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TNO report

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Assessing physical activity in children and adolescents. A review of different methods.

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Samenvatting

In de discussie over overgewicht bij kinderen en adolescenten wordt steeds vaker gewezen op het gebrek aan beweging bij de jeugd. Er wordt door jongeren steeds meer tijd voor de televisie of achter de computer doorgebracht. De indruk bestaat daarnaast dat er minder buiten wordt gespeeld en dat steeds meer kinderen met de auto naar school worden gebracht.
Echter voordat er campagnes of interventies ontwikkeld en/ of geëvalueerd kunnen worden, is het noodzakelijk meer inzicht te krijgen in de verschillende methoden die er bestaan om fysieke activiteit bij kinderen en adolescenten te meten. Het is van groot belang om meer inzicht te krijgen in het beweegpatroon van kinderen en adolescenten in termen van energieverbruik, frequentie, intensiteit, tijd en type activiteit. In Nederland is nog weinig onderzoek verricht waarbij zowel aandacht wordt besteed aan gestructureerde fysieke activiteiten (sport, bewegingsonderwijs) als aan vormen van transport (lopen of fietsen naar school), minder gestructureerde fysieke activiteiten als buiten spelen en fysieke inactiviteit. Het meten van fysieke activiteit kan ook bijdragen aan kennis over de gezondheidseffecten van laag en matig intensieve fysieke activiteiten en de dosisrespons relatie tussen fysieke (in)activiteit en overgewicht.
Het rapport geeft antwoord op de vraag: Welke objectieve en subjectieve meetmethoden zijn er op dit moment in binnen- en buitenland beschikbaar om fysieke activiteit bij kinderen en adolescenten (4-18 jaar) te meten?
Uit de literatuurstudie zijn de volgende objectieve meetmethoden naar voren gekomen: indirecte calorimetrie, dubbel gelabeld water, hartslagmeters, stappentellers en versnellingsmeters. Subjectieve meetmethoden zijn: directe observatie, vragenlijsten, dagboekjes en interviews. Elke methode heeft voor- en nadelen.
Dit rapport laat duidelijk zien dat onze kennis over beweegpatronen van kinderen en adolescenten en onderzoek op het gebied van meetmethoden nog in haar kinderschoenen staat. Hoewel er veel hartslagmeters, stappentellers en versnellingsmeters op de markt zijn, is er weinig onderzoek gedaan naar de validiteit en betrouwbaarheid van deze meetmethoden bij kinderen en adolescenten. Ook zijn er op dit moment geen valide en betrouwbare Nederlandse vragenlijsten beschikbaar voor kinderen en adolescenten. Aangezien elke methode net weer andere aspecten meet, lijkt een combinatie van, zo mogelijk betrouwbare en gevalideerde, objectieve en subjectieve meetmethoden op dit moment het meest geschikt. Men kan hierbij denken aan de combinatie van een versnellingsmeter en een vragenlijst. Het is daarnaast duidelijk dat onderzoek naar de betrouwbaarheid en validiteit van hartslagmeters, stappentellers, versnellingsmeters en Nederlandse vragenlijsten en dagboekjes zeer gewenst is. Deze methoden dienen zich niet alleen te richten op het totale energieverbruik, maar ook inzicht te verschaffen in het bewegingspatroon (frequentie, intensiteit, tijd en type activiteit).

Dit rapport is geschreven in opdracht van het Ministerie van Volksgezondheid, Welzijn en Sport, directie Sport.

Summary

In the discussion about paediatric obesity more often the physical inactive lifestyle of youth is pointed out. Ever increasing time is spent in front of the television or behind the computer. Also, there are reasons to believe that children spend less time playing outside and more children are brought to school by car.
However, before campaigns or interventions can be developed and/ or evaluated, more insight is needed in the different methods that exist to assess physical activity in children and adolescents. It is of great importance to gain more insight in physical activity patterns of children and adolescents in terms of energy expenditure, frequency, intensity, time, and type of physical activity. In the Netherlands studies in which attention is paid to structured physical activities (sports, physical education class) as well as to transportation modes (walking or cycling to school), less structured physical activities as playing outside, and physical inactivity, are sparse. Assessing physical activity can also contribute to our knowledge of health-related effects of low to moderate physical activities, and the dose-response relationship between physical (in) activity and obesity.
This report will give an answer to the following question: Which objective and subjective methods are available at present, in the Netherlands and abroad, to assess physical activity in children and adolescents (4-18 yr)?
In the literature search the following objective assessment methods were found: indirect calorimetry, doubly labelled water, heart rate monitors, pedometers, and accelerometers. Subjective assessment methods are: direct observation, questionnaires, diaries, and interviews. Each method has advantages and disadvantages.
This report shows clearly that our knowledge of physical activity patterns, and research in the field of assessment methods for children and adolescents are still in their infancy. Although a variety of heart rate monitors, pedometers, and accelerometers are available commercially, few studies have been performed on the validity and reliability of these methods in children and adolescents. Also to date no valid and reliable Dutch questionnaires are available for children and adolescents. Because each method measures just other aspects, a combination of, if possible valid and reliable, objective and subjective assessment methods seems most appropriate at this moment. One can think of a combination of an accelerometer and a questionnaire. Beside this, it is clear that research on the validity and reliability of heart rate monitors, pedometers, accelerometers, and Dutch questionnaires and diaries is desirable. At last, it is important that methods not only address total energy expenditure, but also provide insight in physical activity patterns (frequency, intensity, time and type of physical activity).

This report has been written by order of the Ministry of Health, Welfare and Sport, Sports Directorate.

Contents

1 Introduction

1.1 Overweigth and obesity

There is a tremendous interest in assessing and promoting physical activity among children. Much of this interest stems from the high publicized increases in the prevalence of paediatric obesity[1] (Welk et al., 2000b). From 1963 to 1991 the percentage of children and adolescents with obesity has doubled according to the American National Health and Nutrition Examination Survey under children and adolescents (6-17 yr) (Stichting Jeugd in Beweging, 2001). In Australia obesity and overweight levels are reported to be between 19-23% (Vincent et al., 2003). In the Netherlands the same increases can be observed (Wit, 1998). In a period of twenty years the number of 5- to 11-year old children with overweight has increased from 4 to more than 10 percent and the number of children who are obese has become eightfold (Janssen, 2002; Voedingscentrum, 2002). TNO Prevention and Health found similar numbers in a study under 14500 children and adolescents showing that one in every seven children weighs too much. Nearly sixteen percent of the boys were overweighed. The percentage of overweighed girls increased from 8.2% in 1980 to 16.1% in 1997 (Hirasing et al., 2001; Hirasing et al., 2002).

Paediatric obesity is associated with several physical and psychosocial consequences. The greatest risk is the increased likelihood of adult obesity with all its associated health risks. One third of the children and adolescents who are overweight will become an overweight adult (Janssen, 2002; Peters & Luijpers, 2002). The maintenance of behaviour, in which initial measures of e.g. obesity or physical (in)activity can predict later levels, is called tracking (Janz et al., 2000).

1.2 Physical inactivity

Physical inactivity and hence a decrease in energy expenditure, is suggested to be one of the main risk factors for developing obesity. Regular physical activity can improve cardiovascular profiles (i.e. lower blood pressure, higher level of HDL-cholesterol), it can improve physical fitness, optimize growth and encourage future participation in physical activity (Stiggelbout et al., 1998).
Many health professionals and scientists have expressed concern about the physical activity status of children. There are reasons to believe that the level of physical activity of children and adolescents has declined during the past decades. In the United States transportation surveys indicate that there has been an increase in the use of personal vehicles for transportation purposes, including chauffeuring the child (Tudor-Locke et al., 2003), and an increase in watching television (Armstrong et al., 1998). In The Netherlands the same trends can be observed (Van Binsbergen & Mathus-Vliegen, 2003; Janz et al., 2002; Stichting Kijkonderzoek, 2003; Wit, 1998).

Knowledge of physical activity patterns is needed to serve as a cornerstone in establishing appropriate federal health objectives. Assessment methods are essential for

[1] Obesity is quantified as weight corrected for height, the body mass index (BMI). In children and adolescents other BMI scores are used than for adults. In contrast to adults the age and sex are taken into account (Westerterp, 1999a).

increasing our understanding of the dose-response relationship between physical activity and obesity. It is also desirable to determine what proportion of children and adolescents are meeting physical activity guidelines and to examine what proportion is in need of intervention programmes or whether to adjust physical education curricula for children.

1.3 Physical activity guidelines

Recently developed physical activity guidelines in which intermittent and not continuous activity is stressed, have heightened the need to assess not only an overall activity measure but also frequency, intensity, time, and type of activity (FITT). It has also become clear that health benefits occur not only as a result of structured vigorous activity but that moderate physical activities are already beneficial for health.

In the Netherlands the physical activity guideline (Nederlandse Norm Gezond Bewegen (NNGB)) for children and adolescents (< 18 yr) is defined as:

Perform physical activities of moderate intensity for at least one hour a day, and in addition perform twice a week physical activities that improve or maintain physical fitness (strength, flexibility, and co-ordination) (Kemper et al., 2000).

The variety of methods to assess physical activity in children and adolescents is enormous. LaPorte et al. (1985) mentioned more than 30 different techniques. This can partially be explained by the complexity of physical activity. Physical activity is a very complex behaviour that has a variety of dimensions. It can be defined as any bodily movement produced by skeletal muscles that result in energy expenditure (Committee on Sports Medicine and Fitness, 1994) and can be expressed in terms of energy (kcal), external workload (Watt), time of activity (minutes), units of movements (counts), frequency, intensity, type of activity, in active versus inactive individuals according to a guideline, as a percentage, etc.

1.4 Aim of the research project

To gain insight in physical activity patterns of Dutch children and adolescents and/ or to develop or evaluate intervention programmes, practical, valid, and reliable methods must be used to assess physical activity.

The aim of this report is to provide an overview of different objective and subjective methods to assess physical activity in children and adolescents (4-18 yr).

1.5 Bookmark

In chapter 2 the method of obtaining information of assessment methods will be discussed. Chapter 3 provides an overview of objective assessment methods as heart rate monitors and motion sensors. In chapter 4 subjective methods to assess physical activity will be reported. In chapter 5 attention is paid to the unique characteristics of activity patterns of children and adolescents in comparison with adults and in chapter 6 conclusions, recommendations and priorities for future research will be presented.

2 Method

2.1 Research design

In this research project three steps were taken:

1. A literature search to locate objective and subjective methods to assess physical activity in children and adolescents (4-18 yr);
2. A critical review of the quality and practical application of the objective and subjective methods by two independent reviewers;
3. Report.

2.2 Searching the literature

To provide an overview of methods to assess physical activity in children and adolescents a literature search was performed in the computerized databases PubMed (Medline), Embase, SpycINFO, and the TNO physical activity literature database. On the basis of single and combined keywords, articles written in Dutch, English and German were selected. The following keywords were used: physical activity, assessment, measurement, evaluation, child(ren), adolescent(s), validity, reliability, calibration and development.

2.3 Critical review

All articles were reviewed and examined on relevance and methodological quality.
To be described in this report the assessment method had to apply to the following inclusion criteria:

- Target population: (healthy) children and/ or adolescents (4-18 yr);
- Objective of the assessment method: to asses physical activity in a quantitative manner in terms of energy expenditure, external workload, units of movements, frequency, intensity, time, type of activity or physical activity guidelines;
- Publication between 1980 and 2003.

In some cases more information was obtained by consulting the authors of the articles, or by searching the internet. Assessment methods not thoroughly described and those focusing on other variables than physical activity were excluded from review.

Selected assessment methods were reported systematically. After a description of the general characteristics of the method, research on the validity and reliability of this method was discussed. Next the advantages and disadvantages of the method have been reported, and finally a combined judgement of two independent reviewers was presented.

Guidelines
The Committee of Tests and Test research in the Netherlands (Commissie Test Aangelegenheden Nederland (COTAN)) has developed a set of methodological guidelines for systematic test review. They presented criteria for the following items: construction of tests, quality, reliability, and validity (Evers et al., 2000a; Evers et al., 2000b).

Also, an important item in assessing physical activity in children and adolescents is the practical use of the method. According to Scruggs et al. (2003) an assessment method must:

- be inexpensive;
- be of acceptable size to the subjects under study (size of a measurement instrument is of utmost importance in field-based studies (Trost, 2001));
- be accessible to researchers;
- cause minimal to no disruption to direct environment.

Based on the COTAN guidelines and earlier reviews of assessment methods (Sallis, 1991) the following items have been selected for this review:

- Name of the assessment method (if the instrument or measure did not have a specific name, one was provided);
- Target population;
- Cost of the assessment method;
- Size (i.e. size and weight of heart rate monitors, size and weight of motion sensors, number of questions in questionnaires and lengths of interviews);
- Comfort;
- Units of measurement (e.g. energy expenditure, frequency, intensity) or content (structure of questionnaires, categories, question format (Konijn & Hildebrandt, 1993));
- Time to train observers;
- Reliability of the assessment method;
- Validity of the assessment method;
- Calibration of the assessment method.

Two very important aspects of an assessment method are the reliability and the validity. They are described in detail.

Reliability

Reliability is a measure of reproducibility. Reliability measures demonstrate whether results of individuals on different occasions (test-retest reliability), or of different observers (inter-observer reliability), or of the same observer on different occasions (intra-observer reliability) produce the same results. The reliability is expressed as a number between 0 and 1, with 0 indicating no reliability and 1 indicating perfect reliability. It is a measure of the proportion of the variability of the results which was due to true differences between individuals.

Reliability can be expressed as internal consistency, inter-observer reliability, intra-observer reliability or test-retest reliability. The internal consistency presents the average of the correlations between all the items of the measure, in other words the homogeneity of the measure. It is often calculated by Cronbach's alpha. The internal consistency however is not a sufficient basis upon which to make a reasoned judgement to use or not to use a measure. Any decision regarding the value of a measure should be based on some information about the stability of a measure, which is expressed by the inter-observer reliability, the intra-observer reliability and the test-retest reliability.

Acceptable reliability coefficients depend on the use of the measure and the cost of misinterpretation. But in general the internal consistency should exceed 0.80. Stability measures should be higher than 0.50 (Baarda & De Goede, 1995; Streiner & Norman, 1995).

If one of the criteria is met a '+' will be assigned to the assessment method by the two reviewers (Table 2.1).

Table 2.1. Criteria for judging reliability coefficients

Items	Criteria	Judgement
Internal consistency	> 0.80	+
Inter-observer reliability	> 0.50	+
Intra-observer reliability	> 0.50	+
Test-retest reliability	> 0.50	+

Validity

Reliability is simply a concept to demonstrate whether an instrument or a scale is measuring something in a reproducible way. It says nothing about what is being measured. To determine whether an assessment method is measuring what was intended requires evidence of validity.

If there are other instruments or scales available which measure the same or similar aspects as the method under study a strong correlation should exist between the two measurements. This is expressed as the concurrent validity, criterion validity or convergent validity. One would preferably use an instrument which has been defined as 'the golden standard'. If no other measure exist construct validity is assessed. The aspect that is measured is linked to another aspect by a hypothesis or a construct (Streiner & Norman, 1995).

The two reviewers assigned a '-', '±', '+', or '?' to different items of the selected assessment methods. Most judgements were based on common sense. If the item did not meet acceptable levels or was not described at all, a '-' was assigned for reliability and validity, and a '?' for the other items. In a consensus meeting both reviewers tried to reach agreement on items on which they had different opinions.

2.4 Report

All selected assessment methods were described with the available information.

After a description of the method, research on the validity and reliability was discussed. Next the advantages and disadvantages of the method have been reported and finally a judgement of the two researchers was presented.

3 Objective methods to assess physical activity in children and adolescents

Methods of assessing physical activity in children and adolescents can be divided into two major categories. First there are methods by which the physiological responses to physical activity are obtained, the so called objective methods. Examples of objective methods are heart rate monitoring and indirect calorimetry. The second category includes methods by which the amount of physical activity is estimated subjectively. Examples of subjective methods are observation methods, questionnaires, diaries and interviews.
In this chapter four objective methods will be discussed.

3.1 Indirect calorimetry

One method to assess physical activity in children and adolescents is to measure energy expenditure in an open-circuit indirect calorimeter[2]. The calorimeter is a room that can be equipped with a bed, table, chair, toilet, television, cycle ergometer and so on. The volume of the outgoing air is determined and the gas is analyzed with an O_2 – analyzer and a CO_2– analyzer. Energy expenditure is calculated according to the equation of Weir: EE (kcal) = 3.9 x O_2 + 1.1 x CO_2 (Emons et al., 1992). In general the subject will stay there for at least 24 hours.

<u>Advantages and disadvantages of indirect calorimetry</u>
Indirect calorimetry is a good method to obtain individualized heart rate - VO_2 regression equations and can therefore be used to calibrate other methods. Another advantage of this method is that energy expenditure can also be monitored during rest or sleep. Unfortunately it is expensive and time-consuming. Also, calorimetry is a laboratory-study and does not measure real-life situations. More and more manufacturers introduce portable, lightweight metabolic systems that should improve the measurement of energy expenditure under more natural conditions. Indirect calorimetry is not an appropriate method for large-scale epidemiologic studies.

<u>Judgement of indirect calorimetry as an assessment method</u>
Indirect calorimetry can be used for calibrating other assessment methods, but equipment and time makes this method disadvantageous.

3.2 Doubly labelled water

The doubly labelled water (DLW) technique measures the disappearance rate of the labelled isotopes H_2 and ^{18}O after an oral dose of $2H_2$ $H_2^{18}O$ to estimate carbon dioxide production rate (VCO_2) over a period of several days (Livingstone et al., 1992; Westerterp, 1999a).

<u>Advantages and disadvantages of doubly labelled water</u>
The DLW technique provides an overall estimate of physical activity related energy expenditure. It can measure integral energy expenditure under real-life situations over a period of up to two weeks with minimal inconvenience to the subject. Disadvantages of this method are the relatively high cost of a single dose of doubly labelled water (about

[2] Direct calorimetry measures energy expenditure through the production of heat (LaPorte et al., 1985).

$3 per isotope dose per kg body weight) and the use of an expensive mass-spectrometer (Saris, 1986). This method doesn't describe changes in energy expenditure over time (physical activity patterns), nor does it differentiate between different types of activity (Goran, 1998).

Judgement of doubly labelled water as an assessment method
The doubly labelled water method is a well established and validated assessment method both in animals and in human. It is considered to be the golden standard of assessing energy expenditure. If time, money and equipment are not a problem it is a perfect method to calibrate or validate other assessment methods. However, one should bear in mind that this method can not provide insight in physical activity patterns.

3.3 Heart rate monitors

Due to advances in telemetry, storage capacity and instrument size, heart rate monitoring has become an attractive method to assess physical activity in real-life situations. Different recording techniques are available at present: 1.) telemetry; 2.) tape recorders; and 3.) solid-state recorders.
The linear relationship between heart rate, oxygen consumption (VO_2) and energy expenditure during physical activity is established in adults, adolescents and children (Melanson & Freedson, 1996; Welk et al., 2000b). Heart rate monitors provide an estimate of daily energy expenditure or activity energy expenditure from individual calibration curves developed during a variety of activities in a laboratory setting.
In the literature search information was found about two heart rate monitors. They have been described in detail. Characteristics of these heart rate monitors are summarized in Table 3.1.

Quantum XL Telemetry heart rate monitor
The Quantum XL Telemetry heart rate monitor (Polar Electro Oy, Kempele, Finland, SF-90440, AMF) is a wireless portable monitor that consists of a transmitter and a receiver. The transmitter is 13.7 x 3.0 x 1.2 cm in size and weighs 43 g, the receiver is 5.1 x 4.5 x 1.5 cm in size and weighs 47 g (Table 3.1). The receiver is a microcomputer that records and stores heart rate data once every minute for 16 hours. The Quantum XL Telemetry heart rate monitor calculates heart rates based on a pulse-to-pulse time-average algorithm. The transmitter can be attached to the chest by self-adhering electrodes.
Validity and reliability: Durant et al. (1992) examined the reliability and variability of heart rate monitoring in preschool children (3-5 yr). Heart rates were measured with the Quantum XL Telemetry heart rate monitor over 12 waking hours in 159 children from three different ethnic groups. Four heart rate variables were examined: mean resting heart rate, mean heart rate during specific time periods, percent of minutes during specific time periods in which the heart rate was higher than 120 beats per minute and longest duration during a time period the heart rate was above 120 beats/ min. Despite very high intra individual standard deviations, within-day reliabilities were found to be in an acceptable range and ranged between r=0.81 and r=0.85. However a principal component analysis revealed three distinct time periods during the day: morning, early afternoon, and late afternoon. This suggests that monitoring heart rate during a specific time period during the day will provide a biased estimate of overall heart rate. The reliabilities for two days of monitoring separated by 3-6 months ranged from r=0.65 to r=0.66 (Table 3.1). Durant et al. concluded that at least four days of monitoring are necessary to estimate an individual's habitual daily heart rate with a reliability of

r=0.80. Heart rate variables did not vary significantly by day of the week, season of the year, gender or ethnic group.
Two years later Durant et al. (1993b) repeated the measurements with 131 children (5-7 yr). In addition to the heart rate variables of the first study they measured the percent of heart rates 25% (PAHR-25) and 50% (PAHR-50) above resting heart rate, indices of physical activity heart rate. Within-day reliability ranged from r=0.75 to r=0.93, with the PAHR-25 having the highest reliability (r=0.92). If only one 60-min measure was used, the reliabilities ranged from r=0.26 to r=0.49. Correlations between heart rate measures across two days separated by 3-6 months ranged from r=0.47 to r=0.81. Again the PAHR-25 had the highest reliability (r=0.81). Single measure reliabilities ranged from r=0.31 to r=0.68. Only 1.9 days of monitoring would be needed to achieve a reliability of r=0.80 for the PAHR-25 index in contrast to 9 days for the mean heart rate. Durant et al. concluded that PAHR-25 and PAHR-50 may be better indicators than previously reported heart rate variables as mean heart rate, especially if an investigator is limited to collection of less than 12 hours of monitoring heart rate.
Janz et al. (1992) examined the reliability and validity of the Quantum XL Telemetry heart rate monitor in 76 children and adolescents (6-17 yr) during a typical summer day. Eleven children were monitored for two days. The correlations between the two days were r=0.70 for total activity (heart rate minus baseline heart rate), and r=0.84 for baseline heart rate values. Total activity was related to a 12-hour recall questionnaire on the monitored day (r=0.50), on another day (r=0.32), and to self-rating (r=0.35). Total activity was related to $VO_{2\ max}$ in girls (r=0.36), but not in boys (r=-0.06). Janz et al. reported that prepubescent children were significantly more physically active than post- and pubescent children. No gender difference was found.

Sport Tester
The Sport Tester (Polar Electrode KY, Kempele, Finland, PE 3000) (also known as the Polar Vantage XL heart rate monitor (Polar Night Vision, Helsinki, Finland)) is another wireless portable heart rate monitor. It consists of a transmitter (13.7 x 3.0 x 1.2 cm, 43 g) and a receiver (5.1 x 4.5 x 1.5 cm, 47 g) (Table 3.1). The transmitter can be attached to the chest using either disposable electrodes or an elastic electrode belt. The receiver is a microcomputer which records, displays, and stores heart rate data at 5- or 15-second intervals for up to 80 or 240 minutes, respectively, or once a minute for up to 16 hours. It has a memory capacity for 1020 heart rates and 256 time values. The receiver can be worn around the wrist. The Sport Tester calculates heart rate data based on a pulse-to-pulse time-average algorithm.
<u>Validity and reliability</u>: Treiber et al. (1989) examined the validity of the Sport Tester in laboratory and field settings. They assessed the validity by comparing simultaneously recorded ECG heart rates with Sport Tester data in three studies. Study 1 obtained heart rate data from 10-year old children during a cycle ergometer task, study 2 examined 4- to 6-year old children performing treadmill exercises and study 3 was a field trial in which 7- to 9-year old children performed six free-play activities. Correlations between ECG data and Sport Tester data ranged from r=0.93 to r=0.99. The maximum difference for individuals between ECG heart rates and Sport Tester heart rates across all three studies was 4.9 beats/ min.
Harro (1997) examined the validity of three questionnaires by simultaneously monitoring heart rate and accelerometer data. Sixty-eight children (4-8 yr) were measured on four consecutive days. Correlations between heart rate monitoring with the Sport Tester and Caltrac accelerometer data was r=0.45 ($p < 0.001$) for heart rate ≥ 140 beats/ min, and r=0.41 ($p < 0.01$) for heart rate ≥ 150 beats/ min.

Treuth et al. (1998) calibrated heart rate data and activity monitor data against 24-h respiration calorimetry to predict activity energy expenditure in real-life situations in 20 children (8-12 yr). Errors and standard deviations of the estimated energy expenditure were the lowest when heart rate data and activity monitor data were combined. With this method energy expenditure can be estimated with an error of -2.6 ± 5.1% kJ/ day.
Emons et al. (1992) compared 24-h energy expenditure rates quantified by three different methods:

1. A 24-h stay in an indirect calorimeter;
2. A 14-day measurement using doubly labelled water;
3. An estimation of energy expenditure based on 24-h heart rate monitoring with the Sport Tester.

Individual calibration curves were derived for 19 children (7-11 yr) from heart rate data and oxygen consumption in the calorimeter during rest and during walking on a treadmill. Estimated energy expenditure based on data from the Sport Tester was 10.4% higher than energy expenditure measured in the calorimeter and 12.3% higher than energy expenditure measured with the doubly labelled water method. Overestimation ranged from 6.3% to 16.2%.
Livingstone et al. (1992) compared energy expenditure estimated by heart rate monitoring with energy expenditure assessed by the doubly labelled water method. Total energy expenditure was measured by the doubly labelled water method over 10-15 days in 36 children (7-15 yr). Heart rates were monitored with the Sport Tester on two school days and one weekend day. Discrepancies between estimated energy expenditure and measured energy expenditure ranged from -16.9% to 18.8%.

Examples of other heart rate monitors are: the UNIQ Heart Watch (Computer Instruments Corp., Hempstead, New York), the Quantum XL Fitness Monitor, and the Holter Monitoring system (Oxford Instruments).

Table 3.1 Characteristics of two heart rate monitors

Method of measurement	Cost	Size	Validity	Reliability	Calibration	Reference
Quantum XL Telemetry	?	transmitter: 13.7 x 3.0 x 1.2 cm, 43 g receiver: 5.1 x 4.5 x 1.5 cm, 47 g	r = 0.50/ 0.32 questionnaire r = 0.35 self-rating r = 0.36/ -0.06 VO2 max	IC: r = 0.81-0.85 IC: r = 0.75-0.93 TR: r = 0.65-0.66 TR: r = 0.47-0.81 TR: r = 0.70/ 0.84	?	Durant et al., 1992 Durant et al., 1993b Janz et al., 1992
Sport Tester	?	transmitter: 13.7 x 3.0 x 1.2 cm, 43 g receiver: 5.1 x 4.5 x 1.5 cm, 47 g	r = 0.93-0.99 ECG r = 0.41/0.45 Caltrac	?	calorimetry DLW	Treiber et al., 1989 Treuth et al., 1998 Emons et al., 1992 Livingstone et al., 1992 Harro, 1997

IC = internal consistency; TR = test-retest reliability; ECG = electrocardiogram; DLW = doubly labelled water

Advantages and disadvantages of heart rate monitors

Heart rate monitoring provides an objective indicator of the physiological responses to physical activity. The reviewed heart rate monitors, the Sport Tester and the Quantum XL Telemetry heart rate monitor, are both wireless heart rate monitors. In general, wireless heart rate monitors are well tolerated by children. This makes them practical for field testing. It also makes them less sensitive for data loss. In the study of Treiber et al. (1989) 14.2% of the data of the ECG was lost due to electrode detachment in comparison with 1.2% of the data of the Sport Tester.

A disadvantage of heart rate monitoring is the fact that heart rate is influenced by several other factors than physical activity, for example by age, body size, anger, stress, temperature, posture, muscle group, type of muscle contraction, training status, food intake, and time of the day (Durant et al., 1992; Durant et al., 1993b; Freedson, 1991; Saris, 1985, Trost, 2001). Another disadvantage is that heart rate monitoring may mask the sporadic activity pattern of children. Children tend to change their activity pattern frequently and can be very active and inactive within one minute. By using time-averaging techniques, in which mean heart rates are calculated, changes in heart rate may not be detected. Another important aspect is the fact that heart rate response lags behind changes in activity. A disadvantage of telemetry is that the receiver has to be in the neighbourhood of the subject. The size and weight of a tape recorder makes this technique less suitable for young children.

Another problem is the resting heart rate. The three most popular heart rate indices, the activity heart rate index, the PAHR-25, and PAHR-50, are based on the resting heart rate. One can imagine that the operational definition of resting heart rate and the protocol used to measure it, have profound effects on the physical activity estimates. In a study of Logan et al. (2000) with 20 preschool children (3-4 yr) the PAHR-25 varied by 10-50%, the PAHR-50 varied by 16-65%, and the activity heart rate index varied by 9-44% depending on the protocol used. Physical activity can be over- or underestimated by about 30-35% as a result of the definition of resting heart rate. However, the different protocols had no significant influence on rank order of physical activity level.

Judgement of the described heart rate monitors

Characteristics of the Quantum XL Telemetry heart rate monitor and the Sport Tester are summarized in Table 3.2.

Table 3.2 Judgement of the characteristics of the two described heart rate monitors

Heart rate monitors	Target population	Cost	Size	Validity	Reliability	Calibration
Quantum XLTelemetry	children, adolescents	?	±	±	+	?
Sport Tester	children, adolescents	?	±	+	-	+

The results of the studies suggest that the Quantum XL Telemetry heart rate monitor may be a reliable measure to assess physical activity in children and adolescents. The Sport Tester has been validated and calibrated in children and adolescents. However, one has to keep in mind that both heart rate monitors are old models. To date no information is published about the validity and reliability of newer heart rate monitors for use in children and adolescents.

Using individualized heart rate - VO_2 regression equations and techniques that control for errors, heart rate monitoring can provide an indication of the intensity, duration, frequency, and energy expenditure of physical activity.

An even better measure of energy expenditure is cardiac output. Oxygen consumption is not only related to heart rate but also to stroke volume and arterio-venous oxygen difference. In the last decades many studies have been conducted to measure cardiac output invasively in laboratory settings. However this method is difficult and impracticable for researchers and inconvenient for subjects. Recently, many studies have been performed to investigate non-invasive assessment of cardiac output in adults. For example, one has looked at the Model flow method, the Doppler echocardiography method, and CO_2 rebreathing technique. So far, literature has shown that no method has been proven valid and reliable to measure cardiac output non-invasively (Remmen et al., 2002; Sugawara et al., 2003; Tam et al., 2003).

3.4 Motion sensors

Motion sensors have evolved from simple mechanical devices as pedometers to one-dimensional and three-dimensional accelerometers. They are often selected because they are lightweight, unobtrusive, and relatively inexpensive in comparison with other objective methods as the doubly labelled water technique for example (Nichols et al., 1999).
One pedometer, five one-dimensional accelerometers and three three-dimensional accelerometers are described in detail. Characteristics of these motion sensors are summarized in Table 3.3.

Pedometers
Pedometers use three mechanisms to record steps. The first and most basic principle is a spring-suspended horizontal lever arm that moves up and down in response to vertical displacement of the hip. Newer models have a glass-enclosed magnetic reed proximity switch. The third principle is similar to that of accelerometers.
Most of the technical limitations of the early pedometers have been overcome. For example the variability of spring tension (Welk et al., 2000c).

Yamax Digi-Walker pedometer
The Yamax Digi-Walker pedometer (Yamax Corp., Japan, Model SW-701) is an unobtrusive instrument that uses a horizontal spring-suspended mechanical lever arm to measure vertical movement. It is 1.9 x 3.9 x 5.2 cm in size and can be worn at the hip. Outcome measures are step counts, distance and energy expenditure (Table 3.3).
<u>Validity and reliability</u>: The validity of the Yamax Digi-Walker pedometer was supported in a study of Scruggs et al. (2003) in which a steps-per-minute-standard was determined in 6- to 7-year old children (n=369) for quantifying lesson time that these children spent in moderate to vigorous physical activity during physical education. The correlation range between step counts per minute and time spent in moderate to vigorous physical activity (MVPA) was r=0.74-0.85. The MVPA was measured with a system for observing fitness instruction time (SOFIT).

Examples of other pedometers are: the Yasama Skeletone (Model EM-180), Sportline (Model 330, Model 345), Omron (Model HJ-105), New Lifestyles (Model NL-2000), Kenz Lifecorder, Oregon Scientific (Model PE316CA), Freestyle Pacer Pro, and The Walk4Life (Model LS 2525). There is not sufficient information available to describe them in detail in this report. To date no validation studies have been performed with these devices in children or adolescents. They have been validated in adults (Crouter et al., 2003).

Advantages and disadvantages of pedometers

In general, pedometers are relatively cheap and unobtrusive devices to assess physical activity in children and adolescents. Unlike heart rate telemetry, pedometers do not require taping or strapping to the body. According to some researchers pedometers can be used to document relative changes in physical activity or to rank groups of children on physical activity participation.

Disadvantages of pedometers are their insensitivity to non-locomotor forms of movement, no detection of static exercise, and insensitivity to changes in inclination (hills, stairs). Furthermore, they have no data storage capabilities, which mean that they only give a total activity score over the entire period of recording and therefore they do not provide information about the frequency, intensity or duration of physical activity, i.e. the activity patterns of children and adolescents. Many commercially available pedometers provide users estimates of energy expenditure; however, the algorithms used for these calculations are not appropriate for children (Trost, 2001). A last disadvantage of pedometers is that they are influenced by factors such as body size (step length) and speed of locomotion, which make them not really appropriate for assessing physical activity in (growing) children and adolescents.

Judgement of the described pedometer

The Yamax Digi-Walker pedometer seems to provide valid assessments of the total volume of physical activity performed by children. It objectively shows information about step counts and distance. However, because of the mentioned disadvantages, one should not use this device for children and draw conclusions about energy expenditure.

Table 3.3 Characteristics of several motion sensors

Method of measurement	Unit of measurement	Cost	Size	Validity	Reliability	Calibration	Reference
Pedometers							
Yamax Digi-Walker pedometer	steps, distance, energy expenditure	€ 30	1.9 x 3.9 x 5.2 cm	r = 0.74-0.85 SOFIT	?	SOFIT	Scruggs et al., 2003
One-dimensional accelerometers							
LSI	activity counts	?	3.8 x 4.5 x 2.2 cm 51 gram	r = 0.40 FATS r = 0.42 Caltrac	?	?	Klesges et al., 1985
Caltrac Activity Monitor	activity counts, energy expenditure	$90	9.7 x 7.0 x 1.3 cm 78 g	r = 0.35/ 0.39/ 0.80 FATS r = 0.42 LSI r = 0.82 oxygen consumption r = 0.54/ 0.42 heart rate monitor r = 0.41/ 0.45 Sport Tester r = 0.55-0.80 heart rate monitor	II: r = 0.89 II: r = 0.96	?	Klesges et al., 1985 Klesges & Klesges, 1987 Sallis et al., 1990 Harro, 1997 Simons-Morton et al., 1994
Biotrainer Monitor	activity counts	$250?	± 9.7 x 7.0 x 1.3 cm 78 g	?	?	?	Welk et al., 2000a

CSA Activity Monitor	activity counts	$350	5.0 x 3.8 x 1.5 cm 42 g	r = 0.86-0.87 indirect calorimetry r = 0.50-0.74 heart rate monitor	II: r = 0.87 TR: r = -0.21-0.53 TR: r = 0.81-0.84	?	Trost et al., 1998 Janz, 1994 Janz et al., 1995
PAM	activity index	€ 149	5.8 x 4.2 x 1.3 cm 28 g	?	?	?	www.pam.com
Three-dimensional accelerometers							
Tritrac-R3D Activity Monitor	activity counts, energy expenditure	$500	11.0 x 6.9 x 3.3 cm 170 g	r = 0.58 heart rate monitor r = 0.88 Caltrac	?	?	Welk & Corbin, 1995
Tracmor 2	activity counts	?	7.0 x 2.0 x 0.8 cm 30 g	?	?	?	Westerterp, 1999b
DynaPort MiniMod	activity counts, energy expenditure, balance,	€ 2750 + software	5.5 x 3.5 x 2.5 cm 70 g	?	?	?	www.mcroberts.nl

II = inter-instrument reliability; TR = test-retest reliability

One-dimensional accelerometers

Accelerometry-based motion sensors have recently gained acceptance as one of the most promising methods to assess physical activity. Several studies have tested the different kind of monitors in laboratory settings as well as under field conditions. Accelerometers not only reflect the occurrence of body movement, like pedometers, but also the intensity of movement.

Large Scale Integrated Movement Activity Counter (LSI)

The Large Scale Integrated Movement Activity Counter (GMM Electronics Inc., Verona, PA) is a device that measures movements in one plane. The activity counter consists of a cylinder with a ball of mercury. A three percent inclination or declination causes the closing of a mercury switch. Every 16 movements result in one count. The LSI measures 3.8 x 4.5 x 2.2 cm and weighs 51 gram (Freedson, 1991) (Table 3.3). It can be worn on the arm, leg or hip.

Validity and reliability: Klesges et al. (1985) assessed the validity of two motion sensors in 30 preschool children (1.6-5.7 yr). Results of this study indicated a very modest relationship between the LSI and physical activity levels observed with the FATS observational system ($r=0.40$, $p < 0.01$). The correlation between the LSI and the Caltrac Activity Monitor was $r=0.42$ ($p < 0.01$).

The relationship between self-reports of physical activity and the LSI has suggested that the device may suffer from floor and ceiling effects. The LSI is relatively insensitive to very low and very high levels of physical activity (Klesges et al., 1985).

Caltrac Activity Monitor

The Caltrac Activity Monitor (Muscle Dynamics, Torence, CA) is an electronic accelerometer that monitors vertical acceleration of the body and automatically computes energy expenditure (kcal) due to physical activity, taking into account the subject's height, weight, age and gender. It measures 9.7 x 7.0 x 1.3 cm and weighs 78 gram (Table 3.3). The Caltrac can be worn at the hip. It is not designed or validated to be worn on the wrist or the ankle. The device can not be used to assess activity patterns because it does not have data storage capacity.

Validity and reliability: Klesges et al. (1985) reported a correlation of $r=0.35$ ($p < 0.05$) between one hour of direct observation (FATS) of 30 preschool children's physical activity (1.6-5.7 yr) during an unstructured free-play situation and the Caltrac. The correlation between the Caltrac Activity Monitor and the LSI was $r=0.42$ ($p < 0.01$). In another study they reported higher correlations when the observation period was extended. The correlation between the two methods was $r=0.39$ for younger children (< 2.6 yr) and $r=0.80$ for older children (2.7-4.0 yr) with a mean value of $r=0.54$ ($p < 0.01$) for all-day observation (Klesges & Klesges, 1987).

Sallis et al. (1990) examined the validity and reliability of the Caltrac in 15 children (8-13 yr) during treadmill walking and running. A correlation of $r=0.82$ was reported between oxygen consumption and Caltrac data across three treadmill speeds. The inter-instrument reliability in the laboratory setting was $r=0.89$. In the same study 35 children wore the Caltrac and a heart rate monitor for two days. The correlation between accelerometer data and activity heart rate was $r=0.54$ ($p < 0.001$) on the first day and $r=0.42$ ($p < 0.02$) on the second day. Inter-instrument reliability in this field setting was $r=0.96$.

Harro (1997) examined the validity of three questionnaires by simultaneously monitoring heart rate (Sport Tester) and accelerometer data. Sixty-eight children (4-8 yr) were measured on four consecutive days. Correlation between heart rate monitoring

and Caltrac data was r=0.45 ($p < 0.001$) for heart rate ≥ 140 beats/ min, and r=0.41 ($p < 0.01$) for heart rate ≥ 150 beats/ min.
Simons-Morton et al. (1994) also validated the Caltrac against heart rate monitoring. Twenty-seven 8-year old and 21 10-year old children wore an accelerometer and a heart rate monitor during one day. Correlations between Caltrac counts and monitored minutes of heart rate ≥ 180% and ≥ 200% resting heart rate ranged from r=0.55 to r=0.80.

Biotrainer Monitor
The Biotrainer Monitor (IM Systems, Baltimore, MD) is a new one-dimensional monitor that is very similar to the Caltrac, the CSA and the Tritrac Activity monitors. The Biotrainer has the size of the Caltrac Activity Monitor and the time sampling capability of the CSA and the Tritrac Activity monitors, but it uses a high-speed sampling technique instead of an integrative approach in which the counts are accumulated over a specific time interval (Welk et al., 2000a). One major advantage of the Biotrainer is that this device doesn't require computer initialization before being used. This feature makes the Biotrainer very useful for field monitoring. Another advantage is the cost. The Biotrainer is about half the price of the CSA or the Tritrac Activity monitor. A final advantage is the easy to use interface that facilitates data analyses (Welk et al., 2003) (Table 3.3). A newer model is the Biotrainer Pro.
Validity and reliability: There is no information available about the validity and reliability of the Biotrainer for use in children or adolescents.

Computer Science Applications (CSA) Monitor
The CSA Monitor (also known as the MTI accelerometer or the Actigraph) (WAM 7164) is a one-dimensional piezo-electric accelerometer. It is designed to measure normal human movement using an internal piezo-electric cantilever beam that creates a charge proportional to the magnitude of the movement. It can detect acceleration ranging in magnitude from 0.05 to 2.00 G with frequency response from 0.25 to 2.50 Hz. Movement values are accumulated and stored over a specific time period. It can store data for up to 6 weeks. The CSA Monitor can not be programmed to estimate energy expenditure.
The accelerometer is small (5.0 x 3.8 x 1.5 cm), lightweight (42 g), and designed to be unobtrusive (Table 3.3). The accelerometer is housed in a stainless steel case which can be attached to a belt, wrist or ankle. To date it is one of the smallest, but most expensive monitor available. The CSA Monitor has a black box design and therefore attracts little attention from children. A major advantage of this device is that it can be pre-programmed and turn itself on or off at a specified time and date.
Validity and reliability: Trost et al. (1998) evaluated the validity and the reliability of the CSA Monitor in 30 children and adolescents (10-14 yr) using energy expenditure assessed by indirect calorimetry as a criterion measure. The children performed three 5-min treadmill bouts at three different speeds wearing an accelerometer at each hip. Inter-instrument reliability was r=0.87. Activity counts from both CSA monitors were highly correlated to energy expenditure (r=0.86-0.87, $p < 0.001$).
Janz (1994) evaluated the validity and utility of the CSA Monitor. Thirty-one children and adolescents (7-15 yr) wore an accelerometer and a heart rate monitor for 12 hours/ day on three days. Correlations between the data assessed with the two methods ranged from r=0.50 to r=0.74. The between-day variability was low to moderate (r=-0.21-0.53). According to Janz more than three days of monitoring are needed to assess physical activity. Unlike the heart rate monitor the accelerometer was judged as comfortable to wear and not hindering their activities.

The within-day reliability of the CSA Monitor ranged between r=0.42 and r=0.47 in another study of Janz et al. (1995). Thirty children and adolescents (7-15 yr) wore a CSA Monitor for 12 hours/ day for six days. Correlations rose to r=0.81-0.84 when data of all six days was used. Acceptable stability measures were achieved with four days of monitoring.

Physical Activity Monitor (PAM)
The Physical Activity Monitor is a Dutch one-dimensional accelerometer that displays activities in an activity index, a PAM score. PAM scores range from 10 (sedentary lifestyle) to higher than 100 (extremely active) (Table 3.4).

Table 3.4 PAM scores and their corresponding activity levels (PAM, 2003)

Activity level	**PAM score**			
	< 20 yr	20-40 yr	40-65 yr	> 65 yr
Low	<30	< 20	< 15	< 10
Slight	30-40	20-30	15-25	10-20
Average	40-60	30-40	25-35	20-30
Active	60-80	40-60	35-50	30-45
Intensive	80-100	60-80	50-70	45-60
Extremely intensive	> 100	> 80	>70	> 60

The PAM is 5.8 x 4.2 x 1.3 cm in size and weighs 28 gram (Table 3.3). It is designed to stimulate people to develop a healthy and active lifestyle (PAM, 2003). PAM also offers a range of possibilities as personal coach via the internet.
Validity and reliability: To date there is no published information available about the validity or reliability of this device. The PAM has been validated in adolescents by the institute for research in extramural medicine (EMGO institute, Amsterdam) lately.

Other one-dimensional accelerometers are the Actitrac Monitor and the Mini Motion logger Actigraph.

Advantages and disadvantages of one-dimensional accelerometers
In general one-dimensional accelerometers have the same advantages and disadvantages as pedometers. They are unobtrusive. Most accelerometers discriminate changes in speed but are insensitive to changes in inclination. They are insensitive to non-locomotor activities. Accelerometers do no accurately assess the energy expenditure of cycling (a very common activity in Dutch children and adolescents) for example. Not all accelerometers are available commercially.

Judgement of the described one-dimensional accelerometers
Characteristics of the five described one-dimensional accelerometers were judged by two independent reviewers (Table 3.5).

Table 3.5 Judgement of the characteristics of the five described one-dimensional accelerometers

1-D accelerometers	Target population	Units of measurement	Cost	Size	Validity	Reliability
LSI	children	+	?	+	±	-
Caltrac	children, adolescents	+	+	+	+	+
Biotrainer	?	+	-	+	-	-
CSA	children, adolescents	+	-	+	+	±
PAM	adolescents	+	+	+	-	-

One-dimensional accelerometers seem to provide objective data about body-movement. They are small and easy to use. However, they do not detect changes in inclination and non-locomotor physical activities. Another disadvantage is the high costs compared to pedometers. So far, only the Caltrac Activity Monitor has shown to be reliable and valid in studies with children and adolescents. Therefore, in studies examining physical activity of children one should use other one-dimensional accelerometers with caution.

Three-dimensional accelerometers

Tritrac-R3D Activity Monitor

The Tritrac-R3D Activity Monitor has recently been developed to correct some of the limitations of one-dimensional accelerometers. The Tritrac is based on the same accelerometry principles as the Caltrac and CSA monitors but can assess activity in three dimensions rather than in one. It measures acceleration in three planes (horizontal, vertical and lateral), and integrates acceleration into a sum of vector magnitude. Other new developments are the ability to assess on a minute-by-minute basis and a serial interface that allows it to download data into a computer. It is designed to be attached to a belt at the waist and can be worn for up to 14 days. The device weighs 170 g and measures 11.0 x 6.9 x 3.3 cm (Nichols et al., 1999) (Table 3.3). The Tritrac-R3D Activity Monitor provides information about energy expenditure rate (kcal/ min) and activity counts. It takes into account the child’s height, weight, age and gender.

Validity and reliability: Welk & Corbin (1995) evaluated the validity of the Tritrac-R3D Activity Monitor by monitoring 35 children (9-11 yr) on three school days. Comparisons were made between data of heart rate monitoring, the Caltrac Activity Monitor and the Tritrac-R3D Activity Monitor. The Tritrac-R3D Activity Monitor was moderately, but statistically significantly, correlated with the heart rate monitoring (r=0.58), and highly correlated with the Caltrac Activity Monitor (r=0.88). It appears that the Tritrac and the Caltrac are measuring the same thing despite a large difference in cost (Caltrac $90 versus Tritrac $500), and in technological sophistication (one-dimensional versus three-dimensional). The correlations between the Tritrac-R3D Activity Monitor and the heart rate monitoring were highest during free-play situations and were lower when activity was more limited (class time) or structured (physical education).

No data has been reported about the reliability or calibration of the Tritrac-R3D with children, but the results for adults look promising. Nichols et al. (1999) assessed the validity and reliability of the Tritrac-R3D with 60 adults in a laboratory setting. The data indicated that the device is highly reliable from day to day and is sensitive to changes in speed during treadmill walking and running but not to inclination. The Tritrac-R3D accurately distinguished various intensities of walking and jogging, but is assumed to be insensitive to several other common activities as cycling. Welk et al. (2000a) found a test-retest reliability of r=0.96 when evaluating the Tritrac-R3D and two other activity monitors.

Tracmor
The Tracmor (Philips Research, Eindhoven, the Netherlands, Model 2) is a Dutch three-dimensional accelerometer. Unlike the previous models the sensor and data acquisition are combined in one system. It weighs 30 gram and measures 7.0 x 2.0 x 0.8 cm (Westerterp, 1999b) (Table 3.3).
Validity and reliability: To date there is no information available about the validity or reliability of this device in use for children or adolescents.

DynaPort MiniMod
The DynaPort MiniMod (McRoberts B.V., The Hague, the Netherlands) is a Dutch modular product line of ambulatory monitors and a remote control unit for synchronisation and event logging. The first module is a three-dimensional accelerometer (TRIACC). It is developed for monitoring human posture and gait parameters and can be used for diagnostics, treatment, evaluation and aftercare. There are several prototypes. DynaPort MiniMod prototype 3 weighs 70 gram, and measures 5.5 x 3.5 x 2.5 cm (Table 3.3). The sample frequency is 100 Hz. It is powered with two AAA cells and can measure up to three days. It can be worn around the waist (at the dorsal side of the lower trunk) with everyday clothing. Outcome measures are: gait parameters (e.g. step length and walking speed), activity counts, postures, balance, and energy expenditure of locomotion (Van Lummel et al., 2003a; Van Lummel et al, 2003b).
Validity and reliability: To date no published information is available yet about the validity or reliability of this device in use in children or adolescents. At the moment several pilot studies take place in healthy as well as in chronically ill subjects (e.g. COPD, cerebral palsy, hemiplegia, leg length discrepancy, knee and hip replacement). In the Netherlands the University of Maastricht and the University of Utrecht will validate the DynaPort MiniMod in children.

Another three-dimensional accelerometer is the RT3 Accelerometer (Stayhealthy, Inc., Monrovia, CA) (Powell et al., 2003).

Advantages and disadvantages of three-dimensional accelerometers
Despite a large difference in cost and technological sophistication it seems that three-dimensional accelerometers have the same advantages and disadvantages as pedometers and one-dimensional accelerometers. Three-dimensional accelerometers are insensitive to many forms of physical activity. Prediction equations assume steady-state exercise over a 1-min period, which is not always true in children and adolescents. Another disadvantage is the conversion of the output in units of energy expenditure. Unlike pedometers and one-dimensional accelerometers however they are better capable of detecting the intermittent activity patterns of children.

Judgement of the described three-dimensional accelerometers
Characteristics of the three described three-dimensional accelerometers were judged by two independent reviewers (Table 3.6).

Table 3.6 Judgement of the characteristics of the three described three-dimensional accelerometers

3-D accelerometers	Target population	Units of measurement	Cost	Size	Validity	Reliability
Tritrac-R3D	children	+	-	±	+	-
Tracmor	?	+	?	+	-	-
DynaPort MiniMod	children adolescents	+	-	+	-	-

In general, three-dimensional accelerometers seem to provide more information about energy-expenditure than the other methods mentioned before. However, no data are available about the reliability and calibration of the instruments. At last, the devices are very expensive and more sophisticated technologically, but still don't detect non-locomotor and static physical activities.

Other motion sensors

A completely different form of a motion sensor is the pressure-sensitive electrical resistor placed in the shoe. So far, no reliable counters have been developed. Other motion sensors include the: actometer, biomotometer and the Mini-Mitter 2000 (a leg vibration sensor) (Treuth et al., 1998).

4 Subjective methods to assess physical activity in children and adolescents

In this chapter four subjective methods to assess physical activity in children and adolescents are discussed including: direct observation, questionnaires and diaries, interviews, and proxy reports.

4.1 Direct observation

One of the most basic approaches to assess physical activity in children and adolescents is direct observation. Observation can provide information on the type of activity in a variety of field settings for variable lengths of time. Recent technological developments permit complex observational codes to be entered, stored and analysed by portable computers.
Characteristics of the reported observation methods are summarized in Table 4.1.

System for Observing Fitness Instruction Time (SOFIT)
SOFIT is an observation method to evaluate the amount of time children spend in moderate to vigorous physical activity during physical education class (Table 4.1). Energy expenditure and energy expenditure rate of each child can be estimated (McKenzie et al., 1996).
Validity and reliability: In the Child and Adolescent Trial for Cardiovascular Health (CATH) with 5106 children (8-10 yr) the inter-observer reliability of all activity and lesson context variables of the SOFIT observation method ranged between r=0.94-0.99 (McKenzie et al.,1996). SOFIT activity codes have been validated and calibrated in other studies. The activity codes correlated highly with Caltrac accelerometer data.

Children's Physical Activity Form (CPAF)
The Children's Physical Activity Form is another observation method and can be used to evaluate a fitness-oriented physical education curriculum (Table 4.1). Children are scored each minute on four categories representing different levels of intensity of movement. The first category is the 'stationary, no movement' category. It represents occasions in which there is no movement to another point in space and virtually no purposeful limb movement. The second category, 'stationary, limb movement', includes periods in which there is limb movement, but no trunk movement. The third category is 'slow trunk movement'. Examples of activities in this category are: walking, sit ups, and trunk twisters. The last category is 'rapid trunk movement' and includes activities as running and rope jumping (O'Hara et al., 1989). Each category can be reported only once a minute. For every observed minute an activity point score can be calculated. MET[3] values can be assigned to calculate energy expenditure.
Validity and reliability: O'Hara et al. (1989) assessed the validity of the CPAF in 36 children (8-10 yr). They were observed during physical education class and were wearing a heart rate monitor. Heart rate in the previous minute was significantly correlated with the observed activity point score (r=0.64 (0.26-0.90)). In another study the inter-observer agreement was obtained. Average inter-observer agreement ranged between 96%-98% across three years.

[3] MET = metabolic equivalent. One MET equals oxygen consumption at rest which is about 3.5 ml/ kg/ min.

Table 4.1 Characteristics of several observational methods

Method of measurement	Outcome variable	Setting	Frequency	Intensity	Time	Type	Light	Moderate	Vigorous	Validity	Reliability	Calibration	Training time	Reference
SOFIT	MVPA, energy expenditure (rate)	physical education class		x	x			x	x	? Caltrac	IO: r = 0.94-0.99	heart rate monitor	10-15 h	McKenzie et al., 1996
CPAF	activity score, energy expenditure	physical education class		x		x	x	x	x	r = 0.26-0.90 heart rate monitor	IO = 96-98%	?	15-25 h	O'Hara et al., 1989
SOPLAY	activity counts, energy expenditure rate, MVPA counts	diverse		x		x	x	x	x	r = 0.71/ 0.73/ 0.35 self-report	IO = 80% r = 0.75	heart rate monitor	> 20 h	McKenzie et al., 2000 McKenzie et al., 1991
CARS	CARS score, time, energy expenditure rate	diverse		x		x	x	x	x	?	IO = 84.1% TR: r = 0.53-0.59	heart rate monitor VO2	30 h	Puhl et al., 1990 Durant et al., 1993a

MVPA = moderate to vigorous physical activity; IO = Inter-observer reliability or inter-observer agreement; TR = test-retest reliability

System for Observing Play and Leisure Activity in Youth (SOPLAY)
SOPLAY is designed to obtain observational data on the number of children and their physical activity levels during play and leisure activities in a specified activity area before school, during lunch time, and after school (Table 4.1) (McKenzie et al., 2000). SOPLAY is based on momentary time sampling techniques in which systematic and periodic scans of individuals and contextual factors are made. The predominant type of activity is classified for each predefined area (Table 4.2). The activity level is mechanically and electronically coded as sedentary (lying, sitting or standing), walking or very active. Separate scans are made for girls and boys. Other factors that are recorded are: time of day, temperature, area accessibility, area usability, presence of supervision, presence and classification of organized activity, and equipment availability. To reliably observe all aspects, a training of at least 20 hours is required.
Depending on the research question (gender, school, period, area) raw counts in each activity level are aggregated. The counts can be transformed into estimates of energy expenditure rate based on constants for each level of activity. The number of intervals (minutes) counted in the sedentary, walking, and very active categories are multiplied by the constants 0.051, 0.096, and 0.144 kcal/ kg/ min, and the child's weight. These constants were derived from a previous study of McKenzie et al. (1991) with 19 children aged 4 to 9 years old who wore a heart rate monitor while being observed. A third score that can be calculated is the moderate to vigorous physical activity score that can be obtained by summing the time spent in walking and very active categories.

Table 4.2 Physical activity codes of SOPLAY (McKenzie, 2002)

Physical activity codes
0. no specific activity (sit, stand, walk)
1. aerobics (dance, step aerobics)
2. baseball/ softball
3. basketball
4. dance (ballet, country, line)
5. football
6. gymnastics
7. martial arts (judo, karate)
8. racquet sports (tennis, badminton)
9. soccer
10. swimming
11. volleyball
12. weight training/ lifting
13. playground games (e.g. tetherball, 4-square)
14. none of the activities above

<u>Validity and reliability</u>: McKenzie et al. (2000) examined the reliability and validity of the SOPLAY observation method. Systematic observations were made of children (11-13 yr) during three days at 24 schools over 20 weeks. Inter-observer agreement (80%) and intraclass correlation (r=0.75) met acceptable criteria for reliable assessment during 14 days of field assessment. Across three measurement days the intraclass correlation for estimating energy expenditure was r=0.88 for boys, and r=0.75 for girls suggesting that three, respectively four days of observation are needed to reach a reliability level of r=0.80. Correlations of observed moderate to vigorous physical activity and self-reported physical activity before school, at lunch time, and after school were r=0.71,

r=0.73, and r=0.35, respectively, providing initial support for the concurrent validity of SOPLAY.

Children's Activity Rating Scale (CARS)
The Children's Activity Rating Scale is a scale for 3- to 5-year old children designed to evaluate children's physical activity involvement during periods of investigator observation (Table 4.1). Children are observed for 6 to 12 hours per day. The intensity of their activities is scored on a five-point scale from stationary till very fast movement (Table 4.3). The five categories of physical activity reflect levels of energy expenditure. The categories are based on research on measured energy expenditure in children during physical activity, energy cost of various physical activities in adults, the relationship between the amount and type of movement and energy expenditure, and research of heart rate monitoring in children during physical activity (Puhl et al., 1990). Activities were assigned to the five levels based on the amount of body movement and the estimated intensity of the activity. In general, level 1 and level 2 activities have no cardiovascular or aerobic training effects.
Observers are trained for approximately 30 hours over an 8-week period using videotapes and group discussions. The trained observer records the activity level continuously at the start of each minute and any subsequent changes of activity level during this minute. It can be recorded into a portable computer. Each activity level can not be coded more than once each minute. There are several methods of scoring the observed data. One can calculate the mean CARS score across minutes. Other indices are the percent of time that activity was recorded at level 3, 4 or 5, the percent of time at which only level 3, 4 or 5 was recorded, the percent of time at which level 4 or 5 was recorded, and the percent of time only level 4 or 5 was recorded (Durant et al., 1993a). CARS scores can also be used to estimate energy expenditure.

Table 4.3 The five activity levels of the CARS (Durant et al., 1993a)

Level/ description	Expected heart rate (beats/ min)	Examples of physical activities
1. stationary – no movement	< 100	lying, sitting
2. stationary – with movement	100 – 119	standing/ colouring, standing/ ball activity
3. translocation – slow/ easy	120 – 139	walking 2.5 mph, 0% grade
4. translocation – medium/ moderate	140 – 160	walking 2.5 mph, 5-10% grade
5. translocation – fast/ very fast/ strenuous	> 160	walking 2.5 mph, 15% grade

<u>Validity and reliability</u>: Puhl et al. (1990) examined the reliability of the CARS. The CARS was used by 11 trained observers over a 12-month period to assess physical activity in children (3-4 yr) in a variety of field settings, including home, playground, and school. The mean percent agreement between observers for 389 paired observations was 84.1% ± 10.1. Twenty-five 5- to 6-year old children participated in a calibration study. The VO_2 and heart rates were measured while performing eight activities representing the five CARS levels. VO_2 values and heart rates values were significantly different between levels, which supports the capability of the CARS to differentiate between intensities of energy expenditure and heart rate. No child reactivity problems were recorded in 93% of the reports filled in by the observers.
Durant et al. (1993a) examined the reliability of the CARS in 180 preschool children (3-4 yr) from three different ethnic groups. CARS scores were measured by two trained

observers for up to 12 hours a day. The mean inter-observer agreement was 84.1% (± 10.1). The data showed that the activity levels of the children varied substantially throughout the day and across days. Single measurement reliabilities ranged from r=0.18 to r=0.21. Between-day reliabilities ranged from r=0.53 to r=0.59. Approximately 16 days of all day observation would be needed to raise the reliability to r=0.80. It appeared there were no significant ethnic or day of the week differences in the activity levels. Boys had higher activity levels than girls and higher activity was performed in the summer and fall than in winter or spring.
No information is available about the validity of the CARS.

Other observation methods are the Activity Patterns and Energy Expenditure (APEE) observation method and the Fargo Activity Time sampling Survey (FATS) observational system (2-4 yr).

Advantages and disadvantages of direct observation
An advantage of direct observation is that this method of assessing physical activity does not require equipment that can hinder children in their movements. It provides information on the specific type of activity that occurs. Observation can take place in a variety of settings for variable lengths of time. Disadvantages of observation are: it is time-consuming, it is labour intensive and trained observers are needed. Therefore this method is impractical for large-scale research.

Judgement of the described observation methods
Characteristics of the four described observation methods are summarized by two independent reviewers (Table 4.4).

Table 4.4 Judgement of the characteristics of the four described observation methods

Direct observation	Target population	Units of measurement	Training time	Validity	Reliability
SOFIT	children	±	+	+	+
CPAF	children	+	±	+	+
SOPLAY	children, adolescents	+	-	+	+
CARS	children	+	-	-	+

As can be seen observational systems for assessing the physical activity level of adolescents were not frequently located. Only one of the four observation methods mentioned, has been tested for use with children beyond 12 years old.
Observation is a useful method to obtain information about the physical activity of (especially) younger children, in whom accurate and self-reported data are more difficult to assess. It can be used for small to moderate sample sizes.

4.2 Self-reports

Due to limited time and manpower self-reports are very popular in large-scale epidemiologic studies. Self-reports include: questionnaires and dairies, interviews, and proxy reports.
Characteristics of self-reports are summarized in Table 4.8.

Questionnaires and diaries

Investigators typically select or develop questionnaires and diaries based on the needs of the particular study.

Physical Activity Questionnaire corresponding to the Dutch physical activity guideline

TNO Prevention and Health and TNO Work and Employment often use two questions to differentiate populations into physical active and physical inactive individuals according to the Dutch physical activity guideline (NNGB) (Table 4.8). The questions are: How many days a week do you have physical activities for at least 30 (adults)/ 60 (children) minutes a day in the summer/ in the winter? According to the Dutch physical activity guideline children should be physically active for at least 60 minutes a day (Kemper et al., 2000).

Validity and reliability: Urlings et al. (2000) examined the validity of this questionnaire in 213 adults (20-68 yr) and 168 children (4-12 yr). They completed the short questionnaire and a more comprehensive Dutch questionnaire, the POLS (Permanent Onderzoek Leefsituatie, > 12 yr, CBS), in which frequency, time, and type of activity are asked. Children who were considered to be active according to the simple questionnaire did not have a significantly higher activity score according to the POLS in comparison with children who were considered to be inactive. Depending on the definition of 'active' (≥ 5, ≥ 6, and 7 days a week) versus 'inactive', the simple questionnaire misclassified 23-39% of the children when compared with the POLS questionnaire.

Short Questionnaire to Assess Health enhancing physical activity (SQUASH)

The SQUASH is a short Dutch questionnaire developed by the National Institute of Public Health and the Environment (RIVM) in consultation with TNO Prevention and Health. It is designed to form a picture of the habitual physical activity level of subjects of 12 years and older (Botterweck et al., 2003; Wendel-Vos & Schuit, 2002). It is not designed to measure energy expenditure. The SQUASH consists of 12-15 questions (Table 4.8). It takes about 3-5 minutes to complete the form (Wendel-Vos et al., 2003). The questions are divided in four categories: 1.) physical activities in commuter traffic; 2.) physical activities at work/ school; 3.) household physical activities; and 4.) leisure time physical activities (e.g. sports, recreational activities) (Table 4.5). The subject has to indicate how many days per week, how much time per day, and how intense he/ she performed certain activities in an average week in the past months.

Table 4.5 Questions in each category (Wendel-Vos & Schuit, 2002)

Category	Questions
Commuter traffic	Walking to/ from work or school
	Cycling to/ from work or school
Physical activities at work/ school	Light and moderate physical activities at work
	Vigorous physical activities at work
Household physical activities	Light and moderate household activities
	Vigorous household activities
Leisure time physical activities	Walking
	Cycling
	Gardening
	Doing odd jobs, repairing
	Sport

By multiplying frequency by duration, total minutes of activity per week can be calculated. The total weekly activity score is calculated by multiplying total minutes of activity by the intensity score. The intensity score is based on Ainsworth's Compendium of Physical Activities (1993) in which MET values are assigned to physical activities, and the reported effort (Table 4.6). Activities are divided in light, moderate, and vigorous intensity categories taking into account the age categories of the Dutch guideline (Table 4.7). A last outcome measure is the compliance with the Dutch physical activity guideline.

Table 4.6 Intensity scores based on Ainsworth's Compendium and self-reported intensity (Botterweck et al., 2003)

Intensity Ainsworth's Compendium & NNGB	**Self-reported intensity**		
	Slow/ light	Moderate	Fast/ vigorous
Light	1	2	3
Moderate	4	5	6
Vigorous	7	8	9

Table 4.7 MET values of light, moderate, and vigorous intensity taking into account the subject's age (Botterweck et al., 2003)

Age	**Light**	**Moderate**	**Vigorous**
≤ 18 yr	< 5 METs	5-8 METs	≥ 8 METs
18- 55 yr	< 4 METs	4-6.5 METs	≥ 6.5 METs
≥ 55 yr	< 3 METs	3-5 METs	≥ 5 METs

<u>Validity and reliability:</u> To date nothing is published about the validity or reliability of this questionnaire in use in children or adolescents. Recently an adjusted version of the SQUASH has been tested in adolescents by the institute for research in extramural medicine (EMGO institute, Amsterdam), but no information is available yet.
The validity and reliability of the questionnaire has been examined in adults (Wendel-Vos et al., 2003; Wendel-Vos & Schuit, 2002). The correlation between CSA Activity Monitor data and the SQUASH was r=0.45 (0.17-0.66). The test-retest reliability of the questionnaire was r=0.58 (0.36-0.74).

Habitual Activity Estimation Scale (HAES)
The Habitual Activity Estimation Scale is another Dutch questionnaire. It is developed by the UMC Utrecht and requires children to report the time they spent in four activity levels on a usual school day and a weekend day in the previous two weeks (Table 4.8) (Klijn, 2001). The four activity levels are: inactive (sleeping, resting), somewhat inactive (e.g. sitting, reading, watching television), somewhat active (e.g. walking, shopping, household physical activities), and very active (e.g. running, jumping, and swimming). The HAES consists of 29 questions.
<u>Validity and reliability:</u> To date no published information is available about the validity or reliability of this questionnaire. Recently the reliability of the HAES has been examined.

Physical Activity Rating Instrument (PARI)
The Physical Activity Rating Instrument is a normative one-item rating scale that requires children to rate their activity level in comparison with their peers (of the same

age and sex). They can rate their activity level from 1 (much less active than others) to 7 (much more active than others) (Table 4.8).
Validity and reliability: The PARI has been validated by Janz et al. (1995). Thirty children and adolescents (7-15 yr) wore an accelerometer for 12 hours/ day for six days and filled in the scale twice. Correlations between the CSA Monitor and the scale ranged from r=-0.03 to r=0.17. Test-retest reliability was r=0.85.
In a study of Sallis et al. (1993a) the test-retest reliability was r=0.89 for rating the physical activity level within two weeks. In a group of 102 children and adolescents (10-16 yr) they also compared energy expenditure estimated by the 7-d Physical Activity Recall and the Godin-Shephard Physical Activity Survey with the Physical Activity Rating Instrument. Correlations with the 7-d PAR ranged from r=0.07 for 11th graders (16 yr) to r=0.38 for the younger age groups, and from r=0.15 to r=0.52 for the Survey. Highest correlations were found for the youngest subjects.

Godin-Shephard Physical Activity Survey
The Godin-Shephard Physical Activity Survey is a self-report measure developed by Godin and Shephard. Subjects report the number of times in an average week they spend more than 15 minutes in activities that are classified as mild (3 METs), moderate (5 METs), or strenuous (9 METs). A total score can be derived by multiplying the frequency of each category by the MET value (Table 4.8).
Validity and reliability: Sallis et al. (1993a) assessed the validity and reliability of the Godin-Shephard Physical Activity Survey and two other self-report measures. Subjects were 102 children and adolescents (10-16 yr). Test-retest reliability of two surveys collected within two weeks was r=0.81. Reliability improved with age, but was significant at all ages. Correlations between energy expenditure estimated by the Survey, the 7-d Physical Activity Recall, and the PARI ranged from r=0.32 to r=0.60, and from r=0.15 to r=0.52, respectively.

3-d Sweat Recall
The 3-d Sweat Recall requires children to report the number of episodes in which they were sweating or breathing hard due to physical activity in the last three days (Table 4.8). Episodes were defined as sports, games, play, work, or movement that lasted approximately 20-90 minutes. An advantage of the 3-d Sweat Recall is that is does not rely on the cognitive abilities of children to recall the precise time they spent in certain activities. A disadvantage of the 3-d Sweat Recall is that young children have lower sweat rates than adults. Thus it may be inappropriate to use a sweat recall to estimate physical activity in preadolescent children.
Validity and reliability: Test-retest reliability was r=0.30 in a study of Janz et al. (1995) with 30 7- to 15-year old children. Correlations between a CSA accelerometer and the 3-d Sweat Recall ranged from r=0.46 to r=0.51 ($p < 0.05$).

3-d Aerobic Recall
The 3-d Aerobic Recall requires children to report the number of episodes in the last three days which caused them to sweat or to breathe hard for at least 20 minutes (Table 4.8).
Validity and reliability: The 3-d Aerobic Recall has been validated by Janz et al. (1995). Thirty children and adolescents (7-15 yr) wore an accelerometer for 12 hours/ day for six days and filled in the scale twice. Correlations between the CSA Monitor and the scale were not significant and ranged from r=0.05 to r=0.39. Test-retest reliability was r=0.54.

Physical Activity Questionnaire for Older Children (PAQ-C)
The Physical Activity Questionnaire for Older Children is a self-administered 7-d recall questionnaire to assess habitual moderate to vigorous physical activity in older children (> 8 yr) (Table 4.8). The PAQ-C was developed through a multi-step process. A list of possible items was generated and tested in a sample of school children (9-13 yr). A revised version of the questionnaire was developed based on feedback of the tested children, research assistants, and item analysis. The final PAQ-C consists of ten items, of which nine are used to calculate a summary activity score. The first question is an activity checklist consisting of common physical activities (i.e. sports, leisure activities, games). It is primarily meant to act as a memory cue. Six questions assess physical activity in physical education class, recess, lunch, after school, in the evening, and on weekend days. Children are asked to score a statement describing low to very high activity levels. The last question asks the children how often he/ she did physical activity for each day of the week. From these questions a final PAQ-C is calculated. It can range from one to five. The questionnaire is not meant to be used to estimate energy expenditure.
Validity and reliability: Crocker et al. (1997) investigated the psychometric properties of the PAQ-C in school children (8-16 yr). They concluded that the PAQ-C had acceptable item and test score characteristics such as item distribution, item-total correlations, and internal consistency (Cronbach's alpha = 0.79-0.89). Test-retest reliability after one week was r=0.75 for boys, and r=0.82 for girls. Crocker et al. examined the reliability of using an average of two or three activity scores from different seasons. Generalizability coefficients exceeded 0.80 for either the average of two or three final PAQ-C scores for both younger (< 13 yr) and older children. The PAQ-C was sensitive for activity differences between boys and girls and differences across seasons.
There is no information available about the validity of the PAQ-C.

PACE+ Adolescent Physical Activity Measure
The PACE+ Adolescent Physical Activity Measure is a screening measure for adolescents. It was developed to identify individuals not meeting physical activity guidelines in a PACE+ (Patient-Centred Assessment and Counselling for Exercise Plus Nutrition) physical activity computer-based intervention in primary care (Prochaska et al., 2001). The PACE+ questionnaire consists of two questions. It measures the number of days the subject has accumulated 60 minutes of moderate to vigorous physical activity (MVPA) in the previous week and in a typical week (Table 4.8). A combined average of the two items yields a score of days per week the adolescent accumulated 60 minutes of MVPA. If the combined score is five or more days per week the physical activity guideline is met.
Validity and reliability: Prochaska et al. (2001) conducted three studies to evaluate the reliability and validity of different versions of the PACE+ Adolescent Physical Activity Measure. The final version was tested in 138 adolescents. The combined MVPA score correlated significantly with CSA accelerometer data (r=0.40, p < 0.001). Test-retest reliability ranged from r=0.53 for a retest at up to one month, to r=0.88 for a same-day retest. The correct classification rate (63%), sensitivity (71%), and false-positive rate (40%) were reasonable for use in clinical settings.

Previous Day Physical Activity Recall (PDPAR)
The Previous Day Physical Activity Recall is a questionnaire to assess children's previous day's physical activities for the after school hours (3.00-11.30 p.m.) (Table 4.8). A one-day recall period was chosen because in general young children have

difficulties in recalling their physical activity behaviour over longer time periods. The PDPAR is divided in 17 30-minute time intervals to improve recall. To further enhance the accuracy of recall, a list of common physical activities is provided. These activities are grouped in the following categories: sleeping/ bathing, eating, transportation, work/ school, spare time, play/ recreation, and exercise/ workout. The child records the activity and the corresponding intensity of the activity for each 30-minute interval. For each level of intensity (very light, light, medium, and hard) a cartoon illustration is provided. By assigning a MET value to each reported activity and intensity, physical activity energy expenditure can be estimated. The PDPAR can also be used to record individual bouts of physical activity at or above specified levels of energy expenditure. The amount of sedentary activities can also be recovered.
Validity and reliability: Weston et al. (1997) evaluated the PDPAR in 119 adolescents (12-18 yr). The inter-rater reliability for scoring the PDPAR was r=0.99 ($p < 0.01$), which means that the scoring protocol of the PDPAR can be used consistently by different investigators. Test-retest reliability was reported as the correlation between the estimated energy expenditure determined from two PDPAR forms completed within one hour. Test-retest reliability was r=0.98 ($p < 0.01$). The validity of the PDPAR was examined in 48 adolescents by a pedometer, a Caltrac accelerometer, and in 26 adolescents by a heart rate monitor (Polar Vantage XL). The Pearson correlation coefficient between total pedometer count and estimated total energy expenditure was r=0.88, and r=0.77 between Caltrac counts and estimated energy expenditure. Percentage of heart rate reserve for each 30-minute interval and estimated rate of energy expenditure in the same interval generally failed to reach statistical significance and ranged between r=-0.62-0.90. Only mean energy expenditure derived from type of activity and intensity were found to be significantly related to percentage of heart rate reserve for the after school period (r=0.53, $p < 0.01$). Weston et al. concluded that adolescents can recall with accuracy the type and level of intensity of their physical activities but often do not accurately recall the exact time period during which they engaged in these activities.

Self-administered Physical Activity Checklist (SAPAC)
The SAPAC assesses the participation of the child in physical activity, both in and out of school. The children report the number of minutes they spent on the previous day in various common physical activities and some sedentary activities (Table 4.8) (McKenzie et al., 1996). To help the children to recall their activities a list of 21 activities is provided. Watching television/ video, and playing computer games is also reported. The child is instructed to report engaging in an activity only if they performed them for more than 5 minutes at a time. Children are also instructed to report the time they were really active and not to include time they were resting or waiting on their turn. In addition to time, children are asked to report if the activity caused them to breathe hard or feel tired none, some, or most of the time. This rating provides a subjective index of intensity.
The self-reported data can be summarized with the following five outcome measures: minutes in sedentary activities, number of activities, minutes spent in moderate to vigorous physical activities, physical activity MET score, and weighted activity MET score. Mean administration time for the SAPAC is about 35 minutes (Sallis et al., 1996).
Validity and reliability: The questionnaire has been validated by Sallis et al. (1996) in a multiethnic population of 10-year old children. Fifty-five boys and 70 girls simultaneously wore an accelerometer and a heart rate monitor for at least 8 hours the day before the questionnaire was filled in. SAPAC scores correlated significantly with

an interview form of the questionnaire (PACI) (r=0.76). The correlations between the different outcome measures of the SAPAC and heart rate ranged from r=0.28 for number of activities to r=0.60 for physical activity MET score. Correlations for the different SAPAC scores and Caltrac accelerometer counts ranged from r=0.02 to r=0.32. Sallis et al. concluded that although children overestimate the absolute amount of minutes of physical activity, their reports are useful as measures of relative amount of physical activity.

Yesterday Activity Checklist, Weekly Activity Checklist, Weekly Activity Sum, 7-Day Activity Tally
Sallis et al. (1993b) developed four forms of questionnaires to assess physical activity in children (9 yr) before and after school (Table 4.8). The 7-Day Tally asks the child to report the number of days they performed activities in the previous week that were hard enough to make them get tired, breathe hard, or sweat. The Yesterday Activity Checklist, the Weekly Activity Checklist, and the Weekly Activity Sum provide a list of 20 physical activities commonly performed by children of that age. Children report if they were engaged in these activities or not in the previous day or week. They are only reported if the activities lasted 15 minutes or more. Each activity is assigned a MET value. Light activities are scored as 3 METs, medium activities as 5 METs, and hard activities as 9 METs. By multiplying the frequency of each activity by it's assigned MET value, energy expenditure can be calculated. Because recall of physical activity is a complex cognitive task careful administration procedures are described in the protocol to prepare the children for the assignment.
Validity and reliability: Sallis et al. (1993b) evaluated the test-retest reliability and the validity of the four questionnaires by comparing the data with Caltrac accelerometer data. Sixty-six children (9 yr) wore an accelerometer for three days. Three-day interval reliability was r=0.60 for the Yesterday Activity Checklist, r=0.74 for the Weekly Activity Checklist, r=0.51 for the Weekly Activity Sum, and r=0.68 for the 7-Day Activity Tally. Correlations between MET scores or number of days moderate to vigorous physical activity was performed, and Caltrac activity counts ranged between r=-0.10 and r=0.40. The reliability and validity data provided some support for the use of the Weekly Activity Checklist and the Yesterday Activity Checklist.

Other examples of questionnaires and diaries are: The Amsterdam Growth Study Questionnaire (VU, Amsterdam, the Netherlands), the Jump-in questionnaire (GG&GD Amsterdam, the Netherlands), the 3-month Activity Recall, the Child/ Adolescent Activity Log, the Physical Activity Questionnaire for Adolescents, the Amherst Health and Activity Study (AHA), adult survey of child health habits and student survey, and Sports, Play, and Active Recreation for Kids (SPARK) physical activity self-reports.

Table 4.8 Characteristics of several self-reports

Method of measurement	Assessment format	Recall period	Outcome variable	Frequency	Intensity	Time	Type	light	moderate	vigorous	organised (sport, p.e.)	unorganised (leisure)	work/ school	household	transport	Validity	Reliability	Reference
NNGB	Q	usual year	NNGB	x	-	-	-	-	-	-	-	-	-	-	-	POLS	?	Urlings et al., 2000
SQUASH	Q	usual week	total activity score, NNGB	x	x	x	x	x	x	x	x	x	x	x	x	?	?	Wendel-Vos et al., 2003 Wendel-Vos & Schuit, 2002
HAES	Q	previous two weeks	?	-	-	x	x	-	-	-	x	x	x	x	x	?	?	Klijn, 2001
PARI	Q	not applicable	physical activity level	-	-	-	-	-	-	-	-	-	-	-	-	r = -0.03-0.17 CSA r = 0.07-0.38 7-d PAR r = 0.15-0.52 Godin-Shephard	TR: r = 0.85 TR: r = 0.89	Janz et al., 1995 Sallis et al., 1993a
Godin-Shephard Physical Activity Survey	Q	usual week	energy expenditure	x	x	-	x	x	x	x	?	?	?	?	?	r = 0.32-0.60 7-d PAR r = 0.15-0.52 PARI	r = 0.81	Sallis et al., 1993a

3-d Sweat Recall	Q	previous 3 days	frequency	x	-	-	x	-	-	-	x	x	x	?	?	r = 0.46-0.51 CSA	TR: r = 0.30	Janz et al., 1995
3-d Aerobic Recall	Q	previous 3 days	frequency	x	-	-	-	-	-	-	-	-	-	-	-	r = 0.05-0.39 CSA	TR: r = 0.54	Janz et al., 1995
PAQ-C	Q	previous week	PAQ-C score	x	x	-	x	-	x	x	x	x	x	-	-	?	ά = 0.79-0.89 TR: r = 0.75/0.82	Crocker et al., 1997
PACE+	Q	previous week, usual week	MVPA, guideline	x	-	-	-	-	-	-	-	-	-	-	-	r = 0.40 CSA	TR: r = 0.53-0.88	Prochaska et al., 2001
PDPAR	Q	previous day	energy expenditure, inactivity, MVPA	-	x	-	x	x	x	x	x	x	x	-	x	r = 0.88 pedometer r = 0.77 Caltrac r = -0.62-0.90 Polar Vantage XL	IR: r = 0.99 TR: r = 0.98	Weston et al., 1997
SAPAC	Q	previous day	time, number of activities, MVPA time, MET score, inactivity	-	x	x	x	x	x	x	x	x	x	?	?	r = 0.28-0.60 Heart Watch r = 0.02-0.32 Caltrac r = 0.76 PACI	?	Sallis et al., 1996
Yesterday Activity Checklist	D	previous day	energy expenditure	x	-	-	x	-	-	-	?	?	-	?	?	r = 0.33/ 0.22 Caltrac	TR: r = 0.60	Sallis et al., 1993b
Weekly Activity Sum	Q	previous week	energy expenditure	x	-	-	x	-	-	-	?	?	-	?	?	r = 0.40/ 0.15 Caltrac	TR: r = 0.51	Sallis et al., 1993b

Weekly Activity Checklist	Q	previous week	energy expenditure	x	-	-	x	-	-	-	?	?	-	?	?	r = 0.34/ 0.26 Caltrac	TR: r = 0.74	Sallis et al., 1993b
7-Day Activity Tally	Q	previous week	number of days of MVPA	x	-	-	-	-	-	-	?	?	-	?	?	r = 0.11/-0.10 Caltrac	TR: r = 0.68	Sallis et al., 1993b
7-d PAR	I	previous week	time, energy expenditure	-	-	x	x	-	-	-	x	x	?	?	?	r = 0.44/ 0.53 Heart Watch	TR: r = 0.54-0.77	Sallis et al., 1993a
MLTPAQ	I	previous year	energy expenditure	-	-	x	x	-	-	-	?	?	?	?	?	r = 0.49/ 0.73 DLW	?	Slinde et al., 2003
PAI	I	previous day	MVPA time	-	-	x	x	-	-	-	x	x	x	?	x	r =0.72/ 0.57 heart rate monitor r = 0.63/ 0.80 Caltrac	?	Simons-Morton et al., 1994
PACI	I	previous day	time, number of activities, MVPA time, MET score	-	x	x	x	x	x	x	x	x	x	?	?	r = 0.76 SAPAC r = 0.22-0.54 Heart Watch r = 0.10-0.38 Caltrac	?	Sallis et al., 1996
Parent-teacher questionnaires	P	previous week	MVPA	-	x	x	x	x	x	x	x	x	x	-	x	r = 0.40 Sport Tester r = 0.53 Caltrac	?	Harro, 1997

Q = questionnaire; D = diary; I = interview; P = proxy report; NNGB = Nederlandse Norm Gezond Bewegen; DLW = doubly labelled water; IR = inter-rater reliability; TR = test-retest reliability; MVPA = moderate to vigorous physical activity

Interviews

7-day Physical Activity Recall (7-d PAR)

The 7-d Physical Activity Recall is an interview that provides insight in the physical activity of a subject of the previous week (Table 4.8). At first it was only used in adults, nowadays it is also used in adolescents and children. During the interview the child is asked to recall time spent sleeping, and performing moderate, hard, and very hard physical activities over the past week. Time spent in light activities can be estimated by subtraction. Only bouts of activity longer than 15 minutes are included. Week days and weekend days are scored separately. The interview protocol uses a segmented recall format that allows a subject to recall activities in the morning, afternoon, and evening. Examples that fit into each category are provided on a paper and are described by a (trained) interviewer. Outcome measures are total time spent in each category per day and per week, and estimated energy expenditure (Welk et al., 2000c). The interview takes about 10-15 minutes.

Validity and reliability: The reliability and the validity of the 7-d PAR have been examined by Sallis et al. (1993a). A hundred-two children and adolescents (10-16 yr) reported their physical activities with three different self-report methods. To validate the 7-d PAR, heart rate monitors (Heart Watch) were used. The 7-d PAR was administered several times. Test-retest reliabilities ranged from r=0.54 to r=0.77 for the five outcome measures. The highest test-retest correlation was found for estimated energy expenditure. Three mediators of the reliability of recalls were found: length of the interval between recall, gender, and memory skills. Reliability decreased from r=0.79 after a 2-3 day interval to r=0.45 after a 4-6 day interval. The selection of seven days as the period of recall appears to be at the limit of children's ability to recall. In general, 7-d PAR scores of very hard activities correlated well with heart rates ≥ 140 (r=0.44, $p < 0.001$) or ≥ 160 beats/ min (r=0.53, $p < 0.001$). Validity improved with age (10 yr: r=0.33/ 0.29; 13 yr: r=0.36/ 0.45; 16 yr: r= 0.57/ 0.72).

Minnesota Leisure Time Physical Activity Questionnaire (MLTPAQ)

The MLTPAQ is an interview to assess what type of physical activities the subject has been doing in the last year. The subject also estimates the duration of the different activities in minutes per week for each season. The time is then multiplied by a MET value to obtain the total energy expenditure. It was originally designed for adults (Table 4.8).

Validity and reliability: The MLTPAQ has been validated for use with adolescents by Slinde et al. (2003). Thirty-five adolescents (15-17 yr) were interviewed using the MLTPAQ and an extended version of the MLTPAQ with additional questions about inactivity during leisure time (eMLTPAQ). Next to these two methods total energy expenditure was assessed by the doubly labelled water method over a 14-d period. Energy expenditure estimated by the interview correlated well with the measured energy expenditure (r=0.49, $p < 0.01$), and the correlation increased (r=0.73, $p < 0.01$) when including questions about inactivity (e.g. sleeping time, homework, watching television, computer games). Although the interviews underestimated total energy expenditure, the MLTPAQ and the eMLTPAQ seem to be valid methods to rank adolescent's energy expenditure and to describe leisure time physical activity patterns.
There is no information available about the reliability of the MLTPAQ or the eMLTPAQ.

Physical Activity Interview (PAI)

In the Physical Activity Interview a child is questioned by a trained interviewer about the type and amount of physical activity the child performed in the previous day (Table

4.8). Interviewers were trained for three hours to learn how to use the PAI protocol and obtain interviewing skills. Prior to data collection they complete three practice interviews. The PAI protocol requires the interviewer to account for the child's time before school, during school, after school, and dinner. Special attention is paid to moderate to vigorous physical activities. It takes about 12 minutes to complete an interview (Simons-Morton et al., 1994). The outcome measure of the PAI is the amount of time spent in moderate to vigorous physical activities (MVPA).
Validity and reliability: The validity of the PAI was examined by Simons-Morton et al. (1994) by comparison with monitored heart rates. Twenty-seven 8-year old children and 21 10-year old children wore a Caltrac accelerometer and a heart rate monitor for one day. The next day they were interviewed with the PAI. They also completed the Physical Activity Record (PAR) to help the children to recall their activities of the previous day. Correlations between reported MVPA time and monitored time heart rates ≥ 180% and ≥ 200% of the rest heart rate was r=0.72 for 10-year olds and r=0.57 for 8-year olds. Correlations between Caltrac counts and reported minutes was r=0.63 for 10-year olds and r=0.80 for 8-year olds. In general, reported time spent in moderate to vigorous physical activities was overestimated in the interview. According to the investigators of the study this may have been due to the children's limited ability to recall, or their tendency to report the minutes they were involved in the activity rather than the amount of time they were truly active. For future use of the PAI they added a column 'true minutes' to the interview form.
There is no information available about the reliability of the PAI.

Physical Activity Checklist Interview (PACI)
The PACI is an interview form of the SAPAC (Table 4.8). The PACI was developed to obtain information about the physical activity level of 10-year old children. Children have to report the time they spent in various common physical activities and some sedentary activities during three time periods of the previous day: before school, during school, and after school. The child is instructed to report engaging in an activity only if they performed them for more than five minutes at a time. In addition to time, children rate the intensity of each activity.
The self-reported data can be summarized with the following five outcome measures: minutes in sedentary activities, number of activities, minutes spent in moderate to vigorous physical activities, physical activity MET score, and weighted activity MET score. Mean administration time of the PACI is about 18 minutes (Sallis et al., 1996).
Validity and reliability: Sallis et al. (1996) validated the PACI against monitored heart rate data (Heart Watch) and accelerometer counts in 125 children (10 yr). PACI scores correlated significantly with a self-administered form of the questionnaire (SAPAC) (r=0.76). The correlations between the different outcome measures of the PACI and heart rate ranged from r=0.22 for number of activities to r=0.54 for weighted physical activity MET score. Correlations for the different PACI scores and Caltrac accelerometer counts ranged from r=0.10 to r=0.38. Sallis et al. concluded that although children overestimate the absolute amount of minutes of physical activity, their reports are useful as measures of relative amount of physical activity and thus to rank groups.

Proxy reports
Not all children are capable of understanding or reading questionnaires or diaries. Especially in young children (< 8 yr) proxy reports are used. In proxy reports a person proximate to the child answers for the child.

Parent and teacher report of physical activity

Because some studies have considered the teacher or the parental recall method unreliable (Janz et al., 2002), Harro (1997) developed a combined parent and teacher report to assess the physical activity of children (4-8 yr) (Table 4.8). By combining information of the teacher and the parent a better, more reliable, estimation of the physical activity of the child during the whole day should be obtained. The assessment method developed by Harro consists of three questionnaires, one for the parents, one for a kindergarten teacher, and one for an elementary school teacher. Parents are asked to report the duration in minutes of the child's indoor activities at home while the child was not sleeping. Teachers report the time the child spends in activities in the kindergarten or elementary school. Parents and teachers also report physical activities with low to moderate intensity and moderate to vigorous physical activities (MVPA). From these data the amount of daily MVPA was calculated in minutes and as a percentage of the child's time awake.

Validity and reliability: The three questionnaires were validated against heart rate monitoring (Sport Tester) and accelerometer data (Caltrac) by Harro (1997). All methods were assessed simultaneously in 68 children (4-8 yr) on four consecutive days. The reported time spent in moderate to vigorous physical activity correlated moderately to heart rate data (time of heart rate $\geq$ 140 beats/ min and $\geq$ 150 beats/ min) ($r=0.40$, $p < 0.01$) and accelerometer data ($r=0.53$, $p < 0.0001$). The reported time spent in MVPA tended to be overestimated, especially in girls.

Other proxy reports are: the Parent and teacher log of a Child's Physical Activity, Parent Rating of Activity, Teacher Rating of Activity, Activity and Play Rating, and the Physical Activity Record of Classes (PARC) (Sallis, 1991). The PARC is designed to record the frequency and duration of physical education classes. It has to be completed by teachers (McKenzie et al., 1996).

Advantages and disadvantages of self-reports

Self-report is the most common and widespread method to assess physical activity in children and adolescents as can be seen from the amount of self-reports. Advantages of this method are the low cost, the relatively short administration and scoring time, and the ability to gather information of large numbers of children and adolescents over a period of time (Crocker et al., 1997).

A disadvantage of self-reports is that they rely on memory recall. In children the problem of recall with questionnaires and interview techniques are confounded (Goran, 1998). There are at least two sources of error. Error due to not remembering certain activities, and error due to underreporting or over reporting certain activities (Klesges et al., 1985). Below the age of 10 the amount of time spent at a certain level of activity is difficult to recall (Scruggs et al., 2003). Children seem to be able to recall the previous day accurately when completing a questionnaire or keeping a diary, but one has to question if the reported activity adequately characterises the activity pattern of the child. Other sources of error of self-reports are misinterpretations and social desirability (Sirard & Pate, 2001).

Judgement of the described self-report methods

All described self-report methods were reviewed and judged by two researchers (Table 4.9).

Table 4.9 Judgement of the characteristics of the twenty described self-reports

Self-reports	Target population	Content	Length/ administration time	Validity	Reliability
Questionnaires and diaries					
NNGB	children	-	+	-	-
SQUASH	adolescents	+	+	-	-
HAES	children	±	±	-	-
PARI	children, adolescents	-	+	±	+
Godin-Shephard Survey	children, adolescents	+	+	+	+
3-d Sweat Recall	children, adolescents	±	+	+	-
3-d Aerobic Recall	children, adolescents	-	+	-	+
PAQ-C	children, adolescents	+	+	-	+
PACE+	adolescents	-	+	+	+
PDPAR	adolescents	±	±	+	+
SAPAC	children	+	-	±	-
Yesterday Activity Checklist	children	±	+	±	+
Weekly Activity Checklist	children	±	+	±	+
Weekly Activity Sum	children	±	+	±	+
7-d Activity Tally	children	-	+	-	+
Interviews					
7-d PAR	children, adolescents	±	+	+	+
MLTPAQ	adolescents	-	?	+	-
PAI	children	+	+	+	-
PACI	children	+	+	±	-
Proxy report					
Parent-teacher Questionnaires	children	+	?	±	-

There are only a few questionnaires and diaries that are specially designed for children or adolescents. None of the Dutch questionnaires have been properly examined in use for children or adolescents yet. Data is missing, or validity was below standard. In spite of this Botterweck et al. (2003) advise to use the SQUASH to improve comparability of results. However the questionnaire has to be adjusted for the use in children or adolescents.

Of the American questionnaires the PDPAR looks most promising. Is seems to be a valid and reliable questionnaire for adolescents.
In general, younger children are more sensitive to the recall period. The reliance on memory recall can be enhanced through the use of memory cues. By using time related cues as separating week and weekend days or using a structured day procedure (breakfast, school, lunch, after school, evening) children and adolescents will be better able to remember frequency, intensity, and duration of different physical activities. Another memory cue could be to list common physical activities that they can check off on a questionnaire.

5 Considerations when assessing physical activity in children and adolescents

Central to the selection of an assessment method for a certain population, is a clear understanding of the nature of the population under study.
The amount and type of physical activities observed in children and adolescents are very different than those in adults. Children's activities tend to be more sporadic and to change frequently. One minute they are sitting quietly in their chair and another minute they are running behind a ball. Their activity pattern varies as a function of gender, age, location, and season. Likewise adolescents can not be compared to adults. They are midway between childhood and adulthood. They are in the middle of a physical and mental growing process.

Another aspect for consideration is the time table of children and adolescents. In comparison with adults, children and adolescents have much more leisure time. Therefore, children and adolescents can differ enormously from adults in frequency, intensity, time, and type of physical activities and inactivity. Assessment methods should be adjusted to the lifestyle of children and adolescents.

The fact that children and adolescents have unique activity patterns necessitates the use of tailor-made assessment methods or outcome measures. For example questionnaires are not very suitable for young children because of their less developed cognitive skills. Also biological differences in metabolism and biomechanical differences in efficiency require different assumptions for energy costs of certain activities (Welk et al., 2000b). Unfortunately there is very limited information on the specific energy costs of different activities in children, making it difficult to translate activity information to energy expenditure. Most of the time MET values obtained in studies with adults are used. Other assumptions, which are frequently made, are:

1. Energy intensity of specific activities can be explained as METs;
2. Resting energy expenditure = 1 kcal/ min in all subjects or energy cost of physical activities is directly proportional to body weight;
3. Intensity is constant among individuals;
4. Intensity is constant within individuals for different activities.

It is clear that our knowledge about physical activity patterns, and research in the field of assessment methods for children and adolescents are still in their infancy (Kemper et al., 2000).

6 Conclusions and recommendations

Many methods have been discussed in this report. All of these methods have limitations (Table 6.1). None of the methods is suitable for all purposes. Selection of an appropriate assessment method depends on the specific research question being addressed as well as the relative importance of accuracy and practicability.

6.1 Objective methods to assess physical activity in children and adolescents

In this report four objective methods have been discussed: indirect calorimetry, doubly labelled water, heart rate monitors, and motion sensors.

Indirect calorimetry and doubly labelled water
Indirect calorimetry and doubly labelled water are very accurate objective methods to assess energy expenditure or to validate or calibrate other assessment methods, but both require sophisticated instrumentation and are expensive (Table 6.1).

Heart rate monitors
Heart rate monitors are less expensive, but have other limitations. Heart rate is influenced by several other factors than physical activity. Another disadvantage is that heart rate monitoring may mask the intermittent activity pattern of children, and the time lag (Table 6.1). Using individualized heart rate - VO_2 regression equations and techniques that control for errors, heart rate monitoring can provide an indication of the intensity, duration, frequency, and energy expenditure of physical activity. In this report two old heart rate monitors have been discussed. No information is available yet about the validity and reliability of newer models in use for children or adolescents.

Pedometers
Although there are several pedometers commercially available, in this review only one pedometer was found which was validated in children. The general consensus is that pedometers provide a valid assessment of physical activity but a less accurate estimate of energy expenditure. Because most of a person’s daily activity involves loco motor movement (walking and jogging), pedometers may offer a cost-effective measurement tool for field-based research applications (Welk et al., 2003). These devices cost approximately $20-25 and are small enough to be unobtrusive to study participants. The immediate feedback available from pedometers also makes them useful as a behaviour modification tool (Welk et al., 2000c).
Like all other assessment methods mentioned here, pedometers have limitations. They are not sensitive to changes in speed. Pedometers tend to overestimate distance travelled at slower speeds and underestimate distance travelled at higher speeds. Many pedometers provide users estimates of energy expenditure; however, the algorithms used for these calculations are not appropriate for children (Trost, 2001). Pedometers are insensitive to inclination. Another limitation is the inability to segment activity by time. It is not possible to determine the intensity or duration of the activity (Welk et al., 2000c) (Table 6.1).
As long as no information is available about the reliability and validity of pedometers in use with children and adolescents, they should be used with caution.

Accelerometers

In this review five one-dimensional and three three-dimensional accelerometers have been discussed. To date, only the Caltrac Activity Monitor has shown to be a reliable and valid accelerometer for use in children and adolescents. The second best accelerometer is the CSA Monitor.

Although accelerometers still have limitations, they are arguably the most effective way to assess physical activity under free-living conditions. They are small and easy to use. A major advantage of accelerometers is that they provide objective information that can be processed and stored over time with limited burden on subjects. They provide a better overall indicator of activity than a simple pedometer because they can assess intensity of activity. They also have fewer sources of variability and error than heart rate monitoring (Welk et al., 2003). Compared to heart rate monitors, accelerometers present fewer burdens to subjects (no electrodes or chest straps) and are capable of detecting the intermittent activity patterns of children. On the other hand, accelerometers are insensitive to many forms of physical activity and it is difficult to convert the output to energy expenditure (Table 6.1). If the outcome of interest is relative participation in physical activity and the measurement of resting heart rate is not a viable option, then accelerometers might be the method of choice. If, however, the goal is to estimate energy expenditure, then heart rate monitoring, using an individualized heart rate - VO_2 calibration curve, would be the method of choice (Trost, 2001).

Another interesting issue is the difference between one- and three-dimensional accelerometers. Three-dimensional accelerometers were developed under the assumption that 'more is better'. By recording in more than one plane, three-dimensional accelerometers are supposed to be better capable of quantifying the movements of children and adolescents during free-living activities. While this assumption has strong intuitive appeal, field- and laboratory-based studies testing the different one- and three-dimensional devices have produced conflicting results (Welk & Corbin, 1995; Westerterp, 1999).

As long as limited information is available about the reliability and validity of many accelerometers, they should be used with caution. At the moment the Caltrac Activity Monitor and the CSA monitor are preferable.

Table 6.1 Summary of advantages and limitations of methods to assess physical activity in children and adolescents

Method	Advantages	Limitations
Objective assessment methods		
Indirect calorimetry	calibration	expensive, time-consuming
Doubly labelled water	unobtrusive, free-living conditions, extended periods	expensive, overall estimate of energy expenditure
Heart rate monitors	unobtrusive, relatively inexpensive, data storage	influenced by several factors, time lag
Motion sensors	unobtrusive, behaviour modification tool	conversion to energy expenditure, insensitive to many forms of physical activity
Subjective assessment methods		
Direct observation	physical activity patterns (FITT)	time-consuming, observer reliability, reactivity
Self-reports	inexpensive, useful for large-scale epidemiologic studies	relies on memory, conversion to energy expenditure, requires motivated subjects

6.2 Subjective methods to assess physical activity in children and adolescents

In this report two subjective methods to assess physical activity in children and adolescents were discussed: direct observation and self-reports.

Direct observation
Three of the four described observation methods in this review were used for children (< 12 yr). Direct observation is a very useful method to obtain information of physical activity patterns (frequency, intensity, time, and type of activity), especially in younger children in whom accurate and self-reported data are more difficult to assess. Observation can take place in a variety of settings for variable lengths of time.
However direct observation methods are time-consuming and labour intensive (Table 6.1). Therefore this method is impractical for large-scale research.

Self-reports
In this review 20 self-reports have been described. As can been concluded from the amount of self-reports, this method is the most common and widespread method to assess physical activity in children and adolescents. Advantages of this method are the low cost, the relatively short administration and scoring time, and the ability to gather information of large numbers of children and adolescents over a period of time (Crocker et al., 1997).
Despite the number of self-reports, there are only a few questionnaires and diaries that are specially designed for children or adolescents. Most of the self-reports focus on the child’s involvement in structured sports. Some children, particularly very young children, may be very active but minimally involved in structured sports (Moore et al., 1995). Recently a Canadian study has shown that children are physically more active during unstructured than during structured activities (Tremblay & Willms, 2003). Thus, it is important to cover all forms of physical activities (e.g. transportation, leisure time activities (structured and unstructured), household activities) in self-reports.

None of the discussed Dutch questionnaires have been properly examined in use for children or adolescents so far. Of the American questionnaires the PDPAR looks most promising. In the PDPAR a one-day recall period is used. In general, children have difficulties recalling their physical activity behaviour over longer time periods. Memory recall can be enhanced by using time related cues as separating week and weekend days or using a structured day procedure (breakfast, school, lunch, after school, evening). Future studies should establish an age limit below which the assessment methods would lack reliability and validity because of cognitive limitations. Another limitation of self-reports is the conversion to energy expenditure (Table 6.1).
Perhaps it is easier to assess physical inactivity (e.g. sleeping, reading, watching television) in stead of physical activity.
Recall errors, misinterpretations, and social desirability probably play a smaller part.

6.3 Conclusion

Assessing physical activity in children and adolescents is an important and challenging enterprise. When selecting a method one has to keep the following questions in mind:

- What is it exactly what you want to know? What is the research question?
- What is your hypothesis?
- What is your budget?
- How much time do you have to obtain your data?
- In which age group you want to assess physical activity?
- How many children do you need to measure?
- How many days of monitoring are needed with this method to characterize a subject’s level of activity?

Preferably an assessment method provides insight in the energy expenditure, frequency, intensity, duration, and type of physical activity of children and adolescents in a reliable, valid, and practical manner. However, at the moment it is not possible to identify one method as the perfect method (Kemper et al., 2000). Investigators who desire to assess children’s physical activity are in a difficult situation. The current choices are to use assessment methods with unknown validity or measures with know limitations in their accuracy.
The greatest obstacle to validate assessment methods is the lack of an adequate criterion to which techniques can be compared. The correlation of various field methods may be of some value, but because there are errors in all methods it is impossible to determine the true validity of any one of them doing so (Westerterp, 1999). The doubly labelled water method is considered the golden standard to assess energy expenditure, but it remains unclear if it is also the golden standard to assess physical activity patterns in terms of frequency, intensity, time, and type of activity (FITT).
At present a strategy of using multiple assessment methods, including objective and subjective methods, is recommended. A combination of different assessment methods is likely to increase the accuracy of the information and to provide insight in physical activity patterns of children and adolescents. On the basis of the reported information a combination of an accelerometer and a questionnaire or diary seems most appropriate.

6.4 Priorities for research

The development of new techniques for the assessment of physical activity is probably one of the most emergent needs that could benefit from incorporation of advanced

technology. Validation of existing technology such as pedometers and three-dimensional accelerometers in children and adolescents is also warranted.
Clearly, there is a strong need for the development or translation and testing of self-reports for use in children and adolescents. But it must be kept in mind that the accuracy of self-reports will always be limited by the ability of the child or the parent to recall information accurately and without bias. Additional improvements in questionnaire accuracy depend on greater understanding of the processing of information retrieval from memory. Interesting questions are: How does the ability to estimate and report time develop? How can reporting exercise duration be improved through training or different reporting formats? How can estimation of exercise intensity be improved? Can estimation of physical activity levels be improved by assessing physical inactivity in stead of physical activity?
With recent public health guidelines improvement of assessments of moderate intense physical activity is needed. There are several difficulties inherent in assessing moderate intense lifestyle activities. Because lifestyle activity is generally less structured than more vigorous bouts of exercise, it may be harder to code and recall on self-report instruments (Welk et al., 2000a).

7 References

AINSWORTH BE, HASKELL WL, LEON AS, JACOBS DR, MONTOYE HJ, SALLIS JF, PAFFENBARGER RS. Compendium of physical activities: classification of energy costs of human physical activities. Med Sci Sports Exerc 1993; 25 (1): 71-80.

ARMSTRONG CA, SALLIS JF, ALCAREZ JE, KOLODY B, MCKENZIE TL, HOVELL MF. Children's television viewing, body fat, and physical fitness. Am J Health Promot 1998; 12 (6): 363-368.

BAARDA DB, GOEDE MPM de. Basisboek methoden en technieken: praktische handleiding voor het opzetten en uitvoeren van onderzoek. Houten: Stenfert Kroese, 1995.

BINSBERGEN JJ van, MATHUS-VLIEGEN EMH. Dikke kinderen: overgewicht is moeilijk te behandelen. Medisch Contact 2003; 58 (14): 560-563.

BOTTERWECK A, FRENKEN F, JANSSEN S, ROZENDAAL LM, VREE M de, OTTEN F. Plausibiliteit nieuwe metingen algemene gezondheid en leefstijlen 2003. Heerlen: CBS, 2003.

COMMITTEE ON SPORTS MEDICINE AND FITNESS. Assessing physical activity and fitness in the office setting. Pediatrics 1994; 93 (4): 686-689.

CROCKER PRE, BAILEY DA, FAULKNER RA, KOWALSKI KC, MCGRATH R. Measuring general levels of physical activity: preliminary evidence for the Physical Activity Questionnaire for Older Children. Med Sci Sports Exerc 1997; 29 (10): 1344-1349.

CROUTER SE, SCHNEIDER PL, KARABULUT M, BASSETT DR. Validity of 10 electronic pedometers for measuring steps, distance and energy cost. Med Sci Sports Exerc 2003; 35 (8): 1455-1460.

DURANT RH, BARANOWSKI T, DAVIS H, RHODES T, THOMPSON WO, GREAVES KA, PUHL J. Reliability and variability of indicators of heart-rate monitoring in children. Med Sci Sport Exerc 1993b; 25 (3): 389-395.

DURANT RH, BARANOWSKI T, PUHL J, RHODES T, DAVIS H, GREAVES KA, THOMPSON WO. Evaluation of the children's activity rating scale (CARS) in young children. Med Sci Sports Exerc 1993a; 25 (12): 1415-1421.

DURANT RH, BARANOWSKI T, DAVIS H, THOMPSON WO, PUHL J, GREAVES KA, RHODES T. Reliability and variability of heart rate monitoring in 3-, 4-, or 5- yr-old children. Med Sci Sport Exerc 1992; 24 (2): 265-271.

EMONS HJG, GROENENBOOM DC, WESTERTERP KR, SARIS WHM. Comparison of heart rate monitoring combined with indirect calorimetry and the doubly labelled water (2h218O) method for the measurement of energy expenditure in children. Eur J Appl Physiol 1992; 65: 999-1003.

EVERS A, VLIET-MULDER JC van, GROOT CJ. Documentatie van tests en testresearch in Nederland. Deel I: Testbeschrijvingen. Assen: van Gorcum, 2000a.

EVERS A, VLIET-MULDER JC van, GROOT CJ. Documentatie van tests en testresearch in Nederland. Deel II: Testresearch. Assen: van Gorcum, 2000b.

FREEDSON PS. Electronic motion sensors and heart rate as measures of physical activity in children. J School Health 1991; 61 (5): 220-223.

GORAN MI. Measurement issues related to studies of childhood obesity: assessment of body composition, body fat distribution, physical activity, and food intake. Pediatrics 1998; 101: 505-518.

HARRO M. Validation of a questionnaire to assess physical activity of children ages 4-8 years. Res Q Exerc Sports 1997; 68 (4): 259-268.

HASKELL WL, YEE MC, EVANS A, IRBY PJ. Simultaneous measurement of heart rate and body motion to quantitate physical activity. Med Sci Sports & Exercise, 1993; 25 (1): 109-115.

HIRASING RA, FREDRIKS AM, BUUREN S van, VERLOOVE-VANHORICK SP, WIT JM. Toegenomen prevalentie van overgewicht en obesitas bij Nederlandse kinderen en signalering daarvan aan de hand van internationale normen en nieuwe referentiediagrammen. Ned Tijdschr Geneesk 2001; 145 (27): 1303-1308.

HIRASING RA, FREDRIKS AM, BUUREN S van, VERLOOVE-VANHORICK SP, WIT JM. Toegenomen prevalentie van overgewicht en obesitas bij Nederlandse kinderen en signalering daarvan aan de hand van internationale normen en nieuwe referentiediagrammen. Tijdschr Jeugdgezondheidsz 2002; 5: 82-87.

JANSSEN N. Dik, dikker, dikst: nieuwe impulsen noodzakelijk voor de preventie van overgewicht bij kinderen. TGV 2002; 5: 12-14.

JANZ. Validation of the CSA accelerometer for assessing children's physical activity. Med Sci Sports Exerc 1994; 26 (3): 369-375.

JANZ KF, DAWSON JD, MAHONEY LT. Tracking of physical fitness and physical activity from childhood to adolescence: the Muscatine study. Med Sci Sports Exerc 2000; 32 (7): 1250-1257.

JANZ KF, GOLDEN JA, HANSEN JR, MAHONEY LT. Heart rate monitoring of physical activity in children and adolescents: the Muscatine study. Pediatrics 1992; 89 (2): 256-261.

JANZ KF, LEVY SM, BURNS TL, TORNER JC, WILLING MC, WARREN JJ. Fatness, physical activity, and television viewing in children during the adiposity rebound period: the Iowa bone development study. Prev Med 2002; 35: 563-571.

JANZ KF, WITT J, MAHONEY LT. The stability of children's physical activity as measured by accelerometry and self-report. Med Sci Sports Exerc 1995; 27 (9): 1326-1332.

KEMPER HGC, OOIJENDIJK WTM, STIGGELBOUT M. Consensus over de Nederlandse Norm Gezond Bewegen. TSG 2000; 78: 180-183.

KLESGES LM, KLESGES RC. The assessment of children's physical activity: a comparison of methods. Med Sci Sports Exerc 1987; 19 (5): 511-517.

KLESGES RC, KLESGES LM, SWENSON AM, PHELEY AM. A validation of two motion sensors in the prediction of child and adult physical activity levels. Am J Epidemiol 1985; 122: 400-410.

KLIJN P. Vragenlijst Fysieke Activiteit. Habitual Activity Estimation Scale – HAES. Utrecht: UMC Utrecht, 2001.

KONIJN G, HILDEBRANDT VH. Vragenlijsten over het functioneren van personen met aandoeningen van het bewegingsapparaat in ADL- en arbeidssituaties: een inventariserend literatuuronderzoek. Leiden: TNO Preventie en Gezondheid, 1993.

LAPORTE RE, MONTOYE HJ, CASPERSEN CJ. Assessment of physical activity in epidemiologic research: problems and prospects. Public Health Reports, 1985; 100 (2): 131-146.

LIVINGSTONE MBE, COWARD WA, PRENTICE AM, DAVIES PSW, STRAIN JJ, MCKENNA PG, MAHONEY CA, WHITE JA, STEWART CM, KERR MJJ. Daily energy expenditure in free-living children: comparison of heart-rate monitoring with the doubly labelled water (2H2 18O) method. Am J Clin Nutr, 1992; 56: 343-352.

LOGAN N, REILLY JJ, GRANT S, PATON JY. Resting heart rate definition and its effect on apparent levels of physical activity in young children. Med Sci Sports Exerc 2000; 32 (1): 162-166.

LUMMEL RC van, HEIKENS SC, SLIKKE RMA van der, HENZEN CHM, ZIJLSTRA W. Gangbeeldanalyse met versnellingsopnemers op de lage rug. Abstract for KNGF Congress, 2003a.

LUMMEL RC van, HEIKENS SC, SLIKKE RMA van der, HEZEN CMH, ZIJLSTRA W. Left-right step detection during walking using only acceleration sensors on the lower back. Abstract for Congress European Society of Movement Analysis for Adults and Children (ESMAC), 2003b.

MCKENZIE TL. System for Observing Play and Leisure Activity in Youth (SOPLAY). 2002.

MCKENZIE TL, MARSHALL SJ, SALLIS JF, CONWAY TL. Leisure-time physical activity in school environments: an observational study using SOPLAY. Prev Med 2000; 30: 70-77.

MCKENZIE TL, NADER PR, STRIKMILLER PK, YANG M, STONE EJ, PERRY CL, TAYLOR WC, EPPING JN, FELDMAN HA, LUEPKER RV, KELDER SH. School physical education: effect of the child and adolescent trial for cardiovascular health. Prev Med 1996; 25: 423-431.

MCKENZIE TL, SALLIS JF, NADER PR, PATTERSON TL, ELDER JP, BERRY CC, RUPP JW, ATKINS CJ, BUONO MJ, NELSON JA. BEACHES: an observational system for assessing children’s eating and physical activity behaviours and associated events. J Appl Behavior Analysis 1991; 24 (1): 141-151.

MELANSON EL, FREEDSON PS. Physical activity assessment: a review of methods. Crit Rev Food Sci Nutr 1996; 36 (5): 385-396.

MOORE et al., 1995. In: Jeugd in Beweging. Handboek jeugd: gezond in beweging. Arnhem: Stichting Jeugd in Beweging/ NOC*NSF, 2001.

NICHOLS JF, MORGAN CG, SARKIN JA, SALLIS JF, CALFAS KJ. Validity, reliability, and calibration of the Tritrac accelerometer as a measure of physical activity. Med Sci Sports Exerc 1999; 31 (6): 908-912.

O’HARA NM, BARANOWSKI T, SIMONS-MORTON BG, WILSON BS, PARCEL GS. Validity of the observation of children’s physical activity. Res Q Exerc Sport 1989; 60 (1): 42-47.

PETERS L, LUIJPERS ETH. Factsheet preventie van overgewicht door voeding en bewegen: probleemanalyse. Woerden: NIGZ, 2002.

POWELL SM, JONES DI, ROWLANDS AV. Technical variability of the RT3 Accelerometer. Med Sci Sports Exerc 2003; 35 (10): 1773-1778.

PUHL J, GREAVES K, HOYT M, BARANOWSKI T. Children’s Activity Rating Scale (CARS): description and calibration. Res Q Exerc Sport 1990; 61 (1): 26-36.

REMMEN JJ, AENGEVAEREN WR, VERHEUGT FW, WERF T van der, LUIJTEN HE, BOS A, JANSEN RW. Finapres arterial pulse wave analysis with Modelflow is not a reliable non-invasive method for assessment of cardiac output. Clin Sci 2002; 103 (2): 143-149.

SALLIS JF, BUONO MJ, ROBY JJ, CARLSON D, NELSON JA. The Caltrac accelerometer as a physical activity monitor for school-age children. Med Sci Sports Exerc 1990; 22 (5): 698-703.

SALLIS JF, BUONO MJ, ROBY JJ, MICALE FG, NELSON JA. Seven-day recall and other physical activity self-reports in children and adolescents. Med Sci Sports Exerc 1993a; 25 (1): 99-108.

SALLIS JF, CONDON SA, GOGGIN KJ, ROBY JJ, KOLODY B, ALCAREZ JE. The development of self-administered physical activity surveys for 4th grade students. Res Q Exerc Sport 1993b; 64 (1): 25-31.

SALLIS JF, JOHNSON MF, CALFAS KJ, CAPAROSA S, NICHOLS J. Assessing perceived physical environment variables that may influence physical activity. Res Q Exerc Sport 1997; 68, 345-351.

SALLIS JF, STRIKMILLER PK, HARSHA DW, FELDMAN HA, EHLINGER S, STONE EJ, WILLISTON J, WOODS S. Validation of interviewer- and self-administered physical activity checklists for fifth grade students. Med Sci Sports Exerc 1996; 28 (7): 840-851.

SARIS WHM. Habitual physical activity in children: methodology and findings in health and disease. Med Sci Sports Exerc 1986; 18 (3): 253-263.

SARIS WHM. The assessment and evaluation of daily physical activity in children:a review. Acta Paediatr Scan Suppl 1985; 318: 37-38.

SIMONS-MORTON BG, TAYLOR WC, WEI HUANG I. Validity of the Physical Activity Interview and Caltrac with preadolescent children. Res Q Exerc Sport 1994; 65 (1): 84-88.

SCRUGGS PW, BEVERIDGDE SK, EISENMAN PA, WATSON DL, SHULTZ BB, RANSDELL LB. Quantifying physical activity via pedometry in elementary physical education. Med Sci Sport Exerc 2003; 35 (6): 1065-1071.

SLINDE F, ARVIDSON D, SLOBERG A, ROSSANDER-HULTHEN L. Minnesota Leisure Time Activity Questionnaire and double labeled water in adolescents. Med Sci Sport Exerc 2003; 35 (11): 1923-1928.

STICHTING JEUGD EN BEWEGING. Handboek jeugd; Gezond in Beweging. Arnhem: Stichting Jeugd in Beweging/ NOC*NSF, 2001.

STIGGELBOUT M, WESTHOFF MH, MULDER YM, OOIJENDIJK WTM, HILDEBRANDT VH, BAKEN W. De gezondheidswaarde van lichamelijke activiteit: een literatuurstudie. Leiden: TNO Preventie en Gezondheid, 1998.

STREINER DL, NORMAN GR. Health measurement scales: a practical guide to their development and use. New York: Oxford University Press Inc., 1995.

SUGAWARA J, TANABE T, MIYACHI M, YAMAMOTO K, TAKAHASHI K, IEMITSU M, OTSUKI T, HOMMA S, MAEDA S, AJISAKA R, MATSUDA M. Non-invasive assessment of cardiac output during exercise in healthy young humans: comparison between Modelflow method and Doppler echocardiography method. Acta Physiol Scand 2003; 179 (4): 361-366.

TAM E, AZABJI KENFACK M, CAUTERO M, LADOR F, ANTONUTTO G, DI PRAMPERO PE, FERRETTI G, CAPELLI C. Correction of cardiac output obtained by Modelflow (R) from finger pulse pressure profiles with a respiratory method in humans. Clin Sci (Lond) nov 2003.

TREIBER FA, MUSANTE L, HARTDAGAN S, DAVIS H, LEVY M, STRONG WB. Validation of a heart rate monitor with children in laboratory and field settings. Med Sci Sports Exerc 1989; 21 (3): 338-342.

TREUTH MS, ADOLPH AL, BUTTE NF. Energy expenditure in children predicted from heart rate and activity calibrated against respiration calorimetry. Am J Physiol 1998; 275: E12-E18.

TROST SG. Objective measurement of physical activity in youth: current issues, future directions. Exerc Sport Sciences Rev 2001; 29 (1): 32-36.

TROST SG, WARD DS, MOOREHEAD SM, WATSON PD, RINER W, BURKE JR. Validity of the computer science and applications (CSA) activity monitor in children. Med Sci Sports Exerc 1998; 30 (4): 629-633.

TUDOR-LOCKE C, AINSWORTH BE, ADAIR LS, POPKIN BM. Objective physical activity in Filipino youth stratified by commuting mode to school. Med Sci Sports Exerc 2003; 35 (3): 465-471.

URLINGS IJM, DOUWES M, HILDEBRANDT VH, STIGGELBOUT M, OOIJENDIJK WTM. Relatieve validiteit van een vragenlijst naar lichamelijke activiteit volgende de ‘beweegnorm’. Geneeskunde en Sport 2000; 33 (4): 17-22.

VINCENT SD, PANGRAZI RP, RAUSTORP A, TOMSON LM, CUDDIHY TF. Activity levels and body mass index of children in the United States, Sweden, and Australia. Med Sci Sports Exerc 2003; 35 (8): 1367-1373.

WELK JW, CORBIN CB. The validity of the Tritrac-R3D Activity Monitor for the assessment of physical activity in children. Res Q Exerc Sport 1995; 66 (3): 202-209.

WELK GJ, ALMEIDA J, MORSS G. Laboratory calibration and validation of the Biotrainer and Actitrac Activity Monitors. Med Sci Sports Exerc 2003; 35 (6): 1057-1064.

WELK GJ, BLAIR SN, WORD K, JONES S, THOMPSON RW. A comparative evaluation of three accelerometry-based physical activity monitors. Med Sci Sports Exerc 2000a; 32 (9): S489-497.

WELK GJ, CORBIN CB, DALE D. Measurement issues in the assessment of physical activity in children. Res Q Exerc Sport, 2000b; 71 (2): 59-73.

WELK GJ, DIFFERDING JA, THOMPSON RW, BLAIR SN, DZIURA J, HART P. The utility of the Digi-Walker step counter to assess daily physical activity patterns. Med Sci Sports Exerc 2000c; 32 (9): S481-S488.

WENDEL-VOS W, SCHUIT J. SQUASH. Short Questionnaire to assess health enhancing physical activity. Bilthoven: RIVM, 2002.

WENDEL-VOS GC, SCHUIT AJ, SARIS WHM, KROMHOUT D. Reproducibility and relative validity of the Short Questionnaire to Assess Health-enhancing physical activity. J Clin Epidemiol 2003; 56: 1163-1169.

WESTERTERP KR. Obesity and physical activity. Int J Obesity 1999a; 23 (1): 59-64.

WESTERTERP KR. Physical activity assessment with accelerometers. Int J Obesity 1999b; 23 (suppl 3): S45-S49.

WESTON AT, PETOSA R, PATE RR. Validation of an instrument for measurement of physical activity in youth. Med Sci Sports Exerc 1997; 29 (1): 138-143.

WIT, 1998. In: Stichting Jeugd in Beweging. Handboek jeugd; Gezond in Beweging. Arnhem: Stichting Jeugd in Beweging/ NOC*NSF, 2001.

8 Internet

http://www.annecollins.com, 2003. Obesity and weight loss articles. Obesity costs.

http://www.cbs.nl, 2003. POLS.

http://kijkonderzoek.nl, 2003. Stichting Kijkonderzoek.

http://www.mcroberts.nl, 2003. DynaPort.

http://www.pam.com, 2003. PAM. Pam keeps you moving.

http://www.scp.nl, 2003. Sociaal en Cultureel Planbureau (SCP).

http://www.tijdbesteding.nl, 2003. Sociaal en Cultureel Planbureau (SCP). Het Tijdsbestedingonderzoek (TBO).

http://www.voedingscentrum.nl, 2002, 2003. Voedingscentrum. Campagne ‘Maak je niet dik’.

http://walk4life.com, 2003. Walk4Life.