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Physical Activity Measures in Children – Which Method to Use?

Juliette Hussey
F.T.C.D. Discipline of Physiotherapy, School of Medicine, Trinity Centre for Health Sciences, St James's Hospital, Dublin Ireland

1. Introduction

There is increasing evidence supporting the health benefits of physical activity in children both in the immediate term in terms of body composition and in the longer term in the prevention of risk factors for cardiovascular disease, type-2 diabetes osteoporosis and certain cancers (Lee at al, 2000; Mohan et al, 2005; Blair et al, 1999; Pan et al, 1997; Tuomilehto et al, 2001; Colditz et al, 2005; Samad et al, 2005).
Physical activity is defined as body movement produced by skeletal muscles which results in energy expenditure (Caspersen et al, 1985). It can be difficult to measure physical activity as it is a variable with many dimensions including type, frequency, duration and intensity. The context and location where activity takes place may also be of interest. As a behaviour physical activity is unstable, as habitual levels of activity vary during the day, throughout the week and at different times of the year. Children have less regular patterns of activity than adults and therefore a picture of overall activity may be more difficult to capture. Spontaneous un-planned activity is typical of children, particularly younger children, and may be due to opportunities that present within their environment such as play facilities and other children. Even in older children who do engage in regular planned sporting activities, there may be a degree of unplanned activity.
The "gold standard" method of measuring energy expenditure as a result of physical activity is by the use of doubly labelled water (DLW). The technique uses stable isotopes of hydrogen and oxygen i.e. deuterium (^2H) and oxygen (^{18}O) ingested as water. Oxygen uptake and therefore energy expenditure are then calculated from the rate at which these isotopes are eliminated from the body. The difference between these is the amount of CO_2 produced. DLW is not a technique that is generally suitable for use in field studies due to the resources required. Even if cost were not a consideration the information gained pertains to total energy expenditure over a time period e.g. a number of days/ weeks and does not permit the examination of acute patterns of physical activity such as time spent in specific activities or intensity of specific exercise sessions.
The methods that can be used in field and most clinical studies are generally divided into the following; subjective methods such as observation and questionnaires and objective methods such as heart rate monitoring and motion sensors. The advantages and limitations of these methods will be outlined below. Before discussing these methods a synopsis of energy expenditure in children will be presented.

2. Energy expenditure in children

The largest factor that determines total daily energy expenditure (TDEE) is the basal or resting metabolic rate. It refers to the energy expended during normal cellular and organ functioning during post-absorptive resting conditions and accounts for roughly 60-75% TDEE. The second factor is the thermic effect of feeding and it accounts for approximately 10% of TDEE. The third component is the energy expended during physical activity. This can occur as a result of volitional mechanical work, such as exercise and daily activities, and non-volitional activity, such as fidgeting, spontaneous muscle contractions, and maintaining posture. It is the most modifiable component of TDEE and accounts for 20-30% of TDEE. As the output of physical activity energy expenditure (PAEE) is the most modifiable component of total daily EE, it may elicit the greatest response to intervention and subsequently, produce a beneficial impact on health related issues.

A sum of the estimation of energy expended in activity can be calculated from the data provided in questionnaires. The concept of measuring energy expenditure as a multiple of an individual's basal metabolic rate is used and examples of many activities are presented in the form of tables and published in compendiums. The compendia express EE in METs which are multiples of the resting metabolic rate (RMR).

The concept of denoting energy expenditure as a multiple of an individual's basal metabolic rate (BMR) has been referred to as 1 MET. In 1955 Passmore and Durnin published a review of measurements of human energy expenditure of various activities made by indirect calorimetry. This enabled the calculation of an individual's daily energy expenditure by the total of the metabolic cost of each activity by its duration. Initial work in this area was performed using a human calorimeter where the heat produced by a subject's metabolism was directly related to the temperature change in a contained environment, but more recent studies have used indirect calorimetry where expired air is continuously sampled.

In adults the resting metabolic rate (RMR) is taken as 3.5 mL O_2/kg/min. However despite the widespread acceptance of the 1 MET = 3.5 mL O_2/kg/min studies that have made such measures in specific cohorts have found different mean values. Byrne et al (2005) found that average resting VO_2 was 2.56 +/- 0.4 ml/O_2/kg and in this case if the 1 MET of 3.5 was used the resting metabolic rate would have been overestimated by 35%.

The RMR is higher in children and teenagers due to a number of factors including growth and puberty. RMR has been found to be higher than the generic adult value for each age group of children and Tanner stage of pubertal development and significantly higher in younger children (Harrell et al, 2005). Boys have been found to have a higher RMR than girls (Goran et al, 1997). Variation in energy expenditure in typical activity in adolescent girls of approximately 20-25% has been found (Pfeiffer et al, 2006). While a number of studies have found higher RMR in overweight children, the differences are negated when corrected for Fat Mass/Fat Free Mass (Treuth et al, 1998; Molnar & Schutz, 1997; Dietz et al, 1994).

The actual energy cost of adult type activities may also be higher due to the smaller muscle mass in children. Generally it is believed that the adult MET values should be multiplied by the child's RMR for an estimation of EE. Clearly in light of the increasing prevalence of childhood obesity there is a need for further work into the actual energy expenditure due to physical activity in children.

3. Observation methods

Observation methods of determining physical activity are generally used only in documenting workplace activity or in young children who are confined to a physical area

e.g. a school playground. Observers are trained to note behavioural information about the types of activities, the time spent in each activity and the frequency of such. Short time periods may not be reflective of habitual physical activity but observing for longer periods can be tedious and may lead to inaccuracies in reporting information. Recording can also be done by video recording providing a permanent record. In order to obtain a complete picture of physical activity of children a number of time periods such as during school break times, lunch times and physical education classes may be required.
Information on the physical surroundings which may influence physical activity levels can be obtained in observational studies, and thus these studies can provide added data which may partly explain the reasons for particular findings e.g. environmental factors such as few public play areas which may explain low levels of activity (Johns & Ha, 1999). While accurate information on the intensity of activity cannot be captured by observation methods they may be useful where classification of activity is all that is required (Chen et al, 2002). Observation methods also allow data to be collected on inactivity as the length of intervals between activities can be determined. With the advent of lightweight activity monitors there may be less need for observation studies in children.

4. Questionnaires

Questionnaires and interviews are frequently the method of collecting data on physical activity in studies involving large numbers of subjects where simple, inexpensive methods are required. Questionnaires measuring activity in adults usually include questions on occupational, transport and leisure time activity. As data is collected after its occurrence the procedure does not influence performance. The validity of questionnaires measuring physical activity is difficult to establish due to the lack of a gold standard criterion against which to compare them and the problems with long term recall of activities and the likelihood of overestimation of time and intensity of activity.
The use of questionnaires in children requires specific considerations. Below the age of 10-12 years children can only give limited information about their activity patterns. Parents, teachers or other adults may give details of the child's physical activity but this information may be estimated especially for outside activities. Regular planned activity is relatively easy to remember in the short term but so much of childrens' activity is spontaneous, unplanned and of a stop start nature and therefore activity may be difficult to recall. Children can also have difficulties estimating the duration of activities and time frames may need to be provided for the child in terms of *"on the way to school, break time, way home from school, before dinner"* etc. Questions about participation in Physical Education (P.E.), method of transport to and from school and extra-curricular activities may be included to gain information on childrens' overall activity levels. Providing a list of activities can aid recall.
The Modifiable Activity Questionnaire for Adolescents (MAQA) assesses physical activity over the previous year (Aaron et al, 1993). It includes questions on the number of times in the previous 14 days the subject engaged in at least 20 minutes of hard and of light exercise. Hours per days spent watching television, videos, playing computer games each day and the number of competitive activities the adolescent participates in is assessed, as is the energy expended in regular physical activity each week.

5. Heart rate monitoring

Heart rate (HR) monitoring is an objective method of measuring physical activity. HR monitoring can provide details on the time, intensity and frequency of specific activities based on the heart rate response to such activity. It is an indirect measure which is based on the linear relationship between heart rate and oxygen uptake, so the relative stress placed on the cardiopulmonary system due to physical activity is assessed. Advances in technology have made it possible to detect and store impulses over a number of weeks prior to being downloaded to a PC. While athletes commonly use heart rate recorders to determine and monitor exercise training zones these instruments can also be used in research and in clinical practice. Heart rates above a percentage of maximum can be identified and the data can be classified into time spent in specific zones for the time measured. Inactivity can be classified from heart rates close to baseline. However if heart rate is elevated for a period of time during inactivity (e.g. due to caffeine), on data analysis it can appear that this was related to activity. Heart rate can also be influenced by emotional stress, ambient temperature, humidity, and drugs and there may be some day to day variation. In addition resting heart rate and heart rate for any given workload is influenced by exercise tolerance. Fitter subjects have higher stroke volumes and hence lower the heart rates for any given workload.

The definition of resting heart rate and its' method of determination has an impact on the apparent level of activity (Logan et al, 2000). The interpretation of physical activity level depends on the threshold used and different thresholds will lead to different overall results. In terms of providing the most accurate results individual fitness testing would need to be performed prior to using heart rate monitoring so that data obtained can be correctly interpreted. Without individual data on exercise tolerance and/or the specifics of the activities being measured, lower heart rate data could be due to less activity in someone unfit or more intense activity for an individual who had a higher fitness level. In those who are less fit the return of heart rate to baseline after activity is slower than for those more fit but in the absence of this information it could appear that a less fit person is active for longer.

In summary heart rate monitoring is a useful method of measuring overall activity in children but interpretation of how active the child is depends on the fitness of the child and the definition of resting heart rate used. In addition heart rate may be influenced by other factors not related to physical activity.

6. Motion sensors

In recent years there has been a move away from other methods as described above to the use of instruments to detect body movement. The selection of motion sensors is ever increasing and ranges from simple pedometers to electronic accelerometers which reflect not only the occurrence of body movement but its intensity and in some instances its location. Pedometers record acceleration and deceleration of the waist in the vertical direction but do not record the intensity of movement. For large studies, where total activity is of interest, the pedometer may be useful and particularly in adults where Sequeia et al (1995) have demonstrated that the pedometer could differentiate between various levels of occupational activity (sitting, standing and moderate effort occupational categories). No differentiation could be made between heavy and moderate work, where heavy work involved much static work such as lifting but in assessing overall activity in large numbers this may not be that important. In adults and children much of the activity accumulated during the day is by walking which can be captured by pedometers.

These monitors have become more available and less expensive. Their use in epidemiological studies is helping to add significantly to our understanding of activity and health status as has been demonstrated by Craig et al (2010) in CANPLAY (Canadian Physical Activity Levels Among Youth) where pedometer data on almost 20,000 children was measured. Validity, reliability and accuracy need to be determined for all pedometers used in research. The Walk4Life 2505 has been found to be within 5.3% of actual time across all speeds and was thus recommended for the quantification of physical activity in children (Beets et al, 2005). However in those with intellectual disability Pitetti et al (2009) found an underestimation of approximately 14% in registered steps and an overestimation of 8.7% in time spent in activity when the Walk4Life was compared to video-recorded activity. Outputs from different pedometers may not be comparable. In addition as stride lengths will vary considerably with different age groups of children data from similar instruments may not be comparable across age groups when distance is the variable of interest. While pedometers may be used in large scale studies due to relatively low cost it is only total ambulatory activity over the measured time period that can be captured. Data on intensity, duration or frequency of activity bouts within that period cannot be obtained.

The assessment of physical activity by accelerometry is based on the measurement of body movement or the dynamic component of activity and accelerometers may be uni-axial, bi-axial or tri-axial. Uni-axial accelerometers such as the Caltrac or the Computer Science Application (CSA) incorporate a single, vertical axis piezoelectric bender element which is displaced with movement, and this generates a signal which is proportional to the force of the movement that produced it (Puyau et al. 2002). A study examining the validity of the CSA in children walking and running on a treadmill found the activity counts were strongly correlated with energy expenditure by indirect calorimetry (Trost et al, 1998). In addition to walking and running other activities typical in children such as Nintendo, arts and crafts, aerobic warm up, and Tae Bo were measured by CSA and the Mini-Mitter Actiwatch (MM) (Puyau et al, 2002) and data was compared to by room respiration calorimetry, and heart rate measured by telemetry. Correlations of $r=0.78 \pm 0.06$ and $r=0.80\pm0.05$ were found for the MM and $r=0.66\pm 0.08$ and $r=0.73\pm 0.07$ for the CSA for the right and left hips respectively.

While uni-axial accelerometers can only measure movement in one plane most movements in the saggital and horizontal planes are accompanied by movement in the vertical plane and some would argue that a uni-dimensional (vertical axis) activity monitor may be just as valid as a three dimensional monitor. However as many activities in young children (such as crawling and climbing) may be captured better by tri-axial accelerometers. The Tritrac R3D is a three dimensional motion sensor which measures the acceleration in three planes and integrates values to a vector magnitude. Vector magnitude is calculated as the square root of the sum squared of activity counts in each vector.

Data from the Tritrac accelerometer has been compared to the energy expenditure measured by indirect calorimetry for treadmill walking and running in 60 young adults who walked and ran on a treadmill at speeds of 3.2, 6.4 and 9.7 km.h^{-1} (Nichols et al, 1999). The mean differences between energy expenditure measured by indirect calorimetry and that measured by the Tritrac ranged from 0.0082 kcal.kg^{-1}.min^{-1} at 3.2 km.h^{-1} to 0.0320kcal.kg^{1}.min^{1} at 9.7 km.h^{1} with the Tritrac consistently overestimating EE during horizontal treadmill walking. Overall it was found that the Tritrac accurately distinguished between the various intensities of walking and running on level ground, was highly reliable from day to day and was sensitive to changes in speed of movement but not to incline.

The RT3 (Stayhealthy Inc, Monrovia, CA) has followed on from the Tritrac and although smaller it has a similar output to its predecessor. The validity of the RT3 in the assessment of physical activities which included walking on a treadmill, kicking a ball, playing hopscotch and sitting quietly was examined in 10 boys and 10 adult males (Rowlands et al, 2004). The RT3 vector magnitude correlated significantly with oxygen consumption in boys and in men. When compared to oxygen uptake excellent correlations with the RT3 have been found in 7-12 year olds (Hussey et al, 2009) and 12-14 year olds r-0,96, p< 001 (Sun et al, 2008). The measurements of inactivity, low activity, and moderate activity are very accurate with the RT3. The limits of agreement for vigorous activity are wider but this may not be highly important in measuring overall physical activity where short time periods are spent in vigorous activity each day and the classification of vigorous activity is needed but the absolute measure may not be required. Up to three weeks data can be acquired when the vector magnitude is sampled every minute. Data can be downloaded to a PC and saved in an excel files so data can be presented as required. The data can be manipulated in a number of ways depending on the needs of the project in question.

In our experience one of the most useful methods in the manipulation of the data has been to calculate the mean number of minutes per day spent in different classifications of activity e.g. inactivity, light activity, moderate activity, and vigorous activity. Alternatively the energy expended in activity may be used. However the intensity thresholds used need to be standardised if data is to be compared across groups. Where intensity is defined into categories on specific cut off points there will still be a wide variation in energy expended in subjects depending on where most of the activity within a wide range occurs. Two subjects may be classified as having spent the same amount of time in moderate/vigorous activity in a day yet one may have been at the lower range and the other at the higher and yet the data analysed will be the same. Thresholds for sedentary behaviour also need to be agreed as slight changes will have considerable impact on time spent sedentary per day as most of the day is spent either sedentary or in light activity. Reilly et al (2008) have demonstrated how using the cut off points provided by different researchers on the same data set can lead to significant differences in the time spent either sedentary or in moderate to vigorous activity. There is a real need for consensus on how data is analysed so data can be compared across studies. This needs to be done in children as well as adults and in children age may need to be a factor considered.

In the past decade there has been a substantial increase in the use of portable accelerometers and examples include the BioTrainer Pro and the SenseWear Armband. The former is a biaxial accelerometer that can sample data between 15 seconds and 5 minute intervals and can store up to 112 days of data. The SenseWear Armband is also a biaxial accelerometer with a heart rate receiver and thermocoupler which can measure heat production. The monitor is a wireless armband and is worn on the upper arm in contact with the skin surface. These newer monitors along with the CSA, the Tritrac R3D and the RT3 (King et al, 2004) were evaluated against indirect calorimetry for treadmill walking and running. No significant difference was found between the mean energy expenditure of the activity monitors at all speeds. The SenseWear Armband, Tritrac and RT3 had significant increases in mean EE as the speeds increased.

Another recent accelerometer is the IDEEA which provides an advantage over other acclerometers as it employs a more sophisticated motion-capture system using two dimensional accelerometers which are placed on the thighs, feet and sternum in conjunction with pattern recognition software which allows movement patterns to be detected (Zhang et al, 2004). A particular attraction of the IDEEA is the data on the type of activity performed e.g. walking, running. The IDEEA is a portable device and consists of 5 sensors that are attached to the body and a small data collection device (or microcomputer). The basic working principle of the IDEEA is that the sensors are attached to the body in specific areas. One sensor is attached to the sternum (preferably just below the sternal angle that is supposedly perpendicular to the vertical axis of the upper body, its correct alignment is crucial for distinguishing between sitting, reclining and lying down), two sensors are placed on the anterior sides of the upper legs, halfway between the hip and the knee, and the other two sensors are placed on the inferior side of the feet. The IDEEA system monitors the body and limb motions constantly through these sensors and the different combinations of signals from the sensors represent different physical activities, which are coded for as different numbers. The monitor collects 32 samples/second while continuously distinguishing among different postures and gaits to identify the type of physical activity.

The ability of the IDEEA to correctly identify the type of activity and to quantify PA intensity allows for calculations of EE in free-living conditions. The IDEEA device has in-built equations that determine the EE in kcal.min^{-1} or kJ.min^{-1}. Recent work in our laboratory was performed with the objective of examining the validity of the IDEEA in the estimation of energy expenditure during rest, walking and running in 28 young adults against the criterion method of physiological energy expenditure by indirect calorimetry (Oxycon mobile VIASYS). Good correlations in rest and walking were detected ($r=0.73$, $p<0.0001$ at rest to $r=0.49$, $p< 001$ at 6 km/h). The IDEEA was able to differentiate between inactivity, light, moderate and vigorous activities and can provide a valid estimate of energy expenditure in rest and walking (Mc Creddin & Hussey, 2009). A particular beneficial feature of the IDEEA is identification of type of activity, gait analysis during walking and running and identifying most postures.

The multisensory monitors the IDEEA and the Sense Wear Pro Armband have also been evaluated in children along with the ActiReg. While it was found that all three needed further development, the IDEEA had the highest ability in assesses energy cost (Arvidsson et al, 2009). The Actireg contains two pairs of sensors worn over the sternum and right thigh. These sensors can determine body position and motion. Along with the data processor the body positions and motion captured are given an “Activity factor” based on a multiple of basal metabolic rate. All three monitors were comparable for resting and sitting but none accurately measured stationary cycling, jumping on a trampoline or playing basketball. The IDEEA was the only one to accurately measure stair walking. In walking and running activities the IDEEA showed a close estimate of EE where the Sense Wear accurately measured slow to normal walking but underestimated higher speeds. In health related research accurate measures of inactivity and light activity may be more important than differentiating between more vigorous activity.

Global positioning systems are potentially valuable in the assessment of physical activity. The technology permits the identification of location and such data is important in our understanding of physical activity behaviours in children. A Global Position System receiver position is calculated by measuring its distance from a number of GPS satellites. Once switched on the GPS device constantly receives signals from satellites and can calculate the distance from each. In addition to providing a profile of the child’s activity patterns the GPS data can be combined with a GIS (Geographical Information Systems) database to provide information on where activity occurs and how the built environment/ transport options may influence activity behaviours (Maddison & Ni Mhurchu, 2009). GPS systems may be combined with accelerometry or other methods to provide richer data. Ideally these should be incorporated into one monitor. A small pilot study that examined how well the combination of GPS and accelerometer data predicted activity modes. Using three variables 91% of observations were correctly classified by the combined methods (Troped et al, 2008) A feasibility study in combining heart rate and GPS data was performed on 39 children during a confined time period (Duncan et al, 2009) and the system was found it to be a promising method for measuring play related energy expenditure. In this instance location, distance, speed and HR data were captured every second using the F500 model.

A limitation to the use of GPS is that it can only be used out doors and even then high buildings and trees may effect the use. The location of the GPS system may effect sitting postures as typically it has been situated on the back in harness/backpack. Increased battery life for devices such as the Garmin is required in order to establish activity patterns in children where at least four days of monitoring is recommended (Trost et al, 2000).

In summary: accelerometers are designed to measure physical movement without impeding activity in free- living situations and can measure periods of inactivity as well as quantity and intensity of movement. The ability of newer accelerometers to store data over a number of weeks permits measurement of habitual activity. Motion sensors are for the most part small unobtrusive devices that have the capacity to store movement data for prolonged time periods. The development of wireless communication to the data collection device could reduce the inconvenience associated with wearing the multiple sensors.

7. Conclusion

Increased time spent inactive has been cited as one reason for the epidemic of childhood obesity and therefore it is important to be able to obtain valid measures. This review has concentrated on methods of measuring physical activity in both clinical and laboratory settings. Observational studies are time consuming, labour intensive and involve many observers who may require intense training. Their cost may be prohibitive in epidemiological or large scale studies where the use of questionnaires may be more appropriate. While assessing physical activity through the use of questionnaires has some limitations, it is the only feasible approach for epidemiologic investigations. Heart rate monitoring can distinguish between different intensities of activity in children and therefore can be used to determine light, moderate and vigorous activity. However as higher degrees of fitness are associated with lower resting heart rates, fitness may need to be individually assessed before measurement. This would be very difficult in large cohort studies. Accelerometers can measure habitual physical activity and inactivity, are easy to wear and do not interfere or influence movement. An additional benefit of accelerometry is the ability to measure intensity of activity. The ultimate choice of activity measure will depend on the question to be studied, the size of the cohort and the resources available.

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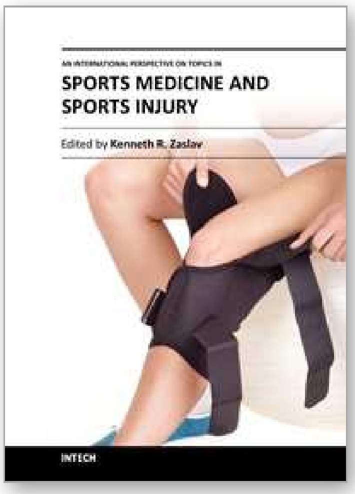

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For the past two decades, Sports Medicine has been a burgeoning science in the USA and Western Europe. Great strides have been made in understanding the basic physiology of exercise, energy consumption and the mechanisms of sports injury. Additionally, through advances in minimally invasive surgical treatment and physical rehabilitation, athletes have been returning to sports quicker and at higher levels after injury. This book contains new information from basic scientists on the physiology of exercise and sports performance, updates on medical diseases treated in athletes and excellent summaries of treatment options for common sports-related injuries to the skeletal system.

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InTech Europe
University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
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中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821