is considered as one of the most accurate subjective instruments (Sirard and Pate, 2001). Its use demands co-operation from the subjects under investigation. When using an activity diary, the subjects are asked to record their physical activities over a specific period of time.

One such diary, developed by Bouchard *et al*, (1983), divides the day into ninety-six 15-minute blocks and the subjects are asked to record their main activity within each block. Activities are ranked on a scale from 1 to 9 according to their intensity. A specific MET value is assigned to each intensity level, which allows calculation of total energy expenditure and energy expenditure associated with physical activity. This diary has been used when assessing the total daily energy expenditure in Swedish adolescents (Bratteby *et al*, 1997), to relate the amount and pattern of physical activity in Swedish adolescents to recommended levels of activity (Ekelund *et al*, 1997), in examining the relationship between physical activity and health-related fitness in adolescents (Katzmarzyk *et al*, 1998), in examining the association between physical activity and body fat in male adolescents (Dionne *et al*, 2000), and when describing the physical activity levels of 10-to-13-year old British schoolchildren (Henry *et al*, 1999).

Despite the relatively wide use of this method in young people, surprisingly little information is available on the validity of this specific instrument. In the original study, TEE expressed in relation to body weight ($kJ \cdot kg^{-1}$) was significantly correlated ($r = 0.31$) to physical work capacity in a group of 150 adults and 150 children (Bouchard *et al*, 1983). This finding provides some support for indirect validity of the method. However, the use of an indirect validation instrument (e.g. aerobic fitness, body composition etc.) when validating self-report methods has been criticised on the ground that they do not measure the true exposure of interest (Rennie and Wareham, 1998). In one previous study, total energy expenditure calculated from the activity diary was compared with TEE measured by the DLW method in adolescents (Bratteby *et al*, 1997). In that study close agreement was found between calculated estimates and measured values with a mean difference for TEE of 0.15 $MJ \cdot d^{-1}$ (1.2%) and a mean difference for PAL of 0.01.

It is not known whether the activity diary provides accurate estimates of the pattern of physical activity, i.e. of the length of time spent at different intensity levels of physical activity. This can only be investigated by a simultaneous comparison with an objective assessment technique that is able to give a detailed picture of the intensity and duration of physical activity over a prolonged period of time. The FLEX HR method is one such technique.

1.3.2 Heart rate monitoring

Heart rate monitoring is not a direct measure of physical activity, but rather is a marker of the relative stress upon the cardiopulmonary system resulting in increased oxygen uptake. The development of light-weight heart rate monitors during the last ten to twenty years, that are able to store large amounts of data on a minute-by-minute basis, has meant that this method has become one of the most frequently used techniques in studies of the physical activity of young people.

The method has been used for assessing habitual physical activity in children and adolescents (Armstrong *et al*, 1990a; Armstrong and Bray, 1991; Falgairette *et al*, 1996; Gavarry *et al*, 1998; Gilbey and Gilbey, 1995; Gilliam *et al*, 1981; Janz *et al*, 1992;

MacConnie *et al*, 1982; McManus and Armstrong, 1995; Riddoch *et al*, 1991; Sallo and Silla, 1997; Sleap and Tolfrey, 2001; Spurr and Reina, 1988; Verschuur and Kemper, 1985), as a criterion instrument in validations of self-report methods (Harro, 1997; Sallis *et al*, 1993a; Sallis *et al*, 1996; Simons-Morton *et al*, 1994; Weston *et al*, 1997), for assessing physical activity under specific circumstances such as in physical education classes (Stratton, 1996), for assessing physical activity in relation to health-related outcomes (e.g. aerobic fitness, obesity, blood lipids) (Al-Hazzaa and Sulaiman, 1993; Armstrong *et al*, 1990b; Atomi *et al*, 1986; Cunningham *et al,* 1981; DuRant *et al*, 1993b; Ekelund *et al*, 2001a; Grund *et al*, 2000; Maffeis *et al*, 1997; Saris *et al*, 1980) and as a method for monitoring the intensity in controlled exercise intervention studies (Ferguson *et al*, 1999; Gutin *et al*, 1999a; Gutin *et al*, 1999b; Kriemler *et al*, 1999).

At least four different approaches have been suggested for expressing the intensity of physical activity when heart rate monitoring is used to assess this activity in field situations. The intensity has been expressed as an absolute heart rate, as a percentage of the heart rate reserve (%HRR), in relation to the resting heart rate, and as a percentage of PVO_2 by means of individual calibration for the relationship between heart rate and oxygen uptake.

The total duration of physical activity, percentage of time above an absolute intensity level, i.e. the heart rate threshold, and the number and lengths of sustained periods of physical activity above this threshold, have been reported by several authors (Armstrong *et al*, 1990; Armstrong and Bray, 1991; DuRant *et al.* 1992; Gilbey and Gilbey, 1995; Gilliam *et al*, 1981; Janz *et al*, 1992; MacConnie *et al*, 1982; McManus and Armstrong 1995). Absolute heart rates of 140 and 160 beats per minute have been suggested as corresponding to moderate and vigorous intensities, respectively (Armstrong *et al*, 1990; Armstrong and Bray, 1991; McManus and Armstrong 1995; Sallo and Silla, 1997).

The %HRR approach has been less frequently used in young people (Falgairette *et al*, 1996; Gavarry *et al*, 1998; Janz *et al,* 1992), but seems, at least from studies in adults, to be a valid indicator of different intensity levels throughout the aerobic work range (Swain and Leutholtz, 1997).

Another approach when determining the relative intensity is to express the heart rate in relation to the resting heart rate (DuRant *et al*, 1993a; Kelly, 2000; Pate *et al*, 1996; Sleap and Tolfrey, 2001). It is claimed that this approach will correct for differences in age and fitness level between subjects. This adjustment is made by calculating the physical activity heart rate-25 (PAHR-25), PAHR-50 and PAHR-75, that is, 1.25 times, 1.50 times and 1.75 times the heart rate at rest, respectively. These intensity levels are considered to correspond to light to moderate intensity, moderate intensity and more vigorous intensity of physical activity, respectively (DuRant *et al*, 1993a; Logan *et al*, 2000).

With the use of individual calibration where the relationship between heart rate and oxygen consumption is defined in each individual consideration is paid to inter-individual differences in age, gender, body composition and fitness level (Livingstone, 1994; Pate, 1993). Thus, although more time- and labour consuming, individual calibration seems to be the preferred choice when identifying thresholds corresponding to physical activity of moderate and vigorous intensity. These thresholds have been defined as 50% and 70% of peak oxygen uptake (PVO_2), respectively (Livingstone *et al*, 1992; Riddoch *et al*, 1991; Spurr and Reina, 1990).

The usefulness of the frequently used absolute heart rate thresholds (i.e. > 139 and > 159 beats per minute) for defining moderate and vigorous intensity levels in young people is not known. Further, possible influences of sex, aerobic fitness level and body fatness on the oxygen uptake – heart rate relationship need to be examined to be able to evaluate the validity of these absolute heart rate thresholds.

1.3.2.1 The FLEX HR method

The FLEX HR method relies on the fact that there is a linear relationship between heart rate and energy expenditure above a critical level (Ceesay *et al*, 1989; Spurr *et al*, 1988). Below this individually determined threshold (FLEX HR) the relationship is less accurate. FLEX HR is used to discriminate between resting and exercising heart rate and consequently between different energy expenditures. Thus, for heart rates below FLEX HR, energy expenditure is calculated from a number of recordings of energy expenditure, usually during supine, quiet sitting and quiet standing, referred to as resting energy expenditure (REE) or sedentary energy expenditure (SEE). For heart rates above FLEX HR, the individual relationship between heart rate and energy expenditure is used. This relationship is established at simultaneous measurement of heart rate and oxygen consumption during standardised 'steady-state' activities (e.g. walking, stationary bicycling, jogging). Four different variables are individually derived from the calibration procedure. These are the slope and intercept of the linear relationship, FLEX HR and REE.

TEE estimated by the FLEX HR method has been validated against energy expenditure measured by whole-room calorimetry in adults (Spurr *et al*, 1988; Ceesay *et al*, 1989) and against TEE measured by the doubly labelled water method in adults with normal activity levels (Livingstone *et al*, 1990; Heini *et al*, 1991; Davidson *et al*, 1997), lactating women (Lovelady *et al*, 1993), obese women before and during weight loss (Racette *et al*, 1995), adult males involved in manual labour (Heini *et al*, 1996), weight-stable overweight women (Fogelholm *et al*, 1998), and young adult cystic fibrosis patients (McCloskey *et al*, 2001), and has shown reasonably good agreement for group estimates of TEE. Validation studies in young people have included normally active children and adolescents (Livingstone *et al*, 1992), obese children (Maffeis *et al*, 1995) and children with reduced physical activity due to spastic cerebral palsy (van den Berg-Emons *et al*, 1996), and these studies have also shown the appropriateness of the method for estimating group averages of TEE. However, the method lacks precision in individuals, with an error of about 20 percent.

There are at least two key factors that might have an impact on the validity and accuracy of the FLEX HR method. One is the definition of FLEX HR. Originally FLEX HR was defined as the mean of the highest HR during rest and the lowest HR during light exercise (Ceesay *et al*, 1989). However, different definitions of FLEX HR have been proposed. Some investigators have defined it as the mean of the heart rate during all resting activities and the lowest heart rate while exercising (Livingstone *et al*, 1992; Heini *et al*, 1996), whereas others (Fogelholm *et al*, 1998) concluded that, as compared to DLW-measured TEE, FLEX HR+10 (defined as the mean of the highest HR during resting activities and the lowest HR during exercise +10 beats$\cdot$min^{-1}) was superior to FLEX HR as originally defined (i.e. FLEX HR +0) in a group of overweight women. Thus, there is no consensus on how to define FLEX HR and it is not known whether the definition of FLEX HR will have an impact on the accuracy of estimated TEE when the FLEX HR method is used in adolescent subjects, including young athletes.

The second key factor that might affect the accuracy of the method is the representativeness of the HR-VO_2 regression equation derived from the laboratory calibration when used in free-living situations. The number and type of calibration activities may influence the accuracy of the method (Christensen *et al*, 1983; Li *et al*, 1995), but the reported data are not consistent (Livingstone *et al*, 2000). In line with this, another issue that remains to be solved is whether the limited calibration activities are representative of the various types of exercises that are often carried out by athletes during different training regimens.

1.3.3 The doubly labelled water method

The doubly labelled water, $^2H_2{}^{18}O$, method is an important development in the assessment of energy expenditure, as it is precise and also can be used over relatively long periods (i.e. 10 to 30 days). It can be applied in free-living subjects with minimal interference with daily living. This method is considered the most accurate technique for measurement of energy expenditure during free-living situations (Murgatroyd *et al*, 1993; Speakman, 1997; Speakman, 1998; Prentice, 1999).

The history, theory and principle of the method have been described previously (Murgatroyd *et al*, 1993; Speakman, 1997; Speakman, 1998; Prentice, 1999). Basically, the DLW method assesses the carbon dioxide production rate by measuring the differential disappearance of the stable isotopes ^2H (deuterium) and ^{18}O (oxygen-18) from the body. To determine the individual isotope enrichment, a baseline sample of blood, urine or saliva is taken immediately before administration of the DLW dose. Carbon anhydrase causes a rapid exchange of oxygen-18 between water and carbon dioxide within the body, leading to an isotopic equilibrium of oxygen-18 in CO_2 and body water. The disappearance rates of the isotopes can be calculated in two ways: either by the multi-point method or by the two-point method. In the former, serial samples of body water are used and exponential disappearance is assumed. Samples from body water, usually through urine, are taken over a period of time covering one to three biological half-lives of the isotopes. Normally a 10- to 14-day measurement period is required. Oxygen-18 is eliminated from the body water pool as carbon dioxide ($CO_2{}^{18}O$) and water ($H_2{}^{18}O$), whereas deuterium is eliminated only as water (^2H_2O). The calculation of the CO_2 production rate is based on the difference in turnover rates between the oxygen and hydrogen labels. For measurement of the deuterium and oxygen-18 contents in biological fluids, gas-isotope-ratio mass spectrometry is used.

The accuracy of the DLW method has been extensively validated and the precision is about 3 to 10 % (Schoeller, 1988; Speakman, 1998). The isotopic natural abundance variation is estimated to contribute to about 50% of the internal error (Ritz *et al*, 1996). Other potential contributions to the internal error are the isotopic fractionation (Lifson *et al*, 1955; Schoeller *et al*, 1986), the estimated ratio between deuterium dilution space (Nh) and oxygen-18 dilution space (No) (Speakman, 1998; Westerterp *et al,* 1995) and the use of a measured or predicted food quotient for estimating the respiratory quotient (Black *et al*, 1986).

The calculation of energy expenditure demands an assumption of the dilution spaces for deuterium (Nh) and oxygen-18 (No). The ratio of Nh to No has been estimated to be approximately 1.03 as a population-based average. However, the appropriateness of this figure is debated. In a recent review comprising 590 adult humans, a weighted mean of 1.0387 was found (Speakman, 1997). The Nh/No ratio seems to fall between 1.03 (Schoeller *et al*, 1986) and 1.0427 (Speakman, 1997). The use of different Nh/No ratios affects the calculated energy expenditure. In a summary of validation studies, it was found that the equation using the 1.03 ratio overestimated energy expenditure measured simultaneously with indirect calorimetry by 2.1%. In contrast, the equation using the high ratio (1.0427) underestimated energy expenditure measured simultaneously in this way by 2.2% (Speakman, 1998).

In order to calculate TEE from the DLW method, information about the subject's respiratory quotient (RQ = carbon dioxide produced / oxygen consumed) is needed. The imprecision of the RQ may increase the error in the estimated energy expenditure by up to 3%. It has been suggested that the use of food quotients (FQ) calculated from food records will reduce this potential error (Black *et al*, 1986). FQ calculated from the dietary intakes of fat, carbohydrates, protein and alcohol is assumed to be equal to RQ provided that the subjects are in energy balance. A measured or predicted FQ can be used in place of RQ, since energy balance is usually maintained over the DLW measurement period.

The DLW method is ideal for use in field studies, since it is non-invasive, non-radioactive, requires minimal subject compliance, and does not interfere with normal living. The main limitation of the method is the cost and the limited supply of the stable isotope, ^{18}O, which together with the complicated and expensive analytical procedures rules out its use in epidemiological studies. However, the method is unequivocally the best available technique today for validating other physical activity assessment methods aimed to assess the total amount of physical activity. Together with an estimate or measure of BMR or measured RMR, the method provides accurate information regarding the energy expenditure due to physical activity (AEE), as well as the physical activity level (Black *et al*, 1996; Prentice *et al*, 1996).

1.3.4 Accelerometry

Assessment of human body movement with activity monitors based on accelerometry is a direct way of measuring physical activity. Accelerometers make use of transducers that measure the acceleration and deceleration of the body in one (vertical), two (vertical and medio-lateral) or three directions (i.e. vertical, medio-lateral and anterior-posterior) (Bouten *et al*, 1994). The recorded accelerations are converted to quantifiable digital signals referred to as counts.

When a subject moves the body, it is accelerated in proportion to the muscular forces responsible for the accelerations. According to the definition of physical activity (Casperson *et al*, 1985), all physical activity is due to muscular contractions, which will lead to energy transformation, resulting in heat loss and external work (i.e. energy expenditure). Muscular work has dynamic dimensions, as in walking, and static dimensions, as in weight bearing. All dynamic work will have its concurrent accelerations and decelerations. Since there is a linear relationship between the integral of body acceleration and oxygen uptake (energy expenditure), a measure of the integral of the absolute value of body acceleration can be used as an estimate of physical activity (Ismail *et al*, 1971; Bhattacharya *et al*, 1980). However, static work and muscular work against external forces are not detected by changes in body accelerations. When interpreting accelerometer data this has to be considered and researchers have to assume that these types of muscular work will only be a small part of the daily habitual physical activity (Westerterp, 1999).

The primary use of activity monitors in young people has hitherto included validation studies of self-report and other assessment instruments (Crocker *et al*, 1997; Finn *et al,* 2000; Harro, 1997; Janz *et al*, 1995; Sallis *et al*, 1993b; Sallis *et al*, 1996; Simons-Morton *et al*, 1994; Weston *et al*, 1997), evaluation of activity patterns in specific groups (van den Berg-Emons *et al*, 2001), assessment of physical activity under free-living conditions (Benefice and Cames, 1999; Benefice *et al*, 2001a; Dale *et al*, 2000; Trost *et al*, 2002), and studies of possible relationships between physical activity and health-related outcomes (Almeida and Fox, 1998; Benefice *et al*, 2001b; Janz *et al*, 2001; Romanella *et al*, 1991; Rowlands *et al*, 1999).

A number of activity monitors are now commercially available, including tri-axial (e.g. the Tritrac), bi-axial (e.g. the Mini Motionlogger Actigraph (www.ambulatory-monitoring.com) and uni-axial accelerometers (e.g. Caltrac, www.muscledynamics.net; and the Computer Science and Applications Inc. [CSA], www.mtifwb.com). The Tracmor accelerometer is a non-commercial tri-axial accelerometer that was developed at Maastrich University, The Netherlands (Westerterp, 1999).

The validity of different activity monitors for use in young people and adults has recently been reviewed (Rowlands *et al*, 1997; Sirard and Pate, 2001; Westerterp, 1999). Most validation studies have included short-term protocols with defined activities (e.g. walking and running) in a controlled laboratory environment. The criterion measure has been energy expenditure measured by indirect calorimetry (Sirard and Pate, 2001; Westerterp, 1999). Only two studies with the aim of validating accelerometer data against energy expenditure estimates obtained by the DLW method under free-living conditions were included in the reviews by Sirard and Pate (2001) and Westerterp (1999). One of those two studies (Bouten *et al*, 1996) showed a significant relationship between activity counts and PAL (r = 0.58), whereas the other led to the conclusion that activity as assessed by the Caltrac uni-axial accelerometer in children did not significantly explain the variation in TEE after adjustments for gender and body composition (Johnson *et al*, 1998).

1.3.4.1 The CSA activity monitor

The CSA activity monitor, model WAM 7164, is a relatively new uni-axial accelerometer. The technical specifications of the CSA accelerometer have been presented elsewhere (Tryon and Williams, 1996). It has been validated in children and adults during recent years. Trost *et al* (1998) reported a high correlation coefficient (r = 0.88) between activity counts and energy expenditure measured by indirect calorimetry in 10-to-14-year old children walking and running on a treadmill. Further, they developed an energy expenditure equation indicating that body weight and activity counts predicted energy expenditure (Trost *et al*, 1998). In two studies (Eston *et al*, 1998; Louie *et al*, 1999) the validity of the CSA accelerometer was evaluated during standardised activities including treadmill walking and running and playing activities (catch, hopscotch and crayoning), in 8-to-11-year old children, using scaled oxygen uptake (ml $O_2 \cdot kg^{-0.75} \cdot min^{-1}$) measured by indirect calorimetry, and correlation coefficients (r) of 0.78 and 0.85, respectively, were found. Other validation studies in young people have included direct observation during an exercise class in preschool children (Fairweather *et al*, 1999; r = 0.87), and direct observation and heart rate monitoring during basketball practice in adolescent boys (Coe and Pirvanik, 2001; r = 0.60 between heart rate and CSA counts). Ott *et al* (2000) measured the intensity of eight different “free play” activities in 9-to-11-year old children using a combination of a CSA accelerometer, a Tritrac three-dimensional accelerometer and heart rate monitoring. They found significant correlations (r = 0.64 and 0.73) between the two accelerometers, on the one hand, and exercising heart rate, on the other. The authors concluded that accelerometers are an appropriate methodology for measuring children's free-play physical activities.

However, all the above-mentioned studies have used short-term protocols, and when a criterion method (e.g. indirect calorimetry), has been used, the validation of the CSA accelerometer has been restricted to a laboratory environment (Trost *et al*, 1998; Eston *et al*, 1998).

Ekelund *et al* (2001b) assessed the validity of the CSA accelerometer for its appropriateness for measuring the total volume of physical activity in 9-year-old boys and girls (n = 26). The subjects wore the accelerometer for 14 consecutive days during which time TEE was measured simultaneously by the DLW method. Activity counts ($counts \cdot min^{-1}$) were significantly correlated with TEE (r = 0.39), AEE (r = 0.54) and PAL (r = 0.58). After adjustments for body weight and gender in a partial correlation analysis, the correlation coefficients increased to 0.67 and 0.66 for TEE and AEE, respectively. In addition, regression equations for the prediction of TEE and AEE were developed and cross-validated in a random subset of study participants. Activity counts, gender and body weight explained 60 % of the variation in TEE, and activity counts and gender explained 45% of the variation in AEE. It was concluded that the CSA accelerometer seems to be a valid instrument for assessing the total volume of physical activity in children.

Besides the validation studies performed in young people, the CSA accelerometer has been assessed for its validity against oxygen uptake measured by indirect calorimetry during walking and running in the laboratory (Freedson *et al*, 1998), during walking and running overground and during life-style activities in adults (Nichols *et al*, 2000; Hendelman *et al*, 2000; Swartz *et al*, 2000; Welk *et al*, 2000). Results from these studies have indicated that the CSA accelerometer is able to differentiate between different walking and jogging speeds, and in addition relatively high correlations have been found for the relationship between CSA counts and energy expenditure, varying from 0.77 to 0.94. However, this relationship seems to be dependent on the activities performed. Hendelman *et al* (2000) reported a significantly lower correlation coefficient (r = 0.59) for a combination of walking and daily life-style activities (e.g. playing golf, vacuuming, dusting, window washing, lawn moving) and found that the metabolic cost of these activities was underestimated by 30 to 60% when based on the energy expenditure equations derived from walking.

Swartz *et al* (2000) combined two CSA accelerometers. One was placed on the hip and the other at the wrist. The authors concluded that the small amount of accuracy gained by combining two accelerometers was offset by the extra time required to analyse the data and by the cost of an extra accelerometer.

In addition to the short-term validation studies summarised above, a few researchers have compared data from the CSA accelerometer with those from other assessment techniques obtained under free-living conditions. The CSA accelerometer has been compared with the Tritrac accelerometer, a Yamax Digi-walker pedometer and a last 7-day physical activity recall (7-d PAR) method (Leenders *et al*, 2000). It was found that compared to 7-d PAR, the CSA accelerometer underestimated energy expenditure by 46% when calculated from a laboratory-derived equation (Freedson *et al*, 1998).

In a similar study, the output (total counts) from the CSA accelerometer was compared with data on energy expenditure calculated from the activity diary developed by Bouchard *et al* (1983). A significant correlation was found between total counts and total energy expenditure throughout the three days of measurement. Furthermore there was significant agreement of 68.4%, as tested by Kappa statistics, between the two measurements. On the other hand, significant differences were observed between the instruments for the total length of time spent at light, hard and very hard physical activity (Sirard *et al*, 2000).

Hitherto, only one study has addressed the validity of the CSA accelerometer under free-living conditions in adult subjects (i.e. young women) (Leenders *et al*, 2001). These authors used the same approach as described above; that is, they evaluated the absolute validity of a laboratory based equation (Freedson *et al*, 1998) for prediction of AEE as compared with AEE calculated from TEE measured by the DLW method and RMR measured by indirect calorimetry. They found that the laboratory-based regression equation significantly underestimated AEE, and that there was no significant correlation between the total amount of activity as measured by the CSA accelerometer (i.e. total counts) and AEE. Unfortunately, no data on the relationship between total activity and PAL were reported. Neither did the authors take into account for inter-individual differences in the length of time for which the subjects wore the monitor.

The usefulness of the CSA accelerometer for assessing the total amount of physical activity needs to be further clarified in various groups of subjects. This type of study should preferably include a comparison with TEE and its components derived from the DLW method. Further, it may be hypothesised that the CSA accelerometer estimates the total volume of physical activity less accurately in subjects engaged in specific training programmes or in those performing activities which cause small movements in the vertical plane as a part of their daily activities or structured exercises (e.g. bicycling, inline skating, weight lifting).

1.4 THE EPIDEMIOLOGY OF YOUNG PEOPLE'S PHYSICAL ACTIVITY

Young children have been characterised as being highly and spontaneously active (Rowland, 1990; Åstrand, 1994), and Blair (1992) has suggested that young people not only are fitter and more active than the majority of adults, but are also active enough to obtain most health benefits associated with physical activity. On the other hand, recent data have indicated that the prevalence of overweight and obesity is increasing among youth worldwide (Chinn *et al*, 1998; Hulens *et al*, 2001; Rasmussen *et al*, 1998; Seidell *et al*, 1995; Thomsen *et al*, 1999; Troiano and Flegal, 1998). The increase in the prevalence of overweight and obesity combined with a proposed reduction in energy intake, by approximately 2.5 to 3 $MJ \cdot d^{-1}$ over the last 40 to 50 years (Durnin, 1992), has been regarded as indirect evidence of a decline in physical activity in the young population. Although it seems logical that in young people the activity level may have declined more that the energy intake, resulting in an increase in body weight, there are unfortunately no measures of physical activity supporting this hypothesis.

1.4.1 Prevalence of habitual physical activity

The prevalence of habitual physical activity in children and adolescents has been reviewed by Cale and Almond (1992), Sallis (1993), Pate *et al* (1994), Riddoch and Boreham (1995), Armstrong and Van Mechelen (1998) and Epstein *et al* (2001).

Cale and Almond (1992) reviewed 15 studies from Great Britain and concluded that British children seldom engage in physical activity of an intensity that is known to increase aerobic fitness or have any beneficial effects on health. In contrast, Sallis (1993) reviewed nine studies, including national surveys, with self-reported physical activity data. The author concluded that average young people aged 10 to 16 years, except for adolescent girls, are sufficiently active to meet adult recommendations that are known to effect aerobic fitness. Further, boys were on average 14% more active than girls and there was a gradual decline in physical activity throughout the age groups in both sexes. A similar pattern was observed in studies using objective measures of physical activity (Sallis, 1993).

Pate *et al* (1994) reviewed four population studies from the US, Canada and England and four small group studies conducted in the US, England, Germany and the Netherlands, in three which physical activity was assessed with an objective instrument in adolescents. The authors estimated that, on average, the adolescents spent approximately one hour per day in physical activity of moderate to vigorous intensity and that most (approximately 80%) of them were active for at least 30 minutes per day at a moderate intensity level. It was estimated that fifty percent of the adolescents engaged in physical activity of moderate to vigorous intensity three times per week on average and at least 20 minutes at a time (Pate *et al*, 1994). In agreement with the findings by Sallis (1993), males were more active than females and younger adolescents were more active than older ones.

Riddoch and Boreham (1995) reviewed twenty-one studies in which heart rate monitoring was used as an objective measure of physical activity in children and adolescents. The authors' noted remarkable agreement across the studies for data on time spent at moderate and vigorous physical activity. However, different criteria were used to identify intensity levels across the studies making comparisons between studies problematic.

In addition, three national surveys and 13 other self-report studies were included in the review by Riddoch and Boreham (1995). A marked decline in physical activity with increasing age was observed in these cross-sectional studies. The authors stated, "*We cannot, from the current literature, conclude with any degree of certainty whether children are active 'enough' for health purposes*." (Riddoch and Boreham, 1995). The main reason for this conclusion was said to be the lack of consensus regarding the amount of physical activity required for optimal health and the differences in methodology used.

Armstrong and Van Mechelen (1998) identified 16 studies, in which habitual physical activity in young people was assessed by an objective instrument or by observation for more than one day. In twelve of the reviewed studies physical activity had been measured by heart rate monitoring, and in 10 of these studies only time spent above a predetermined heart rate threshold (139 beats·min·d^{-1}) was reported (Armstrong and Van Mechelen, 1998). The reviewers concluded that although most reported data concerned small and often unrepresentative samples, the data were generally consistent across studies. Boys tended to be more active than girls, especially regarding vigorous physical activity. Moreover, physical activity declined with increasing age and it was concluded, "*that some children and adolescents undoubtedly lead sedentary lifestyles but other young people appear to be active*" (Armstrong and Van Mechelen, 1998).

Recently, 26 studies, with direct heart rate measurements of physical activity on a minute-by-minute basis were reviewed (Epstein *et al*, 2001). The review included 1883 children and adolescents, aged 3 to 17 years, with sample sizes varying from 11 to 230 subjects. Heart rate data from all studies were recalculated into percentage of HRR. The authors concluded that all subjects spent > 60 min·d^{-1} at low-intensity physical activity and that the average subject accumulated approximately 50 min·d^{-1} at an intensity corresponding to 5 METs and 30 min·d^{-1} at an intensity > 50% HRR. No more than five of the cited studies defined physical activity intensity thresholds using the individual relationship between heart rate and energy expenditure, which is considered to be more valid than the use of the same cut-off values for all subjects (Epstein *et al*, 2001).

Among these five studies, Atomi *et al* (1986) reported that 9-to-10-year old Japanese boys spent 34 $min \cdot d^{-1}$ at an intensity level corresponding to > 60 % PVO_2. Riddoch *et al* (1991) observed 46 Northern Irish schoolchildren, aged 11 to 16 years, and reported that the boys and girls accumulated 24 and 17 $min \cdot d^{-1}$, respectively at physical activity of moderate intensity or higher (> 50 % PVO_2). Livingstone *et al* (1992) reported that 12-to-15-year old British boys and girls, on average, spent 52 and 15 $min \cdot d^{-1}$, respectively in physical activity at a > 50 % PVO_2 intensity level. Maffeis *et al* (1996) found that 8-to-10-year-old Italian children accumulated, on average, 70 and 18 $min \cdot d^{-1}$ at moderate (> 50% PVO_2) and vigorous (> 70% PVO_2) intensity of physical activity, respectively. In a similar study it was found that 9-year-old boys and girls (n = 13) accumulated 42 and 16 $min \cdot d^{-1}$ at these intensity levels, respectively (Maffeis *et al*, 1995).

There are two additional studies not included in the review by Epstein *et al* (2001) in which the subjects were calibrated regarding the individual relationship between heart rate and energy expenditure. Verschuur and Kemper (1985) reported that 12-to-13 and 17-to-18-year-old Dutch boys and girls spent 68 and 58 $min \cdot d^{-1}$, and 34 and 24 $min \cdot d^{-1}$, in physical activity at a moderate intensity level (50% PVO_2), respectively. Spurr and Reina (1990) found that 6-to-16-year-old Colombian boys and girls spent an average of 20 to 60 $min \cdot d^{-1}$ at an intensity level > 50 % PVO_2.

The decline in physical activity with age is consistently reported in all reviews (Cale and Almond, 1992; Sallis, 1993; Pate *et al*, 1994; Riddoch and Boreham, 1995; Armstrong and Van Mechelen,1998; Epstein *et al*, 2001) and has been confirmed by longitudinal studies (Kimm *et al*, 2000; Telama and Yang, 2000; Van Mechelen *et al*, 2000). There is strong support for the idea of a biological basis of this phenomenon involving the central dopamine system (Ingram, 2000).

Cross-sectional studies indicate a higher rate of decline in girls than in boys (Armstrong and Van Mechelen, 1998; Pate *et al*, 1994; Sallis, 1993), whereas the opposite has been observed in longitudinal analyses (Telama and Yang, 2000; Van Mechelen *et al*, 2000). The greatest decline in activity seems to occur from 13 to 18 years of age (Sallis, 2000).

Boys of all ages seem to be more active than girls, at least regarding vigorous physical activity (Armstrong and Van Mechelen, 1998; Caspersen *et al*, 2000; Pate *et al*, 1994; Riddoch and Boreham, 1995), although some studies, using heart rate monitoring to assess physical activity, have not shown any gender differences (Gavarry *et al*, 1998; Riddoch *et al*, 1991; Verchuur and Kemper, 1985). However, there is no single study showing that girls are more active than boys.

1.4.2 Recommendations for physical activity in young people

Physical activity recommendations for young people have been suggested by Blair *et al* (1989), Corbin *et al* (1994), Sallis and Patrick (1994) and the Health Education Authority (England) (1998). Blair *et al* (1989) proposed an energy expenditure recommendation based on epidemiological studies that link physical activity to health in adults. They estimated energy expenditure in physical activity of 3 $kcals \cdot kg^{-1} \cdot d^{-1}$ to be an appropriate target. Corbin *et al* (1994) proposed a "lifetime physical activity" guideline, recommending, as a minimum, that children and adolescents should spend at least 30 accumulated minutes in physical activity of moderate intensity and preferably 60 minutes in physical activity of moderate and vigorous intensity daily (equivalent of 3-4 and 6-8 $kcals \cdot kg^{-1} \cdot d^{-1}$, respectively).

Based on a review of the scientific literature on various health effects of physical activity in adolescents, an international consensus conference generated two guidelines (Sallis and Patrick 1994). The first guideline could be interpreted as an accumulation of 30 minutes in moderate physical activity daily, whereas the second guideline stated that adolescents should engage in at least three sessions per week of activities that last 20 minutes or more and that require moderate to vigorous effort. Recently, another international consensus conference updated the physical activity recommendations for young people (Health Education Authority, 1998). The primary recommendation states that young people should engage in physical activity of at least moderate intensity for at least one hour per day. Moderate intensity was defined as equivalent to brisk walking, approximately resulting in energy expenditure at a rate of 5 METs (Pate *et al*, 1998). Even though the latest guidelines (Sallis and Patrick, 1994 and Health Education Authority, 1998) were based on reviews of the health effects of physical activity in young people, it has been stated that there is not sufficient empirical evidence to recommend general guidelines (Epstein *et al*, 2001). Thus, the present guidelines are as much based on empirical evidence as on expert opinion (Fox and Riddoch, 2000).

The number of young people achieving the current recommendations of health enhancing physical activity is more or less unknown. On the basis of self-reported physical activity, Pate *et al* (1994) estimated that approximately 80% of adolescents engaged in moderate physical activity for at least 30 minutes per day (comparable to the guideline proposed by Sallis and Patrick, 1994). In the above-mentioned review by Epstein *et al* (2001) it was suggested that young people attain a large amount of physical activity and that the average adolescent spends approximately 50 $min \cdot d^{-1}$ in moderate physical activity (comparable to the guideline from the Health Education Authority, 1998). However, no estimates of the number of young people who were actually active according to the recommendations were made.

Only a few studies have directly addressed the issue as to whether young people fulfil the current physical activity recommendations for maintenance of good health. Ekelund *et al* (1997) assessed physical activity by means of an activity diary in a random sample of 127 fourteen-to fifteen-year-old boys and girls in Sweden. It was found that, on average, boys and girls spent approximately 82 and 67 $min \cdot d^{-1}$, respectively in physical activity of moderate intensity. However, it was concluded that 15 to 30% of the subjects did not meet the guidelines for physical activity (Sallis and Patrick, 1994). Sleap and Tolfrey (2001) assessed habitual physical activity in 79 nine-to twelve-year-old boys and girls by means of minute-by-minute heart rate monitoring. Moderate physical activity was defined as the percentage of time spent with a heart rate > 1.5 times of the resting heart rate (PAHR-50) and at an absolute heart rate (> 120 $beats \cdot min^{-1}$). Almost all children (except for one girl) were active for at least 60 $min \cdot d^{-1}$ at PAHR-50 and 71 of 79 children accumulated at least 60 min with a heart rate > 120 $beats \cdot min^{-1}$. The authors did not report any energy expenditure estimates or MET values corresponding to the selected HR thresholds. They concluded that there is still need for more extensive assessments of activity levels in representative samples of youth and that health-related criteria for children need to be based on robust research evidence (Sleap and Tolfrey, 2001).

1.4.3 Total energy expenditure and physical activity level

Torun *et al* (1996) critically reviewed published studies on total energy expenditure measured by the DLW method, minute-by-minute heart rate monitoring and the activity diary method in 1-to-18-year-old children and adolescents. The aim of the review was to make recommendations for consideration by a group of experts, who planned to revise the FAO/WHO/UNU energy requirement report from 1985 (WHO 1985). The relatively limited number of studies from a small number of countries, showed a consistent trend in that total energy expenditure expressed in relation to body weight ($kJ \cdot kg^{-1} \cdot d^{-1}$) decreased with increasing age in both sexes. On the other hand, estimated PAL values derived from DLW and heart rate monitoring studies showed that PAL increased somewhat with increasing age in boys, whereas it remained almost constant across age groups in girls (Torun *et al*, 1996). Proposed PAL values corresponding to light, moderate and heavy habitual physical activity were 1.60, 1.80 and 2.05 for male adolescents (14 to 18 years) and 1.45, 1.65 and 1.85 for female adolescents (Torun *et al*, 1996).

Additional studies with assessment of TEE and PAL in healthy adolescents (11 to 21 years), not included in the review by Torun *et al* (1996), are summarised in **Table 1**. Only studies in which TEE was assessed in healthy adolescent subjects (including obese subjects and athletes) are included. The majority of the studies are of small-scale with volunteer subjects. Two studies using an activity diary (Bratteby *et al*, 1997; Ekelund *et al*, 1997) have included randomly selected samples of subjects of Swedish adolescents. In two additional studies (Ebine *et al*, 2000; Trappe *et al,* 1997) TEE was measured in young female athletes, synchronized swimmers (n = 5) and swimmers (n = 5), who showed high and very high PAL values, respectively. Thus, even more markedly in young athletes as compared to 'normally active' adolescents, the current understanding of the energy needs which are equal to the energy expended, is limited (Thompson, 1998).

Table 1. Summary of studies (published 1997-) with assessment of total energy expenditure (TEE) and physical activity level (PAL) in healthy adolescent subjects (aged 11 to 21 years) under free-living conditions.

Citation	Subjects	Method	Main outcome
Bratteby *et al*, (1997)	171 M, 203 F; 15 years	Activity diary; BMR predicted	**TEE**: 14.2 $MJ \cdot d^{-1}$ (M), 10.9 $MJ \cdot d^{-1}$ (F) **PAL**: 1.95 (M), 1.80 (F)
Ekelund *et al*, (1997)	60 M, 67 F; 14.8 years	Activity diary; BMR predicted	**TEE**: 12.8 $MJ \cdot d^{-1}$ (M), 10.3 $MJ \cdot d^{-1}$ (F) **PAL**: 1.74 (M), 1.72 (F)
Trappe *et al*, (1997)	5 F (high volume training); 19 years	DLW; RMR measured	**TEE**: 23.4 $MJ \cdot d^{-1}$ **PAL**: 3.0

Table 1 continued

Ambler *et al*, (1998)	6 (exercising) + 6 (control) F, 10 (exercising) + 10 (control) M; 15 to 17 years	DLW	**TEE**: 8.8 $MJ{\cdot}d^{-1}$ (control M), 10.1 $MJ{\cdot}d^{-1}$ (exercising M), 7.5 $MJ{\cdot}d^{-1}$ (control F), 8.7 $MJ{\cdot}d^{-1}$ (exercising F)
Bratteby *et al*, (1998)	25 M, 25 F; 15 years	DLW; BMR measured	**TEE**: 13.8 $MJ{\cdot}d^{-1}$ (M), 10.7 $MJ{\cdot}d^{-1}$ (F) **PAL**: 1.89 (M), 1.79 (F)
Warner *et al*, (1998)	32 children and adolescents (18 M and 14 F); 12.4 years, control subjects	FLEX HR, BMR measured	**TEE**: 9.2 $MJ{\cdot}d^{-1}$ **PAL**: 1.70
Henry *et al*, (1999)	12 M, 26 F; 11.9 years	Activity diary; BMR measured	**TEE**: 8.7 $MJ{\cdot}d^{-1}$ (M), 8.5 $MJ{\cdot}d^{-1}$ (F) **PAL**: 1.50 (M), 1.53 (F)
Wong *et al*, (1999)	40 Caucasian and 41 Afro-American F; 13.5 years	DLW; BMR measured	**TEE**[a]: 11.2 $MJ{\cdot}d^{-1}$ (Caucasian), 9.0 $MJ{\cdot}d^{-1}$ (Afro-American); **PAL**: 1.90 (Caucasian), 1.61 (Afro-American)
Ebine *et al*, (2000)	5 F (athletes); 17.6 years	DLW; RMR measured	**TEE**: 11.5 $MJ{\cdot}d^{-1}$ **PAL**: 2.14
Roemmich *et al*, (2000)	15 M, 18 F; 13.4 (M) and 12.8 (F) years	DLW; BMR measured	**TEE**: 10.7 $MJ{\cdot}d^{-1}$ (M), 9.4 $MJ{\cdot}d^{-1}$ (F) **PAL**: 1.57 (M), 1.65 (F)
Larsson *et al*, (2002)	16 vegans + 16 omnivores (18 M and 14 F); 17.4 years	DLW; BMR estimated	**TEE**[b]: 13.9 $MJ{\cdot}d^{-1}$ (vegan M), 15.7 $MJ{\cdot}d^{-1}$ (omnivores M); 9.6 $MJ{\cdot}d^{-1}$ (vegan F), 11.2 $MJ{\cdot}d^{-1}$ (omnivores F) **PAL**: 1.87 (vegan M), 2.05 (omnivores M); 1.41 (vegan F), 1.84 (omnivores F)
Buchowski *et al*, (2002)	22 adolescents (gender not specified); 15.9 years, control subjects	Tritrac accelerometer; RMR measured	**TEE**: 9.1 $MJ{\cdot}d^{-1}$ **PAL**: 1.48
Ekelund *et al*, (2002)	18 obese + 18 normal-weight (16 M, 20 F); 18.1 (M), 17.2 (F) years	DLW; RMR measured	**TEE**: 15.5 $MJ{\cdot}d^{-1}$ (obese M), 13.2 $MJ{\cdot}d^{-1}$ (normal-weight M); 12.4$MJ{\cdot}d^{-1}$ (obese F), 10.4 $MJ{\cdot}d^{-1}$ (normal-weight F); **PAL**: 1.70 (obese M), 1.85 (normal-weight M); 1.63 (obese F), 1.74 (normal-weight F)

[a] Values adjusted for soft lean tissue mass (unadjusted values not reported)

[b] calculated by the present author

2 PURPOSE

The overall purpose of the investigations summarised in this thesis was to enhance our understanding of the suitability and accuracy of different physical activity assessment methods in normally active adolescents and in adolescent athletes; and to gain further knowledge of the total energy expenditure and the amount and pattern of physical activity in adolescents.

The specific aims of the separate studies were as follows:

- To evaluate the absolute validity of an activity diary for assessing total energy expenditure and the time spent at moderate and vigorous physical activity in adolescents (**Study I**).

- To determine the accuracy of absolute heart rates in defining intensity levels and to examine a possible effect of aerobic fitness and body fatness on the heart rate – oxygen uptake relationship in adolescents (**Study II**).

- To assess total energy expenditure, the physical activity level and patterns of physical activity among a random sample of male and female adolescents and to relate the amount and intensity of physical activity to existing recommendations for health-enhancing physical activity in young people (**Study III**).

- To examine the effects of different definitions of FLEX HR and different training conditions on total energy expenditure assessed by the FLEX HR monitoring method as compared to total energy expenditure measured by the doubly labelled water method, in adolescent athletes (**Study IV**).

- To evaluate the validity of the CSA activity monitor for assessing the total amount of physical activity in adolescent athletes under two different training conditions (**Study V**).

3 MATERIALS AND METHODS

3.1 SUBJECTS AND STUDY DESIGNS

Four groups of subjects participated in **Studies I to V**. Some of the characteristics of the subjects are summarized in **Table 2**.

Table 2. Physical characteristics of participating subjects.

Study	Subjects (n)	Age (years)	Height (m)	Weight (kg)	Body fat (%)	PVO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$)
I	16 M	15.0	1.73	59.2		54.2
		(14 – 16)	(1.58 –1.90)	(47.2 – 77.3)		(45.5 – 59.6)
	14 F	15.0	1.63	55.7		40.7
		(14 – 16)	(1.49 – 1.72)	(39.7 – 71.6)		(35.0 – 50.0)
II	60 M	14.8	1.72	61.9	16.4	54.1
		(14 – 15)	(1.52 – 1.89)	(40.4 – 96.5)	(7 – 41)	(35.4 – 69.2)
	67 F	14.8	1.64	55.2	24.1	43.7
		(14 – 15)	(1.52 – 1.75)	(38.0 – 75.5)	(12 – 42)	(31.1 – 54.0)
III	42 M	14.8	1.72	61.6	15.5	53.5
		(14 – 15)	(1.52 – 1.89)	(40.4 – 96.5)	(7 – 41)	(35.4 – 65.4)
	40 F	14.8	1.64	55.9	23.6	43.3
		(14 – 15)	(1.52 – 1.75)	(38.0 – 75.5)	(12 – 41)	(31.1 – 54.0)
IV	7 M	18.5	1.79	73.3	13.0	64.5
		(16 –20)	(1.75 – 1.85)	(70.4 – 76.8)	(8.6 – 17.7)	(59.1 – 66.8)
V	8 M	18.2	1.79	75.7	12.8	64.0
		(16 –20)	(1.75 – 1.85)	(70.4 – 92.3)	(8.6 – 17.7)	(59.1 – 66.8)

The subjects in **Study I** were randomly selected from one comprehensive school in the municipality of Örebro, Sweden. Thirty (16 boys, 14 girls) of 36 (18 boys and 18 girls), 14-to-16-year-old adolescents agreed to participate. All subjects were individually calibrated for the relationship between oxygen uptake and heart rate, and within two week after the calibration procedure, TEE and patterns of physical activity were assessed by means of the FLEX HR monitoring method over a period of 3 consecutive days, including one weekend day. TEE and physical activity were assessed simultaneously by means of an activity diary (Bouchard *et al*, 1983). Peak oxygen uptake (PVO_2) was measured by indirect calorimetry.

In **Study II**, the subjects were randomly selected, through a two-stage procedure, in order to obtain representative sample of 14-to-15-year-old adolescents. First, 6 of 13 comprehensive schools were selected. Thereafter, the students from these schools were selected at random. The number of students from each school was proportional to the size of the school. Totally 241 subjects (21% of the eligible population) were selected and 150 (62%) agreed to participate. Of these, 127 subjects completed all parts of the study. VO_2 and heart rate were measured simultaneously during two 6-minute workloads while exercising on a treadmill according to an incremental exercise protocol (Bruce *et al*, 1973). Thereafter, the following stages were performed for 3 minutes each, until exhaustion. All subjects included in the study completed at least three stages and performed a maximal aerobic fitness test. Linear regression equations were calculated in order to establish the relationship between oxygen uptake and heart rate in each individual. Each variable was expressed in absolute and relative values. Four skinfold thickness measurements were performed and relative body fatness was calculated (Slaughter *et al*, 1988).

In **Study III**, 82 subjects (42 boys, 40 girls) randomly selected from the 127 subjects who participated in **Study II** were included. The relationship between oxygen uptake and heart rate was individually established for all subjects, and within two week after the calibration procedure, TEE and patterns of physical activity were assessed by means of the FLEX HR monitoring method over a period of 3 consecutive days, including one weekend day. PVO_2 was measured by indirect calorimetry and fat mass and fat free mass were calculated from skinfold measurement (Slaughter *et al*, 1988).

In **Studies IV** and **V**, eight young athletes (speed skaters) were studied during two different training periods, five months apart. All measurements were performed in exactly the same way during two different training periods. The first period was a 10-day off-season period and the second one was a 10-day pre-season training period. During the off-season period all physical training was voluntary, and the main exercise performed by the subjects was jogging or running. The pre-season period was mainly focused on training of skating techniques. During this period the exercises included weight training, in-line skating, slideboard training, circuit training and skating imitations.

Both periods were preceded by an individual calibration for the relationship between oxygen uptake, heart rate and activity counts from the CSA activity monitor during standardised activities. Physical activity was measured by the CSA accelerometer and heart rate was measured on a minute-by-minute basis during the first eight days of the two 10-day periods. TEE was simultaneously measured by the DLW method over the two 10 day periods. Body weight was measured on day 1 and day 10 to investigate energy balance. A schematic presentation of the study protocol is shown in **Figure 1**.

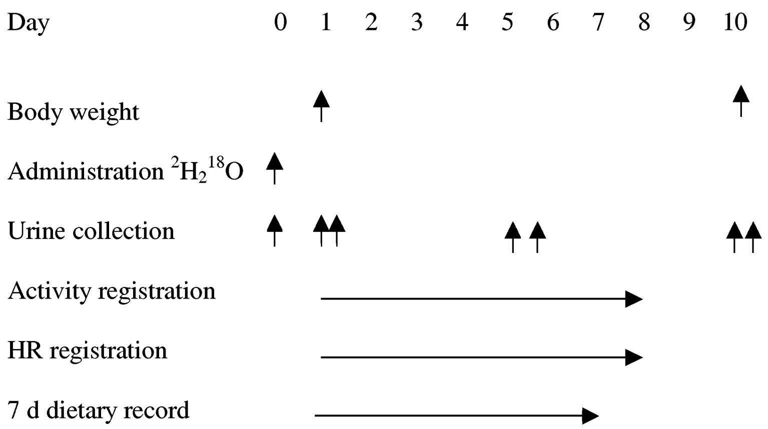


Figure 1. A schematic presentation of the protocol followed in **Studies IV** and **V**.

3.2 ANTHROPOMETRICS AND BODY COMPOSITION

In all studies (**I** to **V**), body weight and height were measured in light clothing using standard laboratory equipment. When appropriate, body mass index (BMI) was calculated, as weight (kg) / height^2 (m).

3.2.1 Skinfold measurements

In **Studies II** and **III**, four skinfold thicknesses (subscapula, triceps, biceps and supra-iliac) were measured using a Harpenden skinfold calliper as described by Lohman *et al* (1991). Relative body fat mass was calculated from triceps and subscapula skinfolds according to Slaughter *et al* (1988). Body fat mass was obtained by multiplying percentages of body fat by body weight. Fat free mass (FFM) was calculated by subtracting fat mass from body weight.

3.2.2 Total body water, fat mass and fat free mass

In **Studies IV** and **V**, total body water (TBW) was measured by means of deuterium dilution (Westerterp *et al*, 1995). The deuterium dilution space was divided by 1.04 to derive TBW. FFM was calculated from TBW assuming a hydration factor for FFM of 0.732 (Pace and Rathbun, 1945). Body fat (%) was calculated as 100 x (body weight – FFM) / body weight.

3.3 LABORATORY ENERGY EXPENDITURE MEASUREMENTS

Energy expenditure was calculated based on respiratory gas exchange, according to a modified formula of de Weir (1949): EE (kcal) = 3.94 VO_2 + 1.00 VCO_2
(where VCO_2 is carbon dioxide production)

3.3.1 Individual calibration

In **Studies I to V** calibration procedures were performed after 30 minutes of supine rest and at least 2 to 3 hours after a meal. All subjects were calibrated once. The between-day and within-day variability in the HR – VO_2 relationship is excellent and does not affect the estimation of TEE by the HR FLEX method (Mc Crory *et al*, 1997).

In **Studies I, II** and **III**, VO_2 and carbon dioxide production (VCO_2) were measured by indirect calorimetry (Medical Graphics Inc., Minnesota, USA) and HR measured with a bipolar lead (S&B Medico Teknik, Denmark) under standardised conditions. The following activities were carried out for determination of the individual relationship between VO_2 and HR: lying supine; sitting quietly; standing quietly; and walking on a treadmill at speeds of 2.7 $km \cdot h^{-1}$ at a 10% gradient and 4 $km \cdot h^{-1}$ at a 12% gradient. The gas sampling time was 6 minutes and calibration points were calculated as the mean VO_2 and HR for the last 3 minutes. The individual relationship between VO_2 and HR was calculated using data points from the two 'steady state' workloads and the values (PVO_2 and HR_{max}) obtained during a maximal workout.

In **Studies IV** and **V**, a somewhat different calibration protocol was used. VO_2 and VCO_2 were measured with a light-weight portable indirect calorimetry system, Cosmed K4 (Cosmed, Srl., Rome, Italy). This system has been validated and has shown accurate readings for VO_2 measurements from sitting at rest to maximal exercise (Hausswirth *et al*, 1997). The following activities were performed for determination of the individual relationship between VO_2 and HR: lying supine, sitting, standing, treadmill walking at 4.5 and 6.5 $km \cdot h^{-1}$, treadmill running at 10 $km \cdot h^{-1}$, and ergometer bicycling at 120 and 180 W. The calibration activities were carried out in sequence, with a break to allow recovery of resting HR between the treadmill and bicycle exercises. HR and VO_2 were measured at 15-second intervals, using the same system as described above. The gas sampling time was 6 minutes, and calibration points were calculated as the mean HR and VO_2 for the last 3 minutes. HR was measured simultaneously using a Polar Vantage HR monitor (Polar Electro OY, Kempele, Finland). During exercising on the treadmill, physical activity (body movement) was measured by the CSA accelerometer (Computer Science and Applications, Inc., Shailmar, USA). The monitor was secured directly to the skin at the lower back and a 15-second time sampling interval was used. Activity counts were averaged over the last 3 minutes and expressed as counts per minute for each exercise condition. Individual calibration data for the relationship between activity counts and EE were used to calculate EE during different types of exercises and compare it with EE calculated from HR (**Study V**).

3.3.2 Resting energy expenditure

REE (**Studies I** and **IV**; in **Study III** called sedentary energy expenditure; SEE), was measured by indirect calorimetry as described above and calculated as the average energy cost for the last 3 minutes of a 6 minute measurement period while lying supine, sitting quietly and standing quietly.

Figure 2. Individual calibration for the heart rate – oxygen uptake relationship during walking on a treadmill.

3.3.3 Resting metabolic rate

RMR was measured after an overnight fast of at least 10 hours by indirect calorimetry (**Study V**). Before each measurement the subjects rested in the supine position for 30 minutes. RMR was measured for 40 minutes and the mean value for the last 15 minutes of the measurement period was used as RMR. All subjects were visually monitored to make sure that they were lying still but awake.

3.3.4 Peak oxygen uptake

In **Studies I** to **V** PVO_2 was measured by indirect calorimetry using the same ergospirometer systems as described above. In **Studies I, II** and **III**, the measurements were made while the subject was running on a treadmill, according to the incremental protocol of Bruce *et al* (1973). Four minutes after the tests, a fingertip blood sample was obtained for measurement of the post-exercise blood lactate concentration. Lactate concentrations in whole blood were measured with an automated analyser (Analox Instruments Ltd. England). PVO_2 was determined on the basis of a combination of variables: a respiratory exchange ratio of 1.0 or more, HR within 5 beats·min^{-1} of the age-predicted HR_{max}, signs of intense effort (hyperpnea, difficulties in keeping up with the speed of the treadmill) and a post-exercise lactate concentration > 7 mmol·l^{-1}. All subjects fulfilled at least two of these criteria. Since many young people do not reach a 'true' plateau in oxygen uptake despite an increasing workload, the term PVO_2 was used in these studies rather than VO_{2max} (Rowland, 1996).

In **Studies IV** and **V**, VO_{2max} was determined during an incremental test on a mechanically braked cycle ergometer (Monark 818E, Monark AB, Sweden). The test was initiated by two 6-minute steady state workloads at 120 and 180 W. The workload was then increased by 25 W per minute to exhaustion. All subjects exhibited a 'true' plateau (i.e. an increase in VO_2 < 2 ml·kg^{-1}·min^{-1}), a respiratory exchange ratio > 1.1 and a post-exercise blood lactate concentration > 8 mmol·l^{-1}, as measured by a photometric method (Dr. Lange, Göttingen, Germany).

Figure 3. Measurement of resting energy expenditure during sitting quietly in a 14-year-old girl.

3.4 TEE MEASUREMENTS UNDER FREE-LIVING CONDITIONS

In **Studies I, III, IV** and **V**, TEE was assessed by means of an activity diary (**Study I**), the HR FLEX method (**Studies I, III** and **IV**) and the DLW method (**Studies IV** and **V**) over a period of 3 to 10 days.

3.4.1 The Activity diary method

In **Study I**, TEE and the time spent in physical activity at different intensity levels were compared between an activity diary (Bouchard *et al*, 1983) and heart rate monitoring by the HR FLEX method.

The activity diary is divided into ninety-six 15-minute periods per day. The main activity in each time period is rated on a scale from 1 to 9 and recorded in the diary throughout the day. Each of the activity category numbers (1 to 9) could be expressed as a multiple of BMR (MET intensity). TEE was calculated as the amount of time spent in each activity category multiplied by the MET intensity for each category and by the estimated BMR. The MET values used were adopted from Ainsworth *et al* (1993) and were close to the original values proposed by Bouchard *et al* (1983).

3.4.2 The FLEX HR method

TEE calculation according to the FLEX HR method relies a) on the individual relationship between HR and EE determined by regression analyses of the subject calibration data in the laboratory, b) on a critical HR (FLEX) that is used to discriminate between activity and sedentary behaviour during the free-living measurements and c) on the laboratory-measured REE. FLEX HR was determined as the mean of the highest HR (i.e. while standing) during the resting measurements and the lowest HR while exercising on the treadmill (**Studies I**, **III and IV**). In **Study IV**, FLEX HR was also calculated as the mean HR of all resting activities (i.e. supine, sitting and standing) and the lowest HR while exercising on the treadmill.

TEE was determined from minute-by-minute HR monitoring for 3 consecutive days, including one weekend day, in **Studies I** and **III** and for 8 consecutive days in **Study IV**. EE was calculated from the individual regression analysis at all time points with HR > FLEX HR. When HR was ≤ FLEX HR, EE was assumed to be equal to REE. EE during sleep was assumed to be equal to the predicted BMR. TEE was obtained by summing the BMR, REE, and EE during activity (= HR > FLEX).

Figure 4 shows a typical relationship between EE and HR as measured during individual calibration.

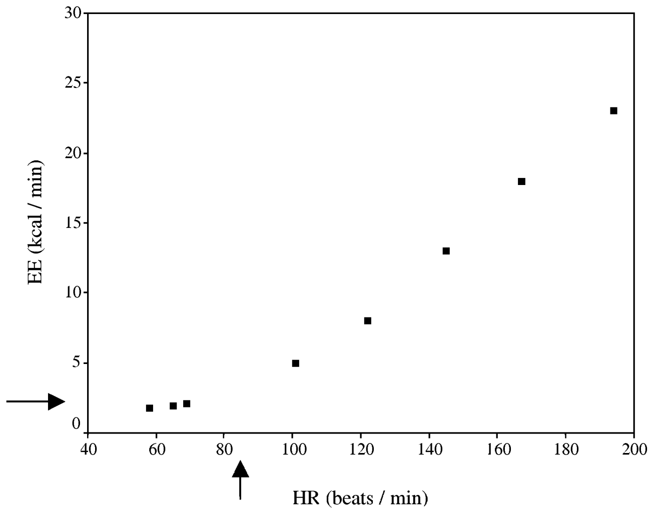


Figure 4. The relationship between energy expenditure and heart rate as determined by calibration according to the FLEX HR method. The arrows indicate the resting energy expenditure (REE) and FLEX HR (EE = energy expenditure; HR = heart rate).

3.4.3 The Doubly labelled water method

In **Studies IV** and **V** TEE was measured in by means of the DLW method according to the Maastricht protocol (Westerterp *et al*, 1995). A baseline sample of urine was taken to determine the individual isotope enrichment. Thereafter the subject was given an individually weighted oral dose of water labelled with ^2H and ^{18}O. This dose increases the baseline level of ^2H by approximately 150 parts per million (ppm) and of ^{18}O by approximately 300 ppm. Urine samples were then collected from the second and last voidings on day one, day five and day 10. The isotope quantities in the urine samples were measured with an isotope-ratio mass spectrometer (Aqua Sira; VG Isogas, Middlewich, Cheshire, England). All samples were measured in duplicate. CO_2 production was derived from the elimination rates of the isotopes, as calculated from the slope of the elimination curve, with correction for changes in body water, which were assumed to be proportional to changes in body mass, from day 1 to day 10. CO_2 production was converted to TEE using an energy equivalent based on the individual food quotient calculated from the macronutrient composition of the diet (Black *et al*, 1986). The estimated coefficient of variation (CV) for TEE measured by DLW is 3.9% in the Maastricht laboratory (Westerterp *et al*, 1988).

3.4.4 Calculation of basal metabolic rate

BMR was calculated according to predictive equations (Schofield *et al*, 1985) (**Studies I, III** and **IV**). Predicted BMR was used in the calculation of TEE by the FLEX HR method as described by Spurr *et al* (1988). Overnight energy expenditure and BMR are equivalent and 1.0 times BMR is an appropriate factor for estimating energy expended during the night (Seale and Conway, 1999).

3.4.5 Calculation of PAL and AEE

PAL was calculated as the ratio of TEE to BMR in **Studies I, III**, and **IV** and as the ratio of TEE to RMR in **Study V**. Energy expenditure associated with physical activity (AEE) was calculated as TEE (from DLW) * 0.9 minus BMR, with correction for a 10% diet-induced thermogenesis (Maffeis *et al*, 1993) in **Study IV**.

3.5 Measurements of patterns of physical activity

The amount of time spent at different intensity levels, i.e. the pattern of physical activity, was assessed by the activity diary in **Study I** and by minute-by-minute HR monitoring in **Studies I, III** and **IV**.

3.5.1 Activity diary

Activity category 2 (sitting activities; equal to 1.5 METs) was defined as sedentary behaviour and categories 3 to 9 (2.3 to 8 METs) was defined as physical activity. Light physical activity referred to categories 3 to 6 (2.3 to 4.5 METs), moderate physical activity as to category 7 and 8 (5.5 and 6 METs) and vigorous physical activity to category 9 (8 MET). The time spent in these activity categories was compared with data obtained by minute-by-minute HR monitoring.

3.5.2 Heart rate monitoring

The individual relationship between HR and oxygen consumption was used to determine intensity thresholds from the minute-by-minute monitoring data. Time ($min \cdot d^{-1}$) spent in physical activity referred to time > FLEX HR, and time spent at ≥ 50% PVO_2 and time spent at ≥ 70% PVO_2 were denoted as moderate (MPA) and vigorous (VPA) intensity of physical activity, respectively (**Studies I, III**, and **IV**).

In order to determine the number of subjects achieving appropriate amounts of physical activity in relation to physical activity recommendations for young people (Sallis and Patrick, 1994; Health Education Authority, 1998) an HR threshold corresponding to 4.5 times REE was calculated individually in **Study III**.

Only subjects accumulating at least 600 minutes of acceptable HR monitoring data were included in the analyses (**Studies I, III** and **IV**).

3.5.3 Accelerometry

In **Study V**, the total amount of physical activity, measured on a minute-by-minute basis by the CSA accelerometer, was calculated as the total number of accumulated counts per day. To take into account inter-individual differences in the length of time for which the accelerometer was worn, the total amount of physical activity was expressed as $counts \cdot min^{-1}$. The total amount of physical activity calculated from the CSA accelerometer was subsequently related to TEE and its derivatives during the two different training periods.

3.6 ENERGY INTAKE

In **Studies IV** and **V**, energy intake was assessed from a weighed food record during the first seven days of the measurement periods in order to derive the individual FQ. All food consumed (i.e. at home, at school and in restaurants) was weighed on a household scale and recorded. Energy intake was calculated from the food records by means of computerised nutrient calculation software using the Swedish nutrient database (National Food Administration).

3.7 TRAINING DIARY

All subjects who participated in **Studies IV** and **V** kept training diaries on a regular basis. These were checked for differences in types of exercise performed and in the duration of physical training between the two training conditions. In addition, the training diaries were re-evaluated through personal communication with the coach.

3.8 ETHICS

The Research Ethics Committee of the Örebro County Council approved the study protocols for **Studies I, II** and **III**. All participants received verbal and written information and all parents or guardians received written information about the study. Participants and parents provided written informed consent.

In **Studies IV** and **V**, the study protocol was approved by the Ethics Committee of Karolinska Institutet, Stockholm and written informed consent was obtained from all participants and from the parents of those who were younger than 18 years of age.

3.9 STATISTICS

For descriptive purposes results are presented as mean ± SD (**Studies I, II, III, IV** and **V**) and mean ± SD and range (**Studies II, III** and **IV**). The unpaired *t*-test was used to compare mean differences between groups and paired *t*-test for within group comparisons (**Studies I**, **III** and **V**). The effect of sex was tested by one-way analysis of variance (ANOVA) in **Studies II** and **III**. The effect of period (off-season and pre-season) on descriptive variables was tested by ANOVA in **Study IV**.

Relationships between variables (e.g. VO_2 and HR and VO_2 and activity counts) were tested by linear regression analysis in **Studies I, II, III, IV** and **V**. The relationship between activity counts and TEE and its components was assessed by calculating the Spearman correlation coefficients in **Study V**. Interindividual differences between slopes and intercepts for the relationship between VO_2 and HR were examined by calculating the coefficient of variation in **Studies II** and **III.**

The influence of sex and method (fixed factors) on the TEE components (EE_{sleep}, EE_{rest} and EE_{act}) and on the time spent at different intensity levels (sedentary, light intensity, moderate intensity and vigorous intensity) was tested by a multivariate analysis of variance (MANOVA) in **Study I**. The same analysis (MANOVA) was used in **Study III** to test the influence of sex and activity group (low, medium and high) on time spent at different intensity levels (light intensity, moderate intensity and vigorous intensity) and on energy expenditure at different intensity levels. Post hoc comparisons were performed by Tukey test (**Study III**). The effect of subject and training period on TEE and activity counts was tested by a two-way MANOVA in **Study V**. The effects of period (off-season and pre-season) and method (FLEX HR1 and FLEX HR2) on the calculated time spent in physical activity (> FLEX HR) and the effects of period and method (FLEX HR1, FLEX HR2 and DLW) on the estimated TEE were tested by a three-way ANOVA where subject was considered as a random factor and period and method were considered as fixed factors (**Study IV**).

In **Study II**, an analysis of covariance (ANCOVA) was performed to test for the effect of sex, aerobic fitness (PVO_2) and body fatness (% body fat), with fitness and fatness as covariates, on predicted HR corresponding to 40%, 60% and 80% of PVO_2 and on predicted VO_2 at the selected absolute HR (120, 140 and 160 beats$\cdot$min^{-1}).

The degree of agreement between methods of assessment of TEE (**Studies I** and **IV**) and of assessment of time spent at MVPA (**Study I**) was determined using the method described by Bland and Altman (1986). Correspondence between methods of assigning subjects into activity categories for TEE and time spent at MVPA was analysed by a Wilcoxon rank test in **Study I**.

4 RESULTS AND COMMENTS

4.1 VALIDITY OF A SELF-REPORTED ACTIVITY DIARY (STUDY I)

TEE calculated from the activity diary was significantly correlated to TEE estimated by the HR FLEX method ($r = 0.81$; $P < 0.01$; **Fig. 5**). Although the individual differences ranged from minus 28% to 21%, the mean difference between methods was not statistically significant. The absolute mean difference was 0.4 $MJ \cdot d^{-1}$ and the limits of agreement were -3.54 $MJ \cdot d^{-1}$ and 2.74 $MJ \cdot d^{-1}$. The data indicate that the AD and HR FLEX methods are comparable for group estimation of TEE, at least within the range of TEE values assessed in the present study. This was further confirmed by the fact that no significant method and interaction effects were observed for TEE and its components, between the methods. No significant relationship was observed for TEE between the mean of the methods and the difference between the methods, indicating that the methods are comparable throughout the range of data assessed in the present study.

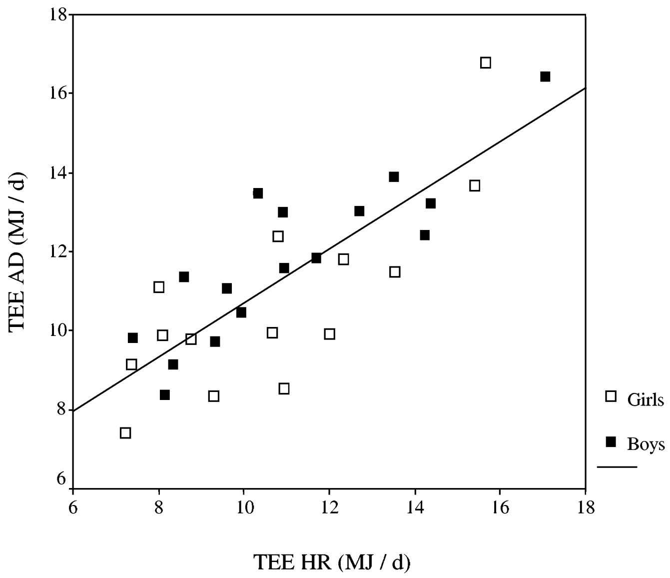
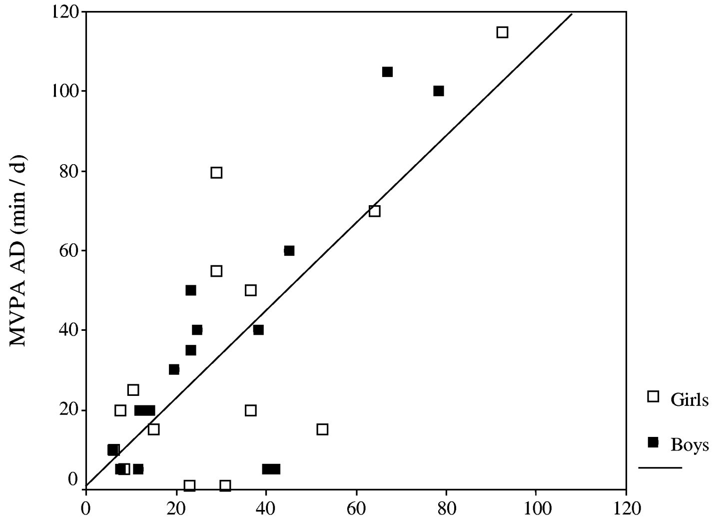


Figure 5. The relationship between total energy expenditure (TEE) calculated from an activity diary (AD) and TEE estimated by the FLEX HR method (n = 30).

When TEE was calculated from AD, a specific MET value was assigned to each activity category. One MET is equal to energy expenditure during rest and was assigned to activity category 1. In adults, one MET is broadly equal to 3.5 ml $O_2 \cdot kg^{-1} \cdot min^{-1}$ or 1 $kcal \cdot kg^{-1} \cdot h^{-1}$. However, in children and adolescents, measured BMR is significantly higher than 1 $kcal \cdot kg^{-1} \cdot h^{-1}$ and this must be taken into account when calculating TEE from self-report data (Roemmich *et al*, 2000). Thus, the mode of calculation of TEE in the present study, by first estimating BMR and thereafter assigning each activity category as a multiple of BMR, seems more appropriate than setting 1 MET equal to 1 $kcal \cdot kg^{-1} \cdot h^{-1}$.

Another issue related to the calculation of TEE from the AD is whether the assigned MET values in the higher activity categories (i.e. 8 and 9) are appropriate.

In the present study, activity category 8 (leisure and sport activities) was categorised as being equal to 6 times BMR, and activity category 9 as equal to 8 times BMR. Since the maximal energy turnover was on average 12 times the predicted BMR in the subjects in the present study, it seems reasonable to categorise leisure and sport activities (category 8) as being approximately equivalent to 50% of PVO_2, and high-intensity physical activity as equivalent to approximately 70% of PVO_2. This assumptions was supported by the findings in **Study II,** the results of which suggested that moderate physical activity corresponded to 5 to 7.99 METs in adolescent boys and 4 to 6.99 METs in adolescent girls and vigorous physical activity corresponded to > 8 and > 7 METs, respectively (see **Table 3**).



MVPA HR (min / d)

Figure 6. The relationship between time spent at moderate and vigorous physical activity (MVPA) calculated from the activity diary (AD) and time spent at MVPA as measured by the FLEX HR method (n = 30).

Time spent at moderate and vigorous physical activity as calculated from the AD was significantly associated with time spent at MVPA as estimated from the HR monitoring method ($r = 0.74$; $P < 0.01$; **Fig. 6**). However, the limits of agreement were wide, ranging from minus 55 $min \cdot d^{-1}$ to plus 41 $min \cdot d^{-1}$, and individual differences ranged from minus 63% to plus 250%, clearly demonstrating the inability of the AD method to estimate time spent at MVPA by an individual. In addition, there was a significant negative relationship between the mean of the methods and the difference between the methods ($r = - 0.51$; $P < 0.01$), as shown by a Bland and Altman plot, indicating that the AD underestimated the time spent at MVPA for subjects with 'low' activity and consequently overestimated subjects with 'high' activity. The time ($min \cdot d^{-1}$) spent inactive (< HR FLEX and category 2 from AD) was significantly higher when estimated by the HR method as compared to the AD, as a result of the definition of inactivity. However, when activities of category 2 (sitting) and 3 (standing) from AD were combined no significant difference was found between the methods, suggesting that the methods are comparable regarding time spent at sedentary activities (sitting and standing).

4.2 THE DEFINITION OF INTENSITY FROM HEART RATE (STUDY II)

The results of **Study II** showed that the predicted absolute intensities of physical activity (i.e. VO_2, ml·kg^{-1}·min^{-1}) at absolute HR of 120, 140 and 160 beats·min^{-1}, differed significantly between the sexes. On the other hand, the predicted values for HR at relative values for PVO_2 (i.e. 40%, 60% and 80%) showed no significant sex differences.

The average slopes for the relationship between HR and VO_2 was significantly steeper ($P < 0.001$) in girls than in boys (**Fig. 7**), whereas no difference in the average slopes between the sexes for the %HR and %PVO_2 relationship was observed (**Fig. 8**).

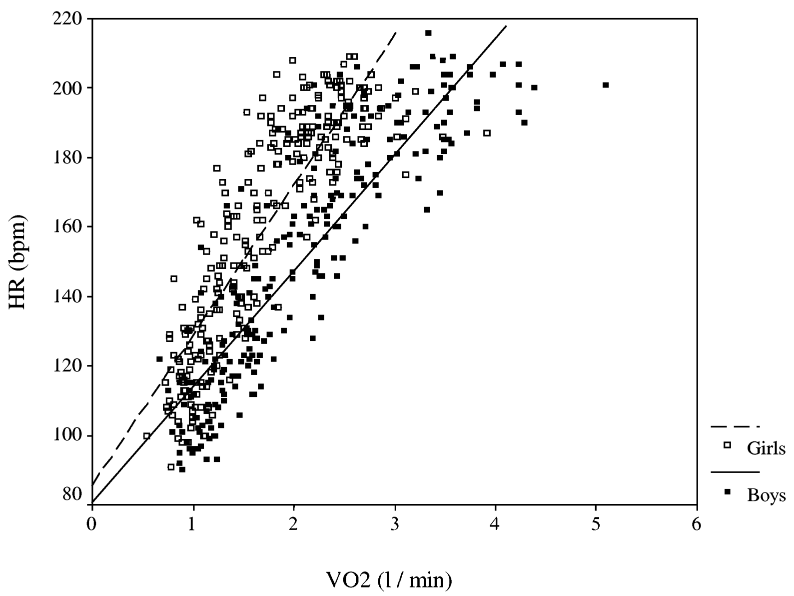


Figure 7. The relationship between heart rate (HR) and oxygen uptake (VO_2) when expressed in absolute values in 14-to-15-year-old boys and girls (n = 127). Note the difference between genders in the slope of the regression line (Girls: HR = 0.04314 VO_2 + 85.7 [R^2 = 0.73]; Boys: HR = 0.03343 VO_2 + 80.6 [R^2 = 0.78]).

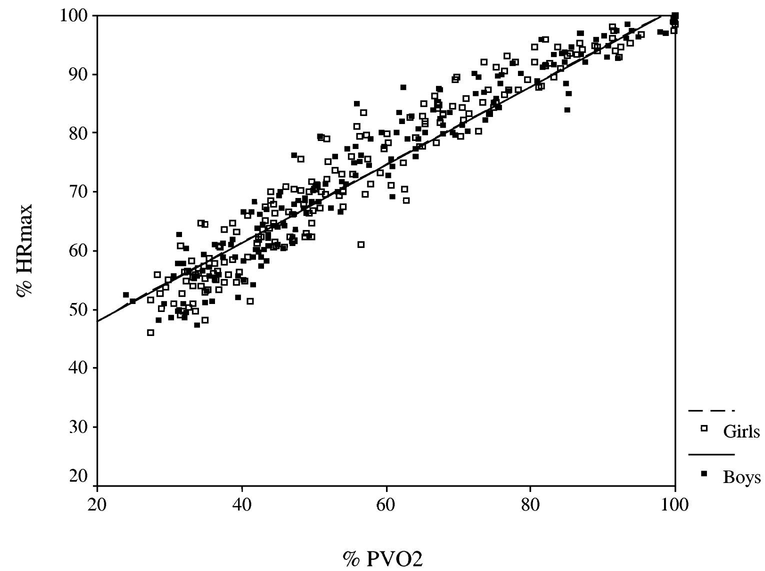


Figure 8. The relationship between relative heart rate ($\%HR_{max}$) and relative oxygen uptake ($\%PVO_2$) in 14-to-15-year-old boys and girls (n = 127). Note the similarity between genders in the slope of the regression line (Girls: $\%HR_{max} = 0.665\ \%PVO_2 + 34.8$ [$R^2 = 0.96$]; Boys: $\%HR_{max} = 0.663\ \%PVO_2 + 34.8$ [$R^2 = 0.96$].

A further analysis of covariance (ANCOVA), with the aim of testing potential influences of sex, aerobic fitness (PVO_2, $ml\cdot kg^{-1}\cdot min^{-1}$) and body fatness (% body fat) on the absolute intensity (i.e. VO_2, $ml\cdot kg^{-1}\cdot min^{-1}$) predicted from absolute HR of 120, 140 and 160 $beats\cdot min^{-1}$, showed a highly significant fitness effect.

In other words, when different intensity levels are defined on the basis of the heart rate, the fitness level of the subjects under investigation must be taken into account. For example, in the present study an absolute HR of 140 $beats\cdot min^{-1}$, yielded a VO_2 ($ml\cdot kg^{-1}\cdot min^{-1}$) which ranged between 13.7 and 41.1 $ml\cdot kg^{-1}\cdot min^{-1}$ or 3.9 to 11.7 METs (here 1 MET is equal to 3.5 $ml\cdot kg^{-1}\cdot min^{-1}$). Thus, an HR of 140 could be equal to a *low* intensity of physical activity in one subject but to a *very high* intensity of physical activity in another. When physical activity is assessed from HR monitoring in adolescent subjects, an aerobically fit subject may be recorded as spending only a very few minutes at the selected intensity levels (e.g. 140 $beats\cdot min^{-1}$) when absolute HR is used, and consequently be assigned to a low activity category, even though the energy expenditure and total amount of physical activity could be high. The present data suggest that the use of absolute HR when assessing young people's physical activity detracts from the usefulness of the data. Although it is more time- and labour consuming, the individual calibration for the HR – VO_2 relationship is a preferable alternative.

Based on the data from **Study II**, a suggested categorisation of absolute and relative intensity levels from $\%HR_{max}$, $\%PVO_2$ and MET is shown in **Table 3** (for comparison, absolute HR levels are included in the table) This categorisation is similar to that proposed by Pate *et al* (1998), although we suggest that a sex difference should be taken into account when expressing the intensity of physical activity in absolute values (i.e.

METs), and it may be used as a template for classifying the intensity of physical activity in adolescents.

Table 3. Suggested absolute and relative intensity levels of physical activity in 14-to-15-year-old adolescent boys and girls. Data derived from individual calibration for the heart rate (HR) – oxygen uptake (VO_2) relationship in 60 boys and 67 girls during treadmill exercise. Absolute heart rate intervals are included for comparison.

Category of intensity	HR (beats·min^{-1})	% HR_{max}	%PVO_2	MET Boys	MET Girls
Low	< 120	< 60	< 40	< 5	< 4
Moderate	120 - 140	60 – 70	41 – 55	5 – 7.99	4 – 6.99
Vigorous	141 - 160	71 – 80	56 – 70	8 – 11	7 – 10
Very vigorous	> 160	> 81	> 70	> 11	> 10

PVO_2 = peak oxygen uptake
MET = metabolic energy turnover

4.3 PHYSICAL ACTIVITY IN RELATION TO GUIDELINES (STUDY III)

Eighty-two of the 127 subjects participating in **Study II** were submitted to minute-by-minute HR monitoring for 3 days, including one weekend day, in **Study III**. As expected, TEE (MJ·d^{-1}) was significantly higher in boys than in girls (12.8 vs. 10.0 MJ·d^{-1}, $P < 0.001$) and the same was found when it was expressed in relation to body weight (210 vs. 182 kJ·kg^{-1}·d^{-1}, $P < 0.01$). Approximately 70% of the energy expended in physical activity referred to physical activity of light intensity (i.e. EE above FLEX HR and ≤ 4.5 times REE). The average PAL values in boys and girls were 1.74 and 1.67, respectively (NS). The TEE and PAL values were almost identical to those obtained by the AD method in the whole sample of 127 subjects (Ekelund *et al*, 1997) and were similar to the data on TEE from **Study I**. However, they are lower than those obtained by the AD method in another sample of Swedish adolescents (Bratteby *et al*, 1997). Since the two populations (**Study III** and the population of Bratteby *et al*, 1997) were similar in height and weight (i.e. BMR is assumed to be similar), the differences observed could be due to real differences in PA between the groups, to differences in the methodology used, or to seasonal differences during the data collection. The latter may be a plausible explanation, since the data from the present study were collected from February to May, as compared to data collection throughout the year in the study by Bratteby *et al* (1997).

The total amount of physical activity, assessed objectively (by accelerometry) in more than 800 Swedish 9-year-old children and 15-year-old adolescents showed a significant difference between months, with the lowest values found in February, March and November (unpublished observations). Seasonal differences in TEE, explained by differences in AEE, have shown that physical activity differs between seasons (Goran *et al*, 1998). This has also been confirmed by self-reported data in children and adolescents (Garcia *et al*, 1998; Rifas-Shiman *et al*, 2001) Thus, there is evidence that physical activity differs between seasons, and this needs to be taken into account when results from different studies are compared.

Most studies presented in **Table 1** seem to be based on convenient samples of subjects, which may limit a direct comparison of TEE and PAL values. Although the average PAL values for boys and girls agreed with those values suggested as corresponding to moderate habitual physical activity in 14-to-18-year-old adolescents, forty percent of the young people in **Study III** could be categorised as having a lifestyle of light habitual physical activity (Torun *et al*, 1996).

On average, the adolescents in the present study accumulated more than one hour of physical activity of moderate intensity. The definition of moderate intensity was based on a multiple (4.5) of measured REE. This definition seems appropriate according to the findings in **Study II** (see **Table 3**). Moderate intensity as defined in **Study III**, is equivalent to 6.2 METs and 5.6 METs in boys and girls respectively, when calculated by setting one MET as equivalent to 3.5 $mlO_2 \cdot kg^{-1} \cdot min^{-1}$. Further, the average oxygen consumption corresponding to a heart rate of 4.5 times REE amounted to 41% of PVO_2 in boys and 45% of PVO_2 in girls.

The average time spent at MVPA, may be compared with that presented in a review of 26 HR monitoring studies by Epstein *et al* (2001). Those authors concluded that the average adolescent accumulated approximately $50 min \cdot d^{-1}$ of physical activity at an intensity of 5 METs or greater and approximately 30 $min \cdot d^{-1}$ of physical activity at what was suggested to be equal to an aerobic fitness training level (i.e. 50% HRR). The amount of physical activity at these intensities was greater than expected (Epstein *et al*, 2001). Furthermore, it was concluded that if an adult intensity criteria (i.e. 3 MET) was used, most children attain 1 to 2 hours of physical activity at that level (Epstein *et al,* 2001). However, given the great variability of habitual physical activity in young people, the use of average values when reporting physical activity levels does not provide any information of the proportion of young people meeting the existing recommendations for health-enhancing physical activity (Health Education Authority, 1998; Pate *et al*, 1995; Sallis and Patrick, 1994).

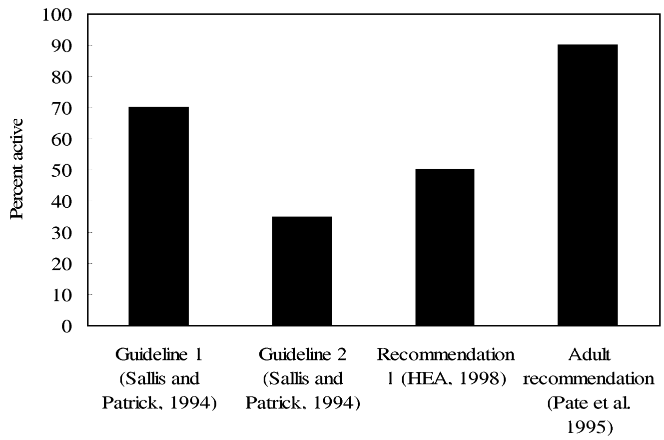


Figure 9. Percentage of 14-to-15-year-old adolescents physically active in relation to different physical activity recommendations for health purposes.

The average values for time spent at MVPA obtained in the present study are higher than those reported in the review by Epstein *et al* (2001). The numbers of subjects meeting different existing recommendations for physical activity are shown in **Figure 9**. Seventy-one percent of the subjects accumulated ≥ 30 min·d^{-1} at MVPA (Guideline 1 from Sallis and Patrick, 1994) and 49% accumulated ≥ 60 min·d^{-1} at MVPA (Recommendation 1, HEA, 1998). Thirty-five percent of the subjects were continuously active for at least 20 minutes at MVPA, on at least one of the three days during the monitoring period (Guideline 2, Sallis and Patrick, 1994). Ninety percent accumulated ≥ 30 min·d^{-1} of MVPA (3 METs) according to the adult recommendation made by Pate *et al* (1995). Clearly, the number of young people achieving appropriate levels of physical activity depends on the thresholds set for intensity levels and whether accumulated or continuous bouts of activity are included in the analysis.

A limitation of the present study may be the number of days of monitoring. Habitual physical activity was assessed for three days. DuRant *et al* (1992), reported a stability reliability coefficient of $r = 0.66$ for two days of heart rate monitoring in children and calculated that just over four days are necessary to achieve a reliability coefficient of 0.80. In adults, it has been shown that the activity level differs from one weekday to the next, and between weekdays and weekend days, so that each should be monitored (Gretebeck *et al*, 1992). Although three days of HR monitoring seems appropriate, on the basis of data from literature and from the feasibility aspect, it is not clear whether such a short period actually reflects the long-term part of time devoted to physical activity.

4.4 TEE MEASURED BY HR AND DLW IN YOUNG ATHLETES (STUDY IV)

No significant difference in energy expenditure derivatives (TEE, AEE and PAL) was observed between the two training periods.

TEE (MJ·d^{-1}) calculated from FLEX HR1 ('low FLEX HR', defined as the mean of all resting activities and the lowest HR during exercising), and TEE calculated from FLEX HR2 ('high FLEX HR', defined as the highest HR during resting activities and the lowest HR during exercising were significantly correlated to TEE obtained by the DLW method ($r = 0.90$, $P < 0.001$ and $r = 0.88$; $P < 0.001$, **Fig. 10**).

Although there was a significant difference between FLEX HR1 and FLEX HR2, and a significant difference in time spent in physical activity (i.e. > FLEX HR), when calculated from FLEX HR1 compared to FLEX HR2, ANOVA showed no significant effect of period (off-season vs. pre-season) or method (TEE DLW, TEE FLEX HR1, TEE FLEX HR2) on the calculated TEE.

Despite a significant difference between FLEX HR 1 and FLEX HR2 and consequently a significant difference in the calculated time spent in physical activity, calculated TEE did not differ between the two FLEX HR approaches. This was most likely due to the relatively small difference between REE (used when HR ≤ FLEX HR) and energy expenditure calculated from the individual regression equations for light physical activity (i.e. for HR between FLEX HR 1 and FLEX HR 2). The maximal calculated difference in energy expenditure was about 700 kJ·d^{-1}, assuming that all time spent in physical activity was spent *at* FLEX HR2, when TEE was calculated from FLEX HR2. However, it is more likely that the surplus in time spent in physical activity when calculated from FLEX HR1, as compared to FLEX HR2, was spent at heart rates between FLEX HR 1 and FLEX HR2 and *not at* FLEX HR2, resulting in an even smaller difference in calculated TEE between the two approaches.

The results suggest that TEE calculated from the FLEX HR method is not affected by the definition of FLEX HR and is in conformity with the findings of Livingstone *et al* (2000).

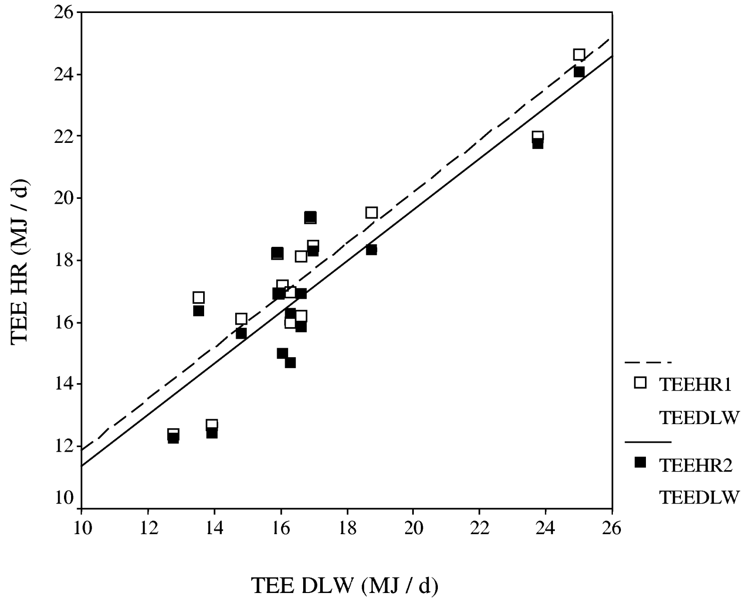


Figure 10. The relationship between total energy expenditure (TEE) estimated by the FLEX HR method and TEE measured by the doubly labelled water (DLW) method. Data are combined for the two different training conditions.

There was a considerable difference in the types of exercises performed between the two training periods. During the first period, all exercises were continuous, mainly jogging and running. The second period included both continuous and intermittent types of activities, such as in-line skating, slideboard training and weight training. Many of these activities were not represented during the individual calibration procedure. However, it seems that the activities included were able to reflect the free-living cardiovascular dynamics during both periods on a group level. This indicates that the types of training regimen do not seem to influence the average group estimation of TEE from the FLEX HR method.

The average TEE ($MJ·d^{-1}$) and TEE expressed in relation to body weight ($kJ·kg^{-1}·d^{-1}$) were, as expected, significantly higher in the adolescent athletes than in the general population investigated in **Study III**. Furthermore, PAL was significantly higher in the adolescent athletes, indicating a higher total amount of habitual physical activity. In contrast, a significantly higher average PAL value was reported for young female swimmers during high volume training (Trappe *et al*, 1997) and in cross-country skiers during a period in a training camp (Sjödin *et al*, 1994). The two studied training periods in the present study were not focused on a high volume of aerobic training. In addition, the subjects were full-time students during the two measurement periods, which may partly explain the differences in PAL between the studies.

During a three-day period in a training camp, involving bicycling 150 to 180 km per day, the average TEE was 30.8 ± 6.1 $MJ \cdot d^{-1}$ and the average PAL was 3.7 ± 0.6, as measured by the FLEX HR method (unpublished data). Thus, these young athletes seem to have, for a limited period, an energy turnover as high as that in professional athletes in endurance sports (Sjödin *et al*, 1994; Trappe *et al*, 1997).

4.5 THE VALIDITY OF THE CSA ACCELEROMETER (STUDY V)

In conjunction with the HR monitoring measurements presented above (**Study IV**), physical activity was also assessed by the CSA accelerometer in the same eight subjects during the first eight days of the two different training periods. Owing to malfunction of one of the accelerometers, only seven subjects were included in the data analyses.

A highly significant relationship (r = 0.97; P< 0.001) was observed between activity counts ($counts \cdot min^{-1}$) and energy expenditure during laboratory calibration (i.e. walking and running on the treadmill).

There was no significant difference in any of the energy expenditure estimates between periods. However, there was a significant effect of period (P = 0.026) on activity counts ($counts \cdot min^{-1} \cdot d^{-1}$). Moreover, a significant relationship was observed between all energy expenditure estimates (TEE, AEE and PAL) and activity counts during the first period, but in no case during the second period.

The lack of significant relationships between activity counts and energy expenditure estimates during the pre-season period, as well as the difference in the total amount of physical activity ($counts \cdot min^{-1} \cdot d^{-1}$), may be explained by the differences in exercises performed. During the off-season period, the vast majority of the exercise consisted of jogging and running, activities characterised by movement in the vertical plane, where the relationship between activity counts and energy expenditure is robust (Freedson *et al*, 1998; Trost *et al*, 1998; Hendelman *et al*, 2000; Swartz *et al*, 2000). In contrast, during the pre-season period a number of exercises, such as in-line skating, slideboard training and skating imitations were performed. These activities are characterised by just as much movement in the medio-lateral plane as in the vertical plane. Thus, it is most likely that the difference observed in activity counts between periods was due to the types of exercises performed and not to a difference in the total amount of physical activity.

A direct comparison between energy expenditure estimated from activity counts and from HR clearly demonstrated that the CSA accelerometer significantly underestimated energy expenditure during specific exercises (**Fig. 11**). Mean energy expenditure was approximately 1.7 to 5 times lower when calculated from activity counts than when calculated from HR for all exercises except running. This difference was most likely due to the inability of the CSA accelerometer to detect body movements in other directions than in the vertical plane.

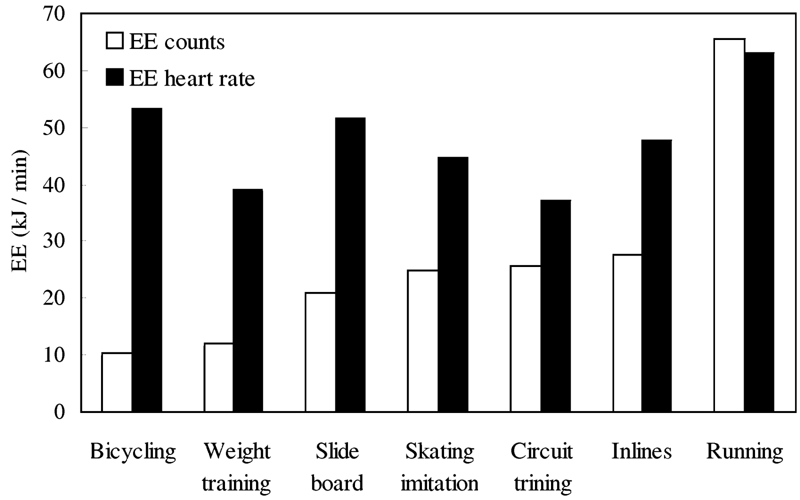


Figure 11. Energy expenditure (EE) calculated from activity counts and from heart rate during different exercising activities in young athletes. EE calculated from heart rate was significantly higher than EE from activity counts for all activities except running.

5 GENERAL DISCUSSION

Four different assessment methods were used in the present studies namely, one self-report method, the activity diary, and three objective methods, that is the FLEX HR method, activity monitoring with the CSA accelerometer, and the DLW method. The latter was used as a criterion method for measuring TEE under free-living conditions in **Studies IV** and **V**. The following general discussion will mainly focus on some specific issues related to the accuracy, validity and practicality of the methods used in **Studies I** to **V**.

5.1 CALCULATION OF TEE AND AEE FROM SELF-REPORTS

The activity diary (**Study I**) provided average data for TEE comparable to those obtained by the FLEX HR method, and has been found in previous research to be a valid method for estimating TEE on a group level in adolescent subjects (Bratteby *et al,* 1997).

The main use of the AD, as for other self-report methods, would be in large population-based studies. It may be hypothesised that the precision of the AD in estimating TEE in an individual would be improved by measuring RMR and energy expenditure during specific daily activities in each subject and thereafter assigning individual MET values to each activity category. This however, would significantly increase the time and costs of the method and thereby limit its use in large-scale studies. Although assigning MET values for the different activity categories used and setting 1 MET equal to the estimated BMR seems appropriate for group estimation of TEE in adolescents (**Study I**), it may not be suitable for specific groups.

For example, in a group of obese adolescents, the MET values, expressed as a multiple of measured RMR, observed while the subjects were walking at 4 and 6 $km \cdot h^{-1}$, were significantly higher than those in a normal-weight control group. This was due to the higher energy costs of moving a larger body (unpublished data). Consequently, when published MET values (Ainsworth *et al*, 1993; Ainsworth *et al,* 2000) corresponding to different self-reported intensities of PA are applied in a self-report method, calculated AEE and TEE in obese subjects will be underestimated (Racette *et al*, 1995).

In addition, the AD may not be an appropriate method when assessing TEE in athletes, with a known high maximal aerobic fitness level. It has been shown that the AD significantly underestimated TEE in endurance athletes, most likely due to the use of inappropriate MET values in the two highest activity categories (Boulay *et al,* 1993). Similar findings were reported by Sjödin *et al* (1994).

Apparently there is a need for more research on the energy costs of different physical activities in normal-weight adolescents as well as in other specific groups (e.g. obese subjects and athletes).

Because of the format of the activity diary, with each day consisting of ninety-six 15-minute blocks, the detailed pattern of physical activity is less well described.

For a researcher who is interested in the time spent at different intensity levels, the activity diary is less sensitive than the FLEX HR method and activity monitoring by use of accelerometry, since these methods are generally based on minute-by-minute monitoring of physical activity. On the other hand, when physical activity patterns are examined in young children, an even shorter time sampling interval may be required. Studies have suggested that the median duration of physical activities in children is less than 10 seconds (Bailey *et al*, 1995), and it was recently shown that a 5-second time sampling interval detected approximately 4 times more of the accumulated physical activity at a high intensity level and 10 times more of the accumulated physical activity at a very high intensity level when assessments were made by an accelerometer in 7-year-old children over a four day measurement period (Nilsson *et al*, 2002).

Only a limited number of studies have addressed the absolute validity of self-report instruments in young people. In contrast to the findings in **Study I**, an approximately 100% overestimation of time spent at MVPA from a self-report instrument has been observed in 11-year-old children (Sallis *et al*, 1996). On the other hand, Bratteby *et al* (1997) concluded that the AD is a valid instrument for assessing TEE in 15-year-old adolescents, as compared to the DLW method. Similarly, Roemmich *et al* (2000) concluded that the 7d PAR is a valid self-report instrument for assessing TEE in pubertal boys and girls if an appropriate MET value (multiple of BMR) is used to transform PAR data to TEE data. To judge from the findings in the limited number of studies concerning the absolute validity of self-report instruments, there may be a difference between children and adolescents in their ability to recall and correctly report the time spent at PA, or alternatively the use of different instruments may explain discrepancies between studies.

Thus, there is obviously a need for more rigorous evaluation of different self-report methods for use in young people. Such studies should preferably be performed by a direct comparison of the self-report method under consideration with a validated objective assessment instrument.

5.2 HR MONITORING – THE DEFINITION OF INTENSITY THRESHOLDS

A critical issue when assessing physical activity on the basis of heart rate monitoring is the definition of the thresholds corresponding to physical activity of moderate and vigorous intensity.

The relationship between heart rate and energy expenditure will differ as a function of sex, aerobic fitness and probably age. The result of **Study II** clearly showed that the use of absolute heart rates when defining intensity thresholds detracts from the usefulness of the data. In another approach, the HR measured under free-living conditions is expressed in relation to the HR at rest (DuRant *et al*, 1993a; Pate *et al*, 1996). This approach may take interindividual differences in age, sex, fitness and body composition into account. However, there is no consensus on how to define HR at rest, and the definition of resting HR has a significant effect on the levels of physical activity observed (Logan *et al*, 2000). In addition, the absolute and relative values for the intensity of physical activity (e.g. VO_2, MET, $\%PVO_2$) corresponding to 1.25 (light intensity), 1.50 (moderate intensity) and 1.75 (vigorous intensity) times HR at rest have not been empirically established in young people.

The use of individual calibration for the relationship between heart rate and energy expenditure provides the most valid definition of intensity thresholds (Epstein *et al*, 2001). Although this approach is both time-and labour consuming and therefore may not practical for use in large-scale epidemiological studies, it has been adopted in one relatively large study of 775 adult subjects (Wareham *et al*, 2000).

A promising relative intensity categorisation is the use of percentage HRR. It has been shown that %HRR is numerically identical to $\%VO_2R$ from low to very high intensity levels in adults (Swain and Leutholtz, 1997; Swain *et al*, 1998). Although not confirmed empirically in young people, it is reasonable to assume that the relationship is similar.

Thus, if a researcher is interested in examining the physical activity patterns (i.e. the intensity and duration) of children and adolescents by means of HR monitoring, the %HRR approach may be promising. In practice, it only requires measurement of resting and maximal HR under standardised conditions. However, it does not provide any estimates of TEE and its derivatives.

Thus, minute-by-minute HR monitoring seems to be a useful tool for assessing the physical activity of young people if the intensity thresholds are defined in an appropriate way.

5.3 ASSESSMENT OF THE TOTAL VOLUME OF PHYSICAL ACTIVITY

Self-report methods underestimate TEE in athletes (Boulay *et al*, 1993; Sjödin *et al*, 1994). The validity and accuracy of objective methods for use in this specific group therefore need to be evaluated.

A direct comparison between the two methods applied in **Studies IV** and **V**, accelerometry and the FLEX HR method, may shed some light on their respective appropriateness, keeping in mind that the accelerometer is a direct measure of physical activity, whereas the FLEX HR method is an indirect measure. The FLEX HR method was shown to be robust when used in the two different training conditions. That is to say, the estimated TEE and therefore also the calculated PAL, were not affected by the different training regimens.

It may be argued that estimating BMR as compared to measuring RMR affects the TEE calculated from the FLEX HR method. In one of the first validation studies of the FLEX HR method it was suggested that the use of a calculated value for BMR would not affect the calculated TEE (Spurr *et al*, 1988), and this approach was applied in the present investigations.

In **Study V**, measured RMR was found to be approximately 10% higher than estimated BMR. However, even if the higher RMR value is used in the calculation of TEE, it will only have a minor impact on the calculated TEE. The calculation of TEE from the FLEX HR method involves REE (for all HR ≤ FLEX HR), the individual relationship between energy expenditure and HR at all time points with HR > FLEX HR, and an estimate of BMR during sleep. Thus, a 10% difference between estimated BMR and measured RMR would only affect the smallest component (i.e. EE during sleep) in the calculation of TEE. In the present study, the energy expenditure during sleep was on average 4.1 $MJ \cdot d^{-1}$ (24%) of TEE calculated from the FLEX HR method. Even if this value were increased by 10% (from measured RMR), this would only increase the calculated TEE by approximately 2%, which would not affect the agreement between the methods in **Study IV**.

Another methodological issue related to the FLEX HR method is whether the FLEX HR definition is dependent of the fitness level on the subjects. That is, in aerobically well-trained subjects, a 'low' FLEX HR may be appropriate, whereas in unfit (e.g. obese) subjects a 'high' FLEX HR (i.e. FLEX HR +10) may be more suitable. This was indicated by a study of overweight women, from which it was concluded that FLEX HR+10 was superior to FLEX HR0 (i.e. FLEX HR 2 in the present study) in estimatinon of TEE (Fogelholm *et al*, 1998). However, this issue needs to be further addressed in future studies before general recommendations on how to define FLEX HR in various groups can be made.

In contrast to the results of **Study IV**, the data from **Study V** indicated that the output from the CSA accelerometer, that is the total volume of physical activity, was affected by the different training conditions. This suggests that the accelerometer method should be used with caution in specific groups.

However, for most groups of subjects it can be assumed that a large proportion of daily life consists of sedentary and walking activities, and considering the accuracy of the CSA accelerometer in discriminating between exercise intensities during walking and jogging, the method seems to be a promising tool for assessment of physical activity in relatively large groups of free-living subjects. Data from our group suggest that activity counts from the CSA accelerometer is a useful measure of the total amount of physical activity in free-living 9-year-old children (Ekelund *et al*, 2001b).

In contrast, Leenders *et al* (2001) concluded that AEE was significantly underestimated by the CSA accelerometer as compared to AEE measured by the DLW method. However, the calculation of AEE from activity counts in the study by Leenders *et al* (2001) was based on a laboratory-derived energy expenditure prediction equation (Freedson *et al*, 1998), and therefore represented more an evaluation of the energy expenditure prediction equation than of the accelerometer *per se*. It is unlikely that a laboratory-derived equation for the relationship between activity counts and energy expenditure will reflect the relationship during free-living situations. It therefore, seems more appropriate to develop TEE and AEE prediction equations based on activity counts, anthropometric variables and RMR in relation to TEE measured simultaneously by the DLW method in free-living subjects.

Another important issue related to the practical use of the CSA accelerometer is the placement of the monitor. In **Study V** a low back placement was adopted. It has been suggested that the output from the accelerometer is affected by the site of placement during walking on a treadmill (Welk *et al*, 2000). However, in a direct comparison between two different placements (low back and right hip) during four days of measurement in free-living children, no significant difference was found between monitor placements, suggesting that the total amount of physical activity is not affected by the placement of the monitor (Nilsson *et al*, 2002).

A more controversial issue relates to the definition of intensity thresholds, or cut-off points, when assessing physical activity by means of the CSA accelerometer. A number of different cut-off points have been suggested and there is currently no consensus on how to define these intensity thresholds, which complicates comparisons between studies.

The cut-off values differ significantly between different studies as a result of the use of different calibration procedures. Calculated cut-off points for moderate, vigorous and very vigorous intensities of physical activity during treadmill walking and running (Freedson *et al*, 1998) have been found to be significantly different from those calculated for a variety of activities, including overground walking and different recreational and household activities of moderate intensity (Hendelman *et al*, 2000). The reported cut-off values for moderate physical activity have varied by a factor of 10, from 190 counts$\cdot$min^{-1} (Hendelman *et al*, 2000) when calculated for a combination of activities to 1952 counts$\cdot$min^{-1} for treadmill walking and running (Freedson *et al*, 1998). Thus, the calculated time spent at a specific intensity level as based on the CSA accelerometer depends on the cut-off points applied. Even if multiple types of activities are included when cut-off points are established, it is not known whether this will improve the accuracy of the estimated time spent at different intensity levels when assessing physical activity in free-living subjects.

Furthermore, in a recent study aimed to evaluate age- and gender-dependent differences in physical activity in 6-to-18-year-old children and adolescents (Trost *et al*, 2002), cut-off points for different intensity levels were calculated from a prediction equation including activity counts and age which indicated that age was a significant predictor of energy expenditure when estimated from activity counts. Age together with activity counts may be a significant predictor of energy expenditure (METs) in young people, although the effect of age may be mediated through an effect of stride frequency, stride length and movement economy while walking and running on the treadmill. In addition, the use of an adult MET definition in the study by Trost *et al* (2002) may influence on the relationship between activity counts and energy expenditure. This issue needs to be examined in future studies.

Before optimal cut-off points that are known to reflect normal daily life have been established, the main application of activity monitors may be in the assessment of the total amount of physical activity.

5.4 FUTURE DIRECTIONS

Despite considerable advancement in the development of methods for physical activity assessment during the last one to two decades, there is today no single such method that is able to assess all different dimensions and aspects of physical activity simultaneously. Consequently, there is still a lack of knowledge about the amount and patterns of physical activity in young people. The existing methods need to be developed even further and new assessment techniques need to be introduced.

Analyses of the metabolic costs of a variety of frequently performed everyday physical activities as well as during different forms of exercise may strengthen the accuracy of self-report methods. The validity and usefulness of expressing HR in relation to resting HR when defining intensity thresholds from heart rate monitoring in young people needs to be evaluated. The effect of the choice of definitions of FLEX HR for different groups of subjects when estimating TEE from the FLEX HR method is another issue for future research. Determination of optimal thresholds for defining intensity levels by means of the CSA accelerometer seems to be a high priority. Finally, a consensus on how to define intensity thresholds, and how to clean and analyse data from heart rate monitoring and accelerometry studies would facilitate comparisons between studies.

A further development of physical activity assessment in young people includes the use of combinations of different assessment techniques. In this way, specific issues regarding the relationship between physical activity and health in young people may be solved. For example, by combining the DLW method and minute-by-minute accelerometry, the first hard evidence of lower levels of physical activity in obese adolescents as compared to a normal-weight control group, despite the absence of a difference in energy expenditure estimates, was provided (Ekelund *et al*, 2002). Other developments of physical activity assessment techniques include the global positioning system (GPS) (Schutz and Chambaz, 1997; Schutz and Herren, 2000) and the use of multi-sensor micro-processors (IDEEA. www.minusun.com). Preliminary results from an evaluation of the latter device indicate that this system is able to detect, the intensity, frequency and duration of physical activity but also the types of activities performed (Zhang *et al*, 2001). If these preliminary data hold true, this device will have the potential to increase our understanding of the type, the pattern and energy expenditure associated with physical activity, as well as the strengths and limitations of other assessment techniques.

6 CONCLUSIONS

- The activity diary is a valid method for assessing total energy expenditure and its derivatives and time spent at physical activity of moderate and vigorous intensity on a group level in adolescent subjects, as compared to data obtained by the FLEX HR method.

- The use of absolute heart rates for defining intensity thresholds when assessing physical activity by heart rate monitoring in adolescents detracts from the validity of the interpretation of the data, mainly due the influence of aerobic fitness on the heart rate – oxygen uptake relationship.

- Adolescent boys and girls accumulate on average, more than one hour per day of physical activity at an intensity suggested to be beneficial for health. On an individual level, approximately 30% of the adolescents did not achieve the recommended amount of physical activity.

- Total energy expenditure estimated by the FLEX HR method is not influenced by the definition of FLEX HR or by the type of training regimen as compared to total energy expenditure measured by the doubly labelled water method in young athletes.

- The relationship between the total amount of physical activity assessed by the CSA accelerometer and total energy expenditure and its derivatives seems to be influenced by the type of training regimen in young athletes.

7 ACKNOWLEDGEMENTS

The studies included in this thesis were carried out at the Unit of Preventive Nutrition, Department of Biosciences, and the Department of Medical Nutrition, Karolinska Institutet in collaboration with the Department of Physical Education and Health, Örebro University.

I would like to express my sincere gratitude to all those friends and colleagues who encouraged me and helped me in the accomplishment of this work. During the years of these studies, many wonderful people have supported me. I cannot mention you all by name, but you are all just as much appreciated as those listed below.

First, I want to acknowledge a debt of gratitude to my tutor **Michael Sjöström** for your thoroughness and constructive criticism and guidance in the "academic world" and for always believing in what I have done and to **Agneta Yngve,** co-tutor and co-author for your generous support and for all the work you have done.

I would like to thank professor **Jan-Åke Gustavsson** for giving me the opportunity to become a graduate student at the Department of Medical Nutrition and for your generous support to the Unit of Preventive Nutrition.

I wish to express my thanks to my co-authors and friends:
Eric Poortvliet, for always being generous in assisting with all the 'nitty-gritty' things, for sharing your knowledge in nutrition epidemiology and body composition assessment and for our great times during the 'assessment courses'; **Anita Hurtig-Wennlöv**, for your support and for sharing your deep knowledge in clinical physiology; and **Andreas Nilsson**, for all your co-operation - I think you have done everything, including being a babysitter.
Good luck to all of you.

My grateful thanks are due to:

Associate professor **Olle Carlsson**, for your invaluable statistical advice and help with all the data analyses. I have learned not only some statistics but also everything ranging from historical nautical charts to the best buys on the stock exchange (Array printers?).

Professor **Klaas Westerterp**, for sharing your deep knowledge in energy metabolism, for critically reviewing my manuscripts and for your generous hospitality during my visit in Maastricht.

Senior lecturer **Rune Hedman**, for introducing me to the field of exercise physiology and for your excellent support during many of the measurements in the laboratory.

Anders Holmberg, for sharing your knowledge in statistics and for sharing a beer or two with me (we did it at least once).

Jukka Ala-Louko (the coach), for your generous support and hospitality when carrying out the measurements in Eskilstuna.

The skaters (Andreas, Daniel, Erik, Lasse, Magnus, Mattias, Nicklas, Patrik), and **the 157 boys and girls from Örebro and their parents**; without your kind participation there would not have been any thesis to write.

Past and present co-workers at PrevNut (Bettina, Christy, Elisabeth, Jeanette, Johan, Kamilla, Kåre, Ludde, Magnus, Maria, Per, Malin, 3 x Åsa), for your generous support during all my times there, and
Rikard Joelsson and Tony Waldemarson, for valuable computer assistance.

The staff at the Department of Clinical Physiology, Örebro University Hospital (Gunilla, Birgitta, Danne), for your highly competent helps with many of the laboratory measurements.

Jan Åman and Stefan Särnblad, for sharing your knowledge in the field of paediatric science.

Maud Marsden, for your high-class help with the language in this thesis.

All research colleagues and friends, including **the European Youth Heart Study group (EYHS), the International Consensus Group for the Development of an International Physical Activity Questionnaire (IPAQ) and the PRO-RE-COR study group in Linköping**; in my co-operation with all of you, I have learnt more than I can tell.

All colleagues and friends at the Department of Physical Education and Health - I hope to see you more frequently during the coffee breaks in the future, and
The students at the Department of Physical Education and Health, for always keeping me alert with all your questions during classes.

Turpojkarna (Anders, Erik, Gunnar, Håkan, Kalle, Ulrik), for bringing me out of the office and away from my laptop, for planning conferences in the sauna and for all the "outdoor expeditions".

My wife and life companion, **Eva** - I will always owe you a dept of gratitude (now you may know finally what this thesis is all about?),
Rasmus and Emil, my sons and sources for joy, for providing the greatest meaning to my life, and
last but definitely not least, my father, **John**; - you have always supported me through life. You are the most generous person I know, and I wish I had at least half of your generosity.

The studies included in this thesis were financially supported by grants from the Stockholm County Council, Karolinska Institutet, the Örebro University, the Örebro County Council, the Swedish National Centre for Research in Sports, and the Sweducation Foundation.

8 REFERENCES

1. Ainsworth B, Haskell W, Leon A, Jacobs D, Montoye H, Sallis J, Paffenbarger Jr R (1993) Compendium of physical activities: Classification of energy costs of human physical activities. *Med Sci Sports Exerc*. 25:71-802
2. Ainsworth B, Haskell W, Whitt M, Irwin M, Swartz A, Strath S, O'Brien W, Bassett Jr. D, Schmitz K, Emplaincourt P, Jacobs Jr. D, Leon A (2000) Compendium of physical activities: an update of activity codes and MET intensities. *Med Sci Sports Exerc*. 32: S498-S516
3. Ainsworth B, Montoye H, Leon A (1994) Methods of assessing physical activity during leisure and work. In Bouchard C, Shepard R, Stephens T (Eds.) *Physical activity, fitness and health: International proceedings and consensus statement*. Human Kinetics, Champaigne, USA, pp. 146-159
4. Al-Hazzaa H and Sulaiman M (1993) Maximal oxygen uptake and daily physical activity in 7- to 12-year –old boys. *Ped Exerc Sci*. 5:357-366
5. Allison D, Paultre F, Goran M, Poehlman E, Heymsfield S (1995) Statistical considerations regarding the use of ratios to adjust data. *Int J Obes*. 19:644-652
6. Almeida J and Fox K (1998) Preliminary evidence for an activity-fatness relationship in Portuguese adolescents. *J Sports Sci*. 16:31-32
7. Alpert B and Wilmore J (1994) Physical activity and blood pressure in adolescents. *Ped Exerc Sci*. 6:361-380
8. Ambler C, Eliakim A, Brasel J, Lee WN, Burke G, Cooper D (1998) Fitness and the effect of exercise training on the dietary intake of healthy adolescents. *Int J Obes*. 22:354-362
9. American College of Sports Medicine (1995) *ACSM's guidelines for exercise testing and prescription*, 5th edition, Williams and Wilkins, Baltimore, USA, pp.153-176
10. Armstrong N, Balding J, Gentle P, Kriby B (1990a) Patterns of physical activity among 11 to 16 year old British children. *Br Med J*. 301:203-205
11. Armstrong N, Balding J, Gentle P, Williams J, Kriby B (1990b) Peak oxygen uptake and physical activity in 11 to 16 year old. *Ped Exerc Sci*. 2:349-358
12. Armstrong N, Bray S (1991) Physical activity patterns defined by continuous heart rate monitoring. *Arch Disease Child*. 66:245-247
13. Armstrong N and Simons-Morton B (1994) Physical activity and blood lipids in adolescents. *Ped Exerc Sci*. 6:381-405
14. Armstrong N and Van Mechelen W (1998) Are young people fit and active? In Biddle S, Sallis J and Cavill N (Eds.) *Young and active? Young people and health-enhancing physical activity – evidence and implications*. Health Education Authority, London, England, pp.69-97
15. Atomi Y, Iwaoka K, Hatta H, Miyashita M, Yamamoto Y (1986) Daily physical activity levels in preadolescent boys related to VO2max and lactate thresholds. *Eur J Appl Physiol*. 55:156-161
16. Bailey R, Olson J, Pepper S, Porszasz J, Barstow T, Cooper D (1995) The level and tempo of children's physical activities: an observational study. *Med Sci Sports Exerc*. 27: 1033-1041

17. Baranowski T (1988) Validity and reliability of self-report of physical activity: An information processing perspective. *Res Q Exerc Sport*. 59:314-327
18. Belko A, Barbieri T, Wong E (1986) Effect of energy and protein intake and exercise intensity on the thermic effect of food. *Am J Clin Nutr*, 83:863-869
19. Benefice E, Cames C (1999) Physical activity patterns of rural Senegalese adolescent girls during the dry and rainy seasons measured by movement registration and direct observation methods. *Eur J Clin Nutr*. 53:636-43
20. Benefice E, Garnier D, Ndiaye G (2001a) High levels of habitual physical activity in west African adolescent girls and relationship to maturation, growth, and nutritional status: results from a 3-year prospective study. *Am J Human Biol* 13:808-820
21. Benefice E, Garnier D, Ndiaye G (2001b) Assessment of physical activity among rural Senegalese adolescent girls: influence of age, sexual maturation, and body composition. *J Adolesc Health* 28:319-327
22. Bhattacharya A, McCutcheon E, Shvartz E, Greenleaf J (1980) Body acceleration distribution and O2 uptake in humans during running and jumping. *J Appl Physiol* 49:881-887
23. Black A, Coward W, Cole T, Prentice A (1996) Human energy expenditure in affluent societies: an analysis of 574 doubly labelled water measurements. *Euro J Clin Nutr*. 50:72-92
24. Black A, Prentice A, Coward W (1986) Use of food quotients to predict respiratory quotients for the doubly-labelled water method of measuring energy expenditure. *Hum. Nutr. Clin. Nutr*. 40:381-391.
25. Blair S (1992) Are American children and youth fit? The need for better data. *Res Q Exerc Sport*. 63:120-123
26. Blair S, Clark D, Cureton K, Powell K (1989) Exercise and fitness in childhood: implications for a lifetime of health. In Gisolfi C and Lamb D (Eds) *Perspectives in exercise science and sports medicine, Vol.2: Youth, exercise and sport*. Mc Graw-Hill, New York. pp.401-430
27. Bland J and Altman D (1986) Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* 1(8476):307-310
28. Boreham C and Riddoch C (2001) The physical activity, fitness and health of children. *J Sports Sci*. 19:915-929
29. Bouchard C, Tremblay A, Leblanc C, Lortie G, Savard R, Thériault G (1983) A method to assess energy expenditure in children and adults. *Am J Clin Nutr*. 37:461-467
30. Boulay M, Serresse O, Almeras N, Tremblay A (1993) Energy expenditure measurements in male cross-country skiers: comparison of two field methods. *Med Sci Exerc Sport*. 26:248-253
31. Bouten C, Westerterp K, Verduin M, Janssen J (1994) Assessment of energy expenditure for physical activity using a triaxial accelerometer. *Med Sci Sports Exerc*. 26:1516-1523
32. Bouten C, Verboeket-van de Venne W, Westerterp K, Verduin M, Janssen J (1996) Daily physical activity assessment: comparison between movement registration and doubly labeled water. *J Appl Physiol*. 81:1019-1026
33. Bratteby LE, Sandhagen B, Fan H, Samuelson G (1997) A 7-day activity diary for assessment of daily energy expenditure validated by the doubly labelled water method in adolescents. *Eur J Clin Nutr*. 51:585-591

34. Bratteby LE, Sandhagen B, Fan H, Enghardt H, Samuelson G (1998) Total energy expenditure and physical activity as assessed by the doubly labeled water method in Swedish adolescents in whom energy intake was underestimated by 7-d diet records. *Am J Clin Nutr*. 67:905-911
35. Bruce R, Kusumi F, Hosmer D (1973) Maximal oxygen intake and nomographic assessment of functional aerobic impairment in cardiovascular disease. *Am Heart J*. 85:546-562
36. Buchowski M, Townsend K, Williams R, Chen K (2002) Patterns of energy expenditure of free-living physical activity in adolescents with sickle-cell anemia. *J Pediatr*. 140:86-92
37. Cale L and Almond L (1992) Children's activity levels: a review of studies conducted on British children. *Phys Edu Review*. 15:111-118
38. Carpenter W, Poehlman E, O´Connell M, Goran M (1995) Influence of body composition and resting metabolic rate on variation in total energy expenditure: a meta-analysis. *Am J Clin Nutr*. 61:4-10
39. Caspersen C, Pereira M, Curran K (2000) Changes in physical activity patterns in the United States, by sex and cross-sectional age. *Med Sci Sports Exerc*. 32:1601-1609
40. Caspersen C, Powell K, Christenson G (1985) Physical activity, Exercise, and Physical Fitness: Definitions and Distinctions for Health-Related Research. *Pub Health Rep*. 100:126-131
41. Ceesay S, Prentice A, Day K, Murgatroyd P, Goldberg G, Scott W, Spurr G (1989) The use of heart rate monitoring in the estimation of energy expenditure: a validation study using indirect whole-body calorimetry. *Br J Nutr* 61:175-186
42. Chinn S, Hughes J, Rona R (1998) Trends in growth and obesity in ethnic groups in Britain, *Arch Dis Child*. 78:513-517
43. Christensen C, Frey H, Foenstelien E, Aadland E, Refsum H (1983) A critical evaluation of energy expenditure estimates based on individual O_2 consumption/heart rate curves and average daily heart rate. *Am. J. Clin. Nutr*. 37:468-472
44. Coe D and Pivarnik J (2001) Validation of the CSA accelerometer in adolescent boys during basketball practice. *Ped Exerc Sic*. 13:373-379
45. Corbin C, Pangrazzi R, Welk G (1994) Toward an understanding of appropriate physical activity levels for youth. President´s Council of Physical Activity and Sport. *Physical Activity and Fitness Research Digest*. 1:1-8
46. Crocker P, Bailey D, Faulkner R, Kowalski K, McGrath R (1997) Measuring general levels of physical activity: Preliminary evidence for the physical activity questionnaire for older children. *Med Sci Sports Exerc*. 29: 1344-1349
47. Cummings S, Nevitt M, Browner W, Stone K, Fox K, Ensrud K, Cauley J, Black D, Vogt T (1995) Risk factors for hip fractures in white women. *N Engl J Med*. 332:767-773
48. Cunningham D, Stapleton J, MacDonald I, Paterson D (1981) Daily energy expenditure of young boys as related to maximal aerobic power. *Can J Appl Sports Sci*. 6:207-211
49. Dale D, Corbin C, Dale K (2000) Restricting opportunities to be active during school time: do children compensate by increasing physical activity levels after school? *Res Q Exerc Sport* 71:240-248

50. Davidson L, McNeill G, Haggarty P, Smith J, Franklin M (1997) Free-living energy expenditure of adult men assessed by continuous heart-rate monitoring and doubly-labelled water. *Br J Nutr.* 78:695-708
51. DeWeir J (1949) New methods for calculating metabolic rate with special reference to protein metabolism. *J Physiol.* 109:1-9
52. Dionne I, Alméras N, Bouchard C, Tremblay A (2000) The association between vigorous physical activities and fat deposition in male adolescents. *Med Sci Sports Exerc.* 32:392-395
53. Dragent-Molina P, Favier F, Grandjean H, Baudoin C, Schott A, Hausherr E, Meunier P, Bréart G (1996) Fall-related factors and risk for hip fractures: the EPIDOS prospective study. *Lancet.* 348:145-149
54. DuRant R, Baranowski T, Davis H, Thompson W, Puhl J, Greaves K, Rhodes T (1992) Reliability and variability of heart rate monitoring in 3-, 4-, or 5-yr-old children. *Med Sci Sports Exerc.* 24:265-271
55. DuRant R, Baranowski T, Davis H, Rhodes T, O Thompson W, Greaves K, Puhl J (1993a) Reliability and variability of indicators of heart-rate monitoring in children. *Med Sci Sports Exerc.* 25:389-395
56. DuRant R, Baranowski T, Rhodes T, Gutin B, Thompson W, Carroll R, Puhl J, Greaves K (1993b) Association among serum lipid and lipoprotein concentrations and physical activity, physical fitness, and body composition in young children. *J Pediatr.* 123:185-192
57. Durnin J (1992) Physical activity levels past and present. In Norgan N (Ed) *Physical activity and health.* Cambridge University Press, Cambridge, England, pp. 20-27
58. Ebine N, Feng JY, Homma M, Saitho S, Jones P (2000) Total energy expenditure of elite synchronized swimmers measured by the doubly labelled water method. *Eur J Appl Physiol.* 83:1-6
59. Ekelund U, Poortvliet E, Nilsson A, Yngve A, Holmberg A, Sjöström M (2001a) Physical activity in relation to aerobic fitness and body fat in 14- to 15-year-old boys and girls. *Eur J Appl Physiol.* 85:195-201
60. Ekelund U, Sjöström M, Yngve A, Poortvliet E, Nilsson A, Froberg K, Wedderkopp N, Westerterp K (2001b) Physical activity assessed by activity monitor and doubly labeled water in children. *Med Sci Sports Exerc.* 33:275-281
61. Ekelund U, Yngve A, Sjöström M (1997) Do adolescents achieve appropriate levels of physical activity? In Armstrong N, Kirby B, Welsman J (Eds.) *Children and Exercise XIX*, E & FN Spon, London, England, pp.169-175
62. Ekelund U, Åman J, Yngve A, Renman C, Westerterp K, Sjöström M (2002) Physical activity but not energy expenditure is reduced in obese adolescents: a case – control study. *Am J Clin Nutr.* (in press)
63. Epstein L, McGowan C, Wodall K (1984) A behavioural observation system for free play activity in young overweight female children. *Res Q Exerc Sport.* 55:180-183
64. Epstein L, Paluch R, Kalakanis L, Goldfield G, Cerny F, Roemmich (2001) How much activity do youth get? A quantitative review of heart-rate measured activity. *Pediatrics.* 108(3) http://www.pediatrics.org/cgi/content/full/3/e44

65. Epstein L, Valoski A, Vara L, McCurley J, Wisniewski L, Kalarchian M, Kelin K, Shrager L (1995) Effects of decreasing sedentary behaviour and increasing activity on weight change in obese children. *Health Psychology*. 14:109-115
66. Eston R, Rowlands A, Ingledew D (1998) Validity of heart rate, pedometry, and accelerometry for predicting the energy cost of children's activities. *J Appl Physiol* 84:362-371
67. FAO/WHO/UNU Expert consultation (1985) *Energy and protein requirements*. WHO technical report series 724. World Health Organisation, Geneva, Switzerland.
68. Fairweather S, Reilly J, Grant S, Whittaker A, Paton J (1999) Using the Computer Science and Applications (CSA) activity monitor in preschool children. *Ped Exerc Sci* 11:413-420
69. Falgairette G, Gavarry O, Bernard T, Hebbelinck M (1996) Evaluation of habitual physical activity from a week's heart rate monitoring in French school children. *Eur J Appl Physiol*. 74:153-161
70. Ferguson M, Gutin B, Owens S, Barbeau P, Tracy R, Litaker M (1999) Effects of physical training and its cessation on the hemostatic system of obese children. *Am J Clin Nutr* 69:1130-1134
71. Finn K and Specker B (2000) Comparison of Actiwatch activity monitor and Children's Activity Rating Scale in children. *Med Sci Sports Exerc*. 32:1794-1797
72. Fogelholm M, Hiilloskorpi H, Laukkanen R, Oja P, Van Marken Lichtenbelt W, Westerterp K (1998) Assessment of energy expenditure in overweight women. *Med Sci Sports Exerc*. 30:1191-1197
73. Fox K and Riddoch C (2000) Charting the physical activity patterns of contemporary children and adolescents. *Proc Nutr Society*. 59:497-504
74. Freedson P (1991) Electronic motion sensors and heart rate as measures of physical activity in children. *J School Health*. 61:220-223
75. Freedson P, Melanson E, Sirard J (1998) Calibration of the Computer Science and Applications, Inc. accelerometer. *Med Sci Sports Exerc* 30:777-781
76. Garcia A, Pender N, Antonakos C, Ronis D (1998) Changes in physical activity beliefs and behaviors of boys and girls across the transition to junior high school. *J Adolescent Health*. 22:394-402
77. Gavarry O, Bernard T, Giacomoni M, Seymat M, Euzet JP, Falgairette G (1998) Continuous heart rate monitoring over 1 week in teenagers aged 11-16 years. *Eur J Appl Physiol* 77:125-132
78. Gilbey H, and Gilbey M (1995) The physical activity of Singapore primary school children as estimated by heart rate monitoring. *Ped Exerc Sci*. 7:26-35
79. Gilliam T, Freedson P, Geenen D, Shahraray B (1981) Physical activity patterns determined by heart rate monitoring in 6-7 year old children. *Med Sci Sports Exerc*. 13:65-67
80. Giovannucci E, Ascherio A, Rimm E, Colditz G, Stampfer M, Willet W (1995) Physical activity, obesity, and risk for colon cancer and adenoma in men. *Ann Int Med*. 122:327-334
81. Goran M, Nagy T, Gower B, Mazariegos M, Solomons N, Hood V, Johnson R (1998) Influence of sex, seasonality, ethnicity, and geographic location on the components of total energy expenditure in young children: implications for energy requirements. *Am J Clin Nutr*. 68:675-82

82. Gretebeck R and Montoye H (1992) Variability of some objective measures of physical activity. *Med Sci Sports Exerc* 24: 1167-1172
83. Grund A, Dilba B, Forberger K, Krause H, Siewers M, Rieckert H, Muller M (2000) Relationships between physical activity, physical fitness, muscle strength and nutritional state in 5- to 11-year-old children. *Eur J Appl Physiol* 82:425-438
84. Gutin B, Owens S, Okuyama T, Riggs S, Ferguson M, Litaker M (1999a) Effect of physical training and its cessation on percent fat and bone density of children with obesity. *Obes Res*. 7:208-214
85. Gutin B, Ramsey L, Barbeau P, Cannady W, Ferguson M, Litaker M, Owens S (1999b) Plasma leptin concentrations in obese children: changes during 4-mo periods with and without physical training. *Am J Clin Nutr* 69:388-394
86. Harro M (1997) Validation of a questionnaire to assess physical activity of children aged 4-8 years. *Res Q Exerc Sport*. 68:259-268
87. Hausswirth C, Bigard A, Le Chevalier J (1997) The Cosmed K4 telemetry system as an accurate device for oxygen uptake measurements during exercise, *Int J Sports Med*. 18:439-445
88. Heini A, Minghelli G, Diaz E, Prentice A, Schutz Y (1996) Free-living energy expenditure assessed by two different methods in rural Gambian men. *Eur J Clin Nutr* 50:284-289
89. Heini A, Schutz Y, Diaz E, Prentice A, Whitehead R, Jequier E (1991) Free-living energy expenditure measured by two independent techniques in pregnant and nonpregnant Gambian women. *Am J Physiol* 261:E9-17
90. Health Education Authority (1998) *Young and active? Young people and health-enhancing physical activity – evidence and implications*. Health Education Authority. London, England, pp.3-16
91. Hendelman D, Miller K, Baggett C, Debold E, Freedson P (2000) Validity of accelerometry for the assessment of moderate intensity physical activity in the field. *Med Sci Sports Exerc* 32(Suppl):S442-S449
92. Henry C, Webster-Gandy J, Elia M (1999) Physical activity levels in a sample of Oxford school children aged 10-13 years. *Eur J Clin Nutr*. 53:840-843
93. Howley E (2001) Type of activity: resistance, aerobic and leisure versus occupational physical activity. *Med Sci Sports Exerc*. 33:S364-S369
94. Hulens M, Beunen G, Claessens A, Lefevre J, Thomis M, Philippaerts R, Borms J, Vrijens J, Lysens R, Vansant G (2001) Trends in BMI among Belgian children, adolescents and adults from 1969 to 1996. *Int J Obes*. 25:395-399
95. Ingram D (2000) Age-related decline in physical activity: generalization to nonhumans. *Med Sci Sports Exerc*. 32:1623-1629
96. Ismail A, Barany J, Smith C (1971) Relationships between mechanical forces and physiological cost during gait in adult man. In Cooper M (Ed.) *Biomechanics*, The Athlete institute, Chicago, USA
97. Janz K, Burns T, Torner J, Levy S, Paulos R, Willing M, Warren J (2001) Physical activity and bone measures in young children: the Iowa bone development study. *Pediatrics* 107:1387-1393
98. Janz K, Golden J, Hansen J, Mahoney L (1992) Heart rate monitoring of physical activity in children and adolescents: the Muscatine Study. *Pediatrics* 89:256-261

99. Janz K, Witt J, Mahoney L (1995) The stability of children's physical activity as measured by accelerometry and self-report. *Med Sci Sports Exerc*. 27:1326-1332
100. Johnson R, Russ J, Goran M (1998) Physical activity related energy expenditure in children by doubly labelled water as compared with the Caltrac accelerometer. *Int J Obes*. 22:1046-1052
101. Kannel W and Sorlie P (1979) Some health benefits of physical activity. *Arch Intern Med*. 139:857-861
102. Karvonen M, Kentala E, Mustala O (1957) The effects of training on heart rate: a longitudinal study. *Ann Med Exp Biol Fenn*. 35:307-315
103. Katzmarzyk P, Malina R, Song T, Bouchard C (1998) *Med Sci Sports Exerc*. 30:709-714
104. Kelly K (2000) Patterns of physical activity in 9-10 year-old American children as measured by heart rate monitoring. *Ped Exerc Sci*. 12:101-110
105. Kimm S, Glynn N, Kriska A, Fitzgerald S, Aaron D, Similo S, McMahon R, Barton B (2000) Longitudinal changes in physical activity in a biracial cohort during adolescence. *Med Sci Sports Exerc*. 32:1445-1454
106. Kohl H III, Fulton J, Caspersen C (2000) Assessment of physical activity: A review and synthesis. *Prev Med*. 31:S54-S76
107. Kreipe R (1992) Normal adolescent somatic growth and development. In McArney E, Kreipe R, Porr D, Comerici G (Eds) *Textbook of adolescent medicine*. W & Saunders, Philadelphia, USA, pp.45-67
108. Kriemler S, Hebestreit H, Mikami S, Bar-Or T, Ayub B, Bar-Or O (1999) Impact of a single exercise bout on energy expenditure and spontaneous physical activity of obese boys. *Pediatr Res* 46:40-44
109. Kriska A and Caspersen C (1997) Introduction to a collection of physical activity questionnaires. *Med Sci Sports Exerc*. 29: S5-S9
110. Lamonte M and Ainsworth B (2001) Quantifying energy expenditure and physical activity in the context of dose response. *Med Sci Sports Exerc*. 33(Suppl):S370-378
111. Larsson C, Westerterp K, Johansson G (2002) Validity of reported energy expenditure and energy and protein intakes in Swedish adolescent vegans and omnivores. *Am J Clin Nutr*. 75:268-274
112. Lee IM, and Paffenbarger Jr R (1998) Physical activity and stroke incidence. The Harvard Alumni Health Study. *Stroke*. 29:2049-2054
113. Leenders N, W Sherman, H Nagaraja (2000) Comparisons of four methods of estimating physical activity in adult women. *Med Sci Sports Exerc*. 32:1320-1326
114. Leenders N, Sherman W, Nagaraja H, Kien C (2001) Evaluation of methods to assess physical activity in free-living conditions. *Med Sci Sports Exerc* 33:1233-1240
115. Leonard W (2001) Assessing the influence of physical activity on health and fitness. *Am J Human Biol*. 13:159-161
116. Li R, Deurenberg P, Hautwast J (1995) A critical evaluation of heart rate monitoring to assess energy expenditure in individuals. *Am. J. Clin. Nutr.* 61:1146-1152
117. Lifson N, Gordon G, McClintock R (1955) Measurement of total carbon dioxide production by means of $D_2{}^{18}O$. *J Appl Physiol* 7:704-710

118. Livingstone B (1994) Energy expenditure and physical activity in relation to fitness in children. *Proc Nutr Soc*. 53:207-221
119. Livingstone B, Coward W, Prentice A, Davies P, Strain J, McKenna P, Mahoney C, White J, Stewart C, Kerr M (1992) Daily energy expenditure in free-living children: comparison of heart-rate monitoring with the doubly labeled water ($^2H_2{}^{18}O$) method. *Am J Clin Nutr* 56:343-352
120. Livingstone B, Prentice A, Coward W, Ceesay S, Strain J, McKenna P, Nevin G, Barker M, Hickey R (1990) Simultaneous measurement of free-living energy expenditure by the doubly labeled water method and heart-rate monitoring. *Am J Clin Nutr* 52:59-65
121. Livingstone B, Robson P, Totton M (2000) Energy expenditure by heart rate in children: an evaluation of calibration techniques. *Med. Sci. Sports Exerc*. 32:1513-1519
122. Logan N, Reilley J, Grant S, Payton J (2000) Resting heart rate definition and its effect on apparent levels of physical activity in young children. *Med Sci Sports Exerc*. 32:162-166
123. Lohman T, Roche A, Martorell R (1991) *Anthropometric standardization reference manual*. Human Kinetics, Champaigne, USA
124. Louie L, Eston R, Rowlands A, Tong K, Ingledew D, Fu F (1999) Validity of heart rate, pedometry, and accelerometry for estimating the energy cost of activity in Hong Kong Chinese boys. *Ped Exerc Sci* 11: 229-239
125. Lovelady C, Meredith C, McCrory M, Nommsen L, Joseph L, Dewey K (1993) Energy expenditure in lactating women: a comparison of doubly-labelled water and heart-rate monitoring methods. *Am J Clin Nutr* 57:512-518
126. MacConnie S, Gilliam T, Geenen D Pels AE (1982) Daily physical activity patterns of prepubertal children involved in a vigorous exercise program. *Int J Sports Med*. 3:202-207
127. Maffeis C, Pinelli L, Zaffanello M, Schena F, Iacumin P, Schutz Y (1995) Daily energy expenditure in free-living conditions in obese and non-obese children: comparison of doubly labelled water ($^2H_2{}^{18}O$) method and heart-rate monitoring. *Int J Obes*. 19:671-677
128. Maffeis C, Zaffanello M, Schutz Y (1997) Relationship between physical inactivity and adiposity in prepubertal boys. *J Pediatr* 131:288-292
129. Maffeis C, Schutz Y, Zoccante L, Micciolo L, Pinelli L (1993) Meal-induced thermogenesis in lean and obese prepubertal children. *Am J Clin Nutr* 57: 481-485
130. Maffeis C, Zaffanello M, Pinelli L, Schutz Y (1996) Total energy expenditure and patterns of activity in 8-10-year-old obese and nonobese children. *J Pediatr Gastroenterol Nutr*. 23:256-261
131. Malina R and Bouchard C (1991) Growth, maturation and physical activity. Human Kinetics, Champaign, USA, pp. 371-390
132. Manson J, Rimm E, Stampfer M, Colditz G, Willett W, Krolewski A, Rosner B, Hennekens C, Speizer F (1991) Physical activity and incidence of non-insulin-dependent diabetes mellitus in women. *Lancet*. 338:774-778
133. Manson J, Nathan D, Krolewski A, Stampfer MJ, Willett W, Hennekens C (1992) A prospective study of exercise and incidence of diabetes among U.S. male physicians. *JAMA*. 268:63-67

134. Martinez M, Giovannucci E, Spiegelman D, Hunter D, Willet W, Colditz G (1997) Leisure-time physical activity, body size and colon cancer in women. Nurse's Health Study Research Group. *J Natl Cancer Inst*. 89:948-955
135. Mc Ardle W, Katch F, Katch V (2001) *Exercise Physiology*, 5th edition, Lippincott, Williams and Wilkins, Baltimore, USA, pp.187-200
136. McCloskey M, Redmond A, Pyper S, McCabe C, Westerterp K, Elborn J (2001) Total energy expenditure in stable patients with cystic fibrosis. *Clin Nutr*. 3:235-241
137. McCrory M, Molé P, Nommsen-Rivers L, Dewey K (1997) Between-day and within-day variability in the relation between heart rate and oxygen consumption: effect on the estimation of energy expenditure by heart rate monitoring. *Am J Clin Nutr*. 66:18-25
138. McKenzie T, Sallis J, Nader P, Patterson T, Elder J, Berry C, Rupp J, Atkins C, Buono M, Nelson J (1991) BEACHES: an observational system for assessing children's eating and physical activity behaviors and associated events. *Appl Behav Anal* 24:141-151
139. McManus A and Armstrong N (1995) Patterns of physical activity among primary schoolchildren. In Ring F (Ed.) *Children in sport*, Bath University press, Bath, England, pp. 17-23
140. Montoye H, Kemper H, Saris W, Washburn R (1996) *Measuring physical activity and energy expenditure*. Human Kinetics, Champaign, USA,
141. Murgatroyd P, Shetty P, Prentice A (1993) Techniques for the measurement of human energy expenditure: a practical guide. *Int J Obes*, 17:549-568
142. Nichols J, Morgan C, Chabot L, Sallis J, Calfas K (2000) Assessment of physical activity with the Computer Science and Applications, Inc. accelerometer: Laboratory versus field validation. *Res Quarterly Exerc Sports*. 71:36-43
143. Nilsson A. Ekelund U, Yngve A, Sjöström M (2002) Assessing physical activity among children with accelerometers using different time sampling intervals and placements. *Ped Exerc Sci*. 14:75-84
144. Ott A, Pate R, Trost S, Ward D, Saunders R (2000) The use of uniaxial and triaxial accelerometers to measure children's "free play" physical activity. *Ped Exerc Sci*. 12:360-370
145. Pace N and Rathbun E (1945) Studies on body composition. III. The body water and chemically combined nitrogen content in relation to fat content. *J Biol. Chem*. 158:685-691
146. Paffenbarger Jr R, Hyde R, Wing A (1978) Physical activity as an index of heart attack risk in college alumni. *Am J Epidemiol*. 108:161-175
147. Paffenbarger Jr R, Hyde R, Wing A, Hsieh C-C (1986) Physical activity, all-cause mortality, and longevity of college alumni. *New Engl J Med*. 314:605-613
148. Paffenbarger Jr R, Hyde R, Wing A, Steinmetz C (1984) A natural history of athleticism and cardiovascular health. *JAMA*. 252:491-495
149. Parizkova J (1996) *Nutrition, physical activity and health in early life*. CRC Press, Boca Raton, USA
150. Pate R (1993) Physical activity assessment in children and adolescents. *Crit Rev Food Sci Nutr*. 33:321-326

151. Pate R, Pratt M, Blair S *et al*. (1995) Physical activity and public health. A recommendation from the Centers for Disease Control and Prevention and the American College of Sports Medicine. *JAMA*. 273:402-407
152. Pate R (1998) Critique of existing guidelines for 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*. Health Education Authority, London, Great Britain, pp.162-176
153. Pate R, Baranowski T, Dowda M, Trost S (1996) Tracking of physical activity in young children. *Med Sci Sports Exerc*. 28:92-96
154. Pate R, Long B, Heath G (1994) Descriptive epidemiology of physical activity in adolescents. *Ped Exerc Sci*. 6:434-447
155. Prentice A (1999) Stable isotopes in nutritional sciences and the study of energy metabolism. *Scand J Nutr*. 43:56-62
156. Prentice A, Goldberg G, Murgatroyd P, Cole T (1996) Physical activity and obesity: problems in correcting expenditure for body size. *Int J Obes*. 20:688-691
157. Puhl J, Greaves K, Hoyt M, Baranowski T (1990) Children's activity rating scale (CARS): description and evaluation. *Res Q Exerc Sport*. 61:26-36
158. Racette S, Schoeller D, Kushner R (1995) Comparison of heart rate and physical activity recall with doubly labeled water in obese women. *Med Sci Sports Exerc*. 27:126-133
159. Rasmussen F, Johansson M, Hansen H (1998) Trends in overweight and obesity among 18-year-old males in Sweden between 1971 and 1995. *Acta Paediatr*. 88:431-437
160. Rennie K and Wareham N (1998) The validation of physical activity instruments for measuring energy expenditure: problems and pitfalls. *Public Health Nutr*.1:265-271
161. Riddoch C (1998) Relationships between physical activity and 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*. Health Education Authority, London, Great Britain, pp.17-48
162. Riddoch C, and Boreham C (1995) The health-related physical activity of children. *Sports Med*. 19:86-102
163. Riddoch C, Mahoney C, Murphy N, Boreham C, Cran G (1991) The physical activity patterns of Northern Irish schoolchildren ages 11 to 16 years. *Ped Exerc Sci*. 3:300-309
164. Rifas-Shiman S, Gillman M, Field A, Frazier L, Berkey C, Tomeo C, Colditz G (2001) Comparing physical activity questionnaires for youth. Seasonal vs annual format. *Am J Prev Med*. 20:282-285
165. Ritz P, Cole T, Couet C, Coward W (1996) Precision of DLW energy expenditure measurements: contribution of natural abundance variations. *Am J Physiol*. 270: E164-E169
166. Roemmich J, Clark P, Walter K, Patrie J, Weltman A, Rogol A (2000) Pubertal alterations in growth and body composition. V. Energy expenditure, adiposity, and fat distribution. *Am J Physiol Endocrinol Metab*. 279:E1426-1436
167. Romanella N, Wakat D, Loyd B, Kelly L (1991) Physical activity and attitudes in lean and obese children and their mothers. *Int J Obes* 15:407-414

168. Rowland T (1990) *Exercise and children's health*. Human Kinetics. Champaign, USA
169. Rowland T (1996) *Developmental exercise physiology*. Human Kinetics, Champaign, USA
170. Rowland T (2001) The role of physical activity and fitness in children in the prevention of adult cardiovascular disease. *Progress Pediatr Cardiol*. 12:199-203
171. Rowlands A, Eston R, Ingledew D (1997) Measurement of physical activity in children with particular reference to the use of heart rate and pedometry. *Sports Med*. 24:258-272
172. Rowlands A, Eston R, Ingledew D (1999) The relationship between activity level, aerobic fitness and body fat in 8-10 year old children. *J Appl Physiol*. 86:1428-1435
173. Sallis J (1991) Self-report measures of children's physical activity. *J School Health*. 61:215-219
174. Sallis J (1993) Epidemiology of physical activity and fitness in children and adolescents. *Crit Reviews Food Sci Nutr*. 33:403-408
175. Sallis J (2000) Age-related decline in physical activity: a synthesis of human and animal studies. *Med Sci Sports Exerc*. 32:1589-1600
176. Sallis J, Buono M, Roby J Micale F, Nelson J (1993a) Seven-day recall and other physical activity self-reports in children and adolescents. *Med Sci Sports Exerc*. 25:99-108
177. Sallis J, Condon S, Goggin K, Roby J, Kolody B, Alcaraz J (1993b) The development of self-administered physical activity surveys for 4th grade students. *Res Q Exerc Sport*. 64:25-33
178. Sallis J, Patrick K (1994) Physical activity guidelines for adolescents: Consensus statement. *Pediatr Exerc Sci*. 6:302-314
179. Sallis J, Strikmiller P, Harsha D, Feldman H, Ehlinger S, Stone E, Williston B, Woods S (1996) Validation of interviewer- and self-administered physical activity checklists for fifth grade students. *Med Sci Sports Exerc*. 28:840-851
180. Sallis J, and Owen N (1999) *Physical activity and behavioural medicine*, SAGE publications, Thousands Oaks, USA,
181. Sallis J and Saelens B (2000) Assessment of physical activity by self-report: Status, limitations, and future directions. *Res Q Exerc Sport*. 71:S1-S14
182. Sallo M, and Silla R (1997) Physical activity with moderate to vigorous intensity in pre-school and first grade children. *Ped Exerc Sci*. 9:44-54
183. Saris W (1986) Habitual physical activity in children: methodology and findings in health and disease. *Med Sci Sports Exerc*. 18:253-63
184. Saris W, Binkhorst R, Cramwinckel A, Van Waesberghe F, Van der Veen-Hezemans A (1980) The relationship between working performance, daily physical activity, fatness, blood lipids, and nutrition in schoolchildren. In Berg K and Eriksson B (Eds.) *Children and Exercise*. University Park press, Baltimore, USA, pp.166-174
185. Schoeller, D (1988) Measurement of energy expenditure in free-living humans by using doubly labeled water. *J Nutr*. 118:1278-89
186. Schoeller D and Jefford G (2002) Determinants of the energy costs of light activities: inferences for interpreting doubly labeled water data. *Int J Obes*. 26:97-101.

187. Schoeller D, Ravussin E, Schultz Y, Acheson K, Baertschi P, Jequier E (1986) Energy expenditure by doubly labelled water: validation in humans and proposed calculation. *Am J Physiol*. 250:R823-R830
188. Schofield W, Schofield C, James P (1985) Predicting basal metabolic rate. New standards and review of previous work. *Hum Nutr Clin Nutr*. 39C:S5-S41
189. Schutz Y and Chambaz A (1997) Could a satellite-based navigation system (GPS) be used to assess the physical activity of individuals on earth? *Eur J Clin Nutr*. 51:338-339
190. Schutz Y and Herren R (2000) Assessment of speed of human locomotion using a differential satellite global positioning system. *Med Sci Sports Exerc*. 32:642-646
191. Schutz Y, Weinsier R, Hunter G (2001) Assessment of free-living physical activity in humans: an overview of currently available and proposed new measures. *Obes Res*. 9:368-379
192. Seale J and Conway J (1999) Relationship between overnight energy expenditure and BMR measured in a room-sized calorimeter. *Eur J Clin Nutr*. 53:107-111
193. Seidell J, Verchuren W, Kromhout D (1995) Prevalence and trends of obesity in the Netherlands 1987-1991. *Int J Obes*. 19:924-927
194. Shetty P, Henry C, Black A, Prentice A (1996) Energy requirements of adults: an update on basal metabolic rates (BMRs) and physical activity levels (PALs). *Euro J Clin Nutr*. 50: S11-S23
195. Simons-Morton B, Taylor W, Huang I (1994) Validity of the physical activity interview and caltrac with pre-adolescent children *Res Q Exerc Sport*. 65:84-88
196. Sirard J, Melanson E, Li L, Freedson P (2000) Field evaluation of the Computer Science and Applications, Inc. physical activity monitor. *Med Sci Sports Exerc* 32:695-700
197. Sirard J and Pate R (2001) Physical activity assessment in children and adolescents. *Sports Med*. 31:439-454
198. Sjödin A, Andersson A, Högberg J, Westerterp K (1994) Energy balance in cross-country skiers: a study using doubly labelled water. *Med Sci Sports Exerc*. 24:720-724
199. Slaughter M, Lohman T, Boileau R, Horswill C. Stillman R, Van Loan M, Bemben D (1988) Skinfold equations for estimation of body fatness in children and youth. *Hum Biol*. 60:708-723
200. Sleap M and Tolfrey K (2001) Do 9- to 12 yr-old children meet existing recommendations for health? *Med Sci Sports Exerc*. 33:591-596
201. Speakman J (1997) *Doubly labelled water: theory and practise*, Chapman and Hall, London, Great Britain
202. Speakman J (1998) The history and theory of the doubly labeled water technique. *Am J Clin Nutr*. 68:S932-S938
203. Spurr G, Prentice A, Murgatroyd P, Goldberg G, Reina J, Christman N (1988) Energy expenditure from minute-by-minute heart-rate recording: comparison with indirect calorimetry. *Am J Clin Nutr*. 48:552-459
204. Spurr G and Reina J (1988) Patterns of daily energy expenditure in normal and marginally undernourished school-aged Colombian schoolchildren. *Eur J Clin Nutr*. 42:819-834

205. Spurr G and Reina J (1990) Daily pattern of %VO_{2max} and heart rates in normal and undernourished school children. *Med Sci Exerc Sport*. 22:643-653
206. Stratton G (1996) Childrens heart rates during physical education lessons: a review. *Ped Exerc Sci*. 8:215-233
207. Swain D, Abernathy K, Smith C, Lee S, Bunn S (1994) Target heart rates for the development of cardiorespiratory fitness. *Med Sci Sports Exerc*. 26:112-116
208. Swain D, Leutholtz B (1997) Heart rate reserve is equivalent to %VO_2 reserve, not to %VO_2max. *Med Sci Sports Exerc*. 29:410-414
209. Swain D, Leutholtz B, King M, Haas L, Branch J (1998) Relationship between % heart rate reserve and % VO_2 reserve in treadmill exercise. *Med Sci Sports Exerc*. 30:318-321
210. Swartz A, Strath S, Bassett D Jr, O'Brien W, King A, Ainsworth B (2000) Estimation of energy expenditure using CSA accelerometers at hip and wrist sites. *Med Sci Sports Exerc*. 32(Suppl):S450-S456
211. Telama R and Yang X (2000) Decline of physical activity from youth to young adulthood in Finland. *Med Sci Sports Exerc*. 32:1617-1622
212. Thompson J (1998) Energy balance in young athletes. *Int J Sports Nutr*. 8:160-174
213. Thomsen B, Ekstrom C, Sorensen T (1999) Development of the obesity epidemic in Denmark: cohort, time and age effects among boys born 1930-1975, *Int J Obes*. 23:639-701
214. Torun B, Davies P, Livingstone B, Paolisso M, Sackett R, Spurr G (1996) Energy requirements and dietary energy recommendations for children and adolescents 1 to 18 years old. *Euro J Clin Nutr*. 50:S37-S81
215. Trappe T, Gastaldelli A, Jozsi A, Troup J, Wolfe R (1997) Energy expenditure of swimmers during high volume training. *Med Sci Sports Exerc*. 29:950-954
216. Troiano R and Flegal K (1998) Overweight children and adolescents: description, epidemiology, and demographics, *Pediatrics*. 101:497-504
217. Trost S, Pate R, Sallis J, Freedson P, Taylor W, Dowda M, Sirard J (2002) Age and gender differences in objectively measured physical activity in youth. *Med Sci Sport Exerc*. 34:350-355
218. Trost S (2001) Objective measurement of physical activity in youth: current issues, future directions. *Exerc Sport Sci Rev*. 29:32-36
219. Trost S, Ward D, Moorehead S, Watson P, Riner W, Burke J (1998) Validity of the computer science and applications (CSA) activity monitor in children. *Med Sci Sports Exerc*. 30:629-633
220. Tryon W and Williams R (1996) Fully proportional actigraphy: A new instrument. *Beh. Res Methods, Instruments & Computers*. 28:392-403
221. US Department of Health and Human Services (1996) *Physical activity and health: A report of the surgeon general*. US Department of Health and Human Services, Centers for disease control and prevention, National center for Chronic Disease Prevention and Health Promotion Atlanta, USA, pp.9-60
222. van den Berg-Emons H, Bussmann J, Brobbel A, Roebroeck M, van Meeteren J, Stam H (2001) Everyday physical activity in adolescents and young adults with meningomyelocele as measured with a novel activity monitor. *J Pediatr* 139:880-886

223. van den Berg-Emons R, Saris W, Westerterp K, Van Baak M (1996) Heart rate monitoring to assess energy expenditure in children with reduced physical activity. *Med Sci Sports Exerc*. 28:496-501
224. Van Mechelen W, Twisk J, Post B, Snel J, Kemper H (2000) Physical activity of young people: the Amsterdam longitudinal growth and health study. *Med Sci Sports Exerc*. 32:1610-1616
225. Verschuur R, Kemper H (1985) Habitual physical activity in Dutch teenagers measured by heart rate. In Binkhorst R, Kemper H, Saris W (Eds.) *Children and Exercise*, Human Kinetics, Champaign, USA, pp.194-202
226. Wannamethee G and Shaper A (1992) Physical activity and stroke in British middle-aged men. *Br Med J*. 304:597-601
227. Wareham N and Rennie K (1998) The assessment of physical activity in individuals and populations: Why try to be more precise about how physical activity is assessed? *Int J Obes*. 22:S30-S38
228. Wareham N, Wong M, Day N (2000) Glucose intolerance and physical inactivity: the relative importance of low habitual energy expenditure and cardiorespiratory fitness. *Am J Epidemiol*. 152:132-139
229. Warner J, Bell W, Webb D, Gregory J (1998) Daily energy expenditure and physical activity in survivors of childhood malignancy. *Ped Research*. 43:607-613
230. Welk G, Blair S, Wood K, Jones S, Thompson R (2000) A comparative evaluation of three accelerometry-based physical activity monitors. *Med Sci Sports Exerc* 32(Suppl):S489-S497
231. Westerterp, K, Brouns F, Saris W, ten Hoor F (1988) Comparison of doubly labeled water with respirometry at low and high activity levels. *J Appl Physiol*. 65:53-56
232. Westerterp K, Saris W, Van Es M, Ten Hoor F (1986) Use of doubly labelled water technique in humans during heavy sustained exercise. *J Appl Physiol*. 61:2162-2167
233. Westerterp K, Wouters L, Van Marken Lichtenbelt W (1995) The Maastricht protocol for the measurement of body composition and energy expenditure with labeled water. *Obes Res*. 3:S49-S57
234. Westerterp K (1999) Physical activity assessment with accelerometers. *Int J Obes*. 23:S45-S49
235. Westerterp K (2001) Limits to sustainable human metabolic rate. *J Experiment Biol*. 204:3183-3187
236. Weston A, Petosa R, Pate R (1997) Validation of an instrument for measurement of physical activity in youth. *Med Sci Sports Exerc* 29:138-143
237. Wong W, Butte N, Ellis K, Hergenroeder A, Hill R, Stuff J, O'Brian Smith E (1999) Pubertal African-American girls expend less energy at rest and during physical activity than Caucasian girls. *J Clin Endocrinol Metab*. 84:906-911
238. Zhang K, Sun M, Pi-Sunyer X, Boozer C (2001) Smart insole measurement system (SIMS): A newly developed device for assessing daily physical activity (PA) in free-living conditions. *Obes Research*. 9:(Suppl) S99
239. Åstrand PO (1994) Physical activity and fitness: evolutionary perspective and trends for the future. In Bouchard C, Shephard R, Stephens T (Eds.) *Physical activity, fitness and health: International proceedings and consensus statement*. Human Kinetics, Champaign, USA, pp.98-105

NOTES: