Assessing Free-Living Physical Activity using Accelerometry: Practical Issues for Researchers and Practitioners

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Abstract.

Physical activity is an integral component of a healthy lifestyle, with relationships documented between physical activity, chronic diseases and disease risk factors. There is increasing concern that large numbers of people are insufficiently active to benefit their health. Consequently, there is a need for assessing the prevalence of physical activity engagement, identifying active and inactive segments of the population, and evaluating the effectiveness of interventions. This article aims to identify and explain a number of methodological and decision-making processes associated with accelerometry, which is the most commonly used objective measure of physical activity in child and adult research. Specifically, this review addresses: a) pre-data collection decisions, b) data collection procedures, c) processing accelerometer data, and d) outcome variables in relation to the research questions posed. An appraisal of the literature is provided to help researchers and practitioners begin field-based research, with recommendations offered for best practice. In addition, issues that require further investigation are identified and discussed to inform researchers and practitioners of the surrounding debates. Overall, it is intended as a starting point for field-based physical activity research using accelerometers and to introduce key issues that should be considered and are likely to be encountered at this time.

Key words: Accelerometers, measurement, objective techniques.

Introduction.

Physical activity is defined as "any bodily movement produced by the skeletal muscles that results in energy expenditure" (Caspersen, Powell & Christenson, 1985, p.126). It is a complex set of behaviours, encompassing a wide range of freely chosen movement types (Sallis & Patrick, 1994). Physical activity consists of the following broad dimensions: frequency (how often the activity occurs); intensity (how strenuous the activity is); time (how long the activity lasts), and type (the actual activity type; Sallis & Patrick, 1994). The benefits of a physically active lifestyle on health are well documented. There is evidence of strong relationships between physical activity and health in adults, with higher levels of activity associated with lower risk of diabetes, obesity, chronic heart disease and osteoporosis, for example (Blair & Connelly, 1996; DH, 2004). In children, higher levels of physical activity are associated with reduced risk of clustered cardiovascular disease factors (Anderson, Harro, Sardinha, Froberg, Ekelund, Brage *et al*., 2006). Though physical inactivity is a major risk factor for numerous chronic diseases, there is concern that children and adults are not engaging in sufficient activity to benefit health. The Health Survey for England (2006) reported that 40% of men and 28% of women met recommended physical activity levels of at least 30 minutes of at least moderate intensity activity (MPA) on five or more days of the week (DH, 2004). Riddoch and colleagues (2007) reported that only 2.5% of children met child recommendations of at least 60 minutes of at least MPA a day. Therefore, accurate physical activity assessments are needed in order to assess the prevalence of physical activity engagement, identify whether populations currently meet physical activity recommendations, understand relationships between physical activity and health outcomes, and to evaluate the effectiveness of physical activity interventions.

1. Physical Activity Measurement.

There is no gold standard for measuring physical activity (Welk, 2002), as no single instrument is able to record the cardiorespiratory stress, mechanical loading and behavioural response during physical activity participation. However, there are a number of methods that can be used to assess the different components of physical activity. These are typically classified as objective or subjective methods. Objective methods provide a numerical assessment of a physiological parameter such as body movement, and do not require the individual to record or interpret this information. Examples include heart rate monitors, accelerometers and pedometers (Sirard & Pate, 2001; Welk, 2002). Comparatively, subjective methods are indirect measures that typically involve the individual recording their own activity. Examples include self-report questionnaires, interviews, and diaries (Sirard & Pate, 2001). Each method assesses different dimensions of physical activity, has a variety of outcome variables, and has its own associated strengths and weaknesses (Table 1). The choice of which method to use for evaluative purposes is linked to these factors. Exemplar references are provided to signpost readers for additional information. The purpose of this article is to introduce the measurement of physical activity with a specific focus on accelerometry, and to address practical issues users may experience when using this physical activity monitoring method. The reliability and validity of accelerometry is beyond the scope of this article, but has been addressed in detail elsewhere (Welk, 2002).

2. What are accelerometers?

Accelerometers are motion sensors that detect accelerations produced by the human body (Welk, 2002). Acceleration is defined as the rate of change in velocity over a given time; therefore the frequency, intensity and duration of physical activity can be assessed through body movement (Welk, 2002). Accelerometers consist of piezoelectric transmitters that are stressed by accelerative forces, leading to the production of an electrical signal that is converted by processing units to produce an indication of movement (Chen & Bassett, 2005; Welk, 2002).

Depending on the model of accelerometer, acceleration can be detected in one (uniaxial), two (biaxial), or three (triaxial) planes of movement (Chen & Bassett, 2005; Rowlands, 2007; Welk, 2002). Most accelerometer models measure in one or three planes. Uniaxial accelerometers (e.g. Actigraph GT1M, Actigraph LLC, Pensacola, FL; Bio Trainer Pro, IM Systems, Baltimore, MD; Personal Activity Monitor, PAM B.V. Doorwerth, the Netherlands) are typically worn in a way that the sensitive axis is oriented to measure vertical acceleration and deceleration (Rowlands, 2007; Tryon & Williams, 1996). Omnidirectional accelerometers (e.g. Actical and Actiwatch, Mini-Mitter Co., Inc., Bend, OR) are capable of measuring activity in all directions, though they are most sensitive in the vertical plane (Rowlands, 2007). In comparison, triaxial accelerometers (e.g. RT3, Stayhealthy Inc., Monrovia, CA) measure movement in three planes, providing data for each plane as well as a combined measure of all three planes together (Chen & Bassett, 2005).

Triaxial accelerometers may provide a more thorough assessment of physical activity than uniaxial accelerometers, particularly in children, as they may be more sensitive to free-living activities such as climbing and jumping, (Eston, Rowlands & Ingledew, 1998; Ott, Pate, Trost, Ward & Saunders, 2000). Furthermore, triaxial accelerometers have been found to correlate more highly than uniaxial accelerometers with energy expenditure in adults (r = 0.89-0.62 vs. 0.77-0.59; Hendelman, Miller, Bagget, Debold & Freedson, 2000) and scaled oxygen consumption children (r = 0.91 vs. 0.78; Eston *et al*., 1998). Rowlands and colleagues (2007) reported that triaxial accelerometers recorded high-intensity physical activity such as running more accurately than uniaxial accelerometers. Interestingly, uniaxial and triaxial accelerometer output is reported to be highly correlated during free living activities (r = 0.86; Ott *et al*., 2000), suggesting that both accelerometer types provide similar information about physical activity engagement.

Consequently, the choice of accelerometer to assess physical activity in research and practice will reflect decisions made that relate to cost, feasibility, size, monitoring capacity, memory, data collected, and ease of use. These decisions are critical in effectively monitoring activity and meeting a study's objectives. To shed some light on this and subsequent decision making processes, the Actigraph accelerometer will be used as an example, as it is the most commonly used accelerometer in adult (Welk, 2002) and child (Corder, Ekelund, Steele, Wareham & Brage, 2008) field-based physical activity research.

3. Using accelerometers in field-based research.

3.1 The accelerometer.

The GT1M Actigraph is a small and lightweight (3.8 x 3.7 x 1.8 cm, 27g; Actigraph, 2007) unixial accelerometer. It has previously been known as the Computer and Science Applications, Inc. (CSA) accelerometer (Melanson & Freedson, 1995), and the Manufacturing Technology Inc. (MTI) accelerometer (Welk, 2005). It measures vertical acceleration and deceleration of human motion between the magnitudes of 0.05 to 2G. Detected accelerations are filtered, converted to a number (counts), and subsequently summed over a specific time period (epoch) specified prior to the commencement of data collection. Counts are the outcome variable from accelerometers, and they are a dimensionless unit (Welk, 2005). The recorded counts for each epoch represent the activity undertaken during that time period. At the end of each epoch, the summed value is stored in the memory and the monitor is automatically reset to zero (Welk, 2005). This process continues until the end of the monitoring period, or when the memory becomes full.

3.2 Accelerometry Decisions

Prior to activity monitoring, specific research questions will influence a number of decisions made concerning the monitor's use. The use of the accelerometer is an integral component of the design of the study, and a number of decisions must be considered during the design phase.

The accelerometer has the capacity to collect data concerning the frequency, intensity and duration of human movement (Table 1). The accelerometer, therefore, can be used to assess habitual physical activity against physical activity recommendations, the intensity of human movement in specific contexts (such as recess or physical education), the patterning of physical activity, or to estimate energy expenditure using regression equations (Freedson, Sirard, Debold, Pate, Dowda, Trost, Sallis, 1997; Hendelman *et al*., 2000). Such research questions can be investigated in populations of different ages, as accelerometers have acceptable reliability and validity in children (Eston *et al*., 1998) and adults (Hendelman *et al*., 2000).

Monitor Placement.

Typically, one accelerometer worn close to an individual‘s centre of mass is used to monitor free-living physical activity (Trost, McIver & Pate, 2005). Most studies require an accelerometer to be worn on the right hip, as this gives an indication of total body movement, though they can also be worn on the lower back, wrist and ankle. Small differences in the amount of MPA and vigorous physical activity (VPA) recorded have been reported between monitors positioned on the hip and lower back (Nilsson, Ekelund, Yngve & Sjöström, 2002). Hip mounted accelerometers reported higher MPA when measured on a short epoch setting compared to the lower back (Nilsson et al., 2002). Additional accelerometers worn on the wrist or ankle predict energy expenditure more accurately than monitors only worn on the hip (Melanson & Freedson, 1995), as hip-mounted accelerometers are limited by their ability to detect upper body movements or non-ambulatory movements such as cycling (Table 1). While the cost and increased participant burden associated with multiple monitor protocols may reduce their feasibility in free-living situations, such approaches may be more beneficial in specific controlled settings where energy expenditure is the main outcome variable and the limitations of hip-mounted accelerometry requires attention.

Accelerometers are usually worn in child and adult populations using an adjustable nylon strap, where the strap is looped through the mountings of the monitor itself, enabling it to be worn on the hip, lower back, ankle and wrist. Alternative methods include belt clips and pouches on nylon straps. Belt clips are attached to the accelerometer using a strong adhesive, but are very difficult to remove, can be uncomfortable when worn on a belt, and cannot be easily worn by females wearing dresses. Pouches may help to protect the monitor, though they can move on the belt, reducing the accuracy of placements, and may be tampered with by curious participants. Lastly, neither the clip-worn nor the pouch-worn method is suitable for ankle or wrist attachment.

Data Collection Intervals.

The epoch (cycle period) length that data is collected over must be considered. Due to memory capacity of earlier models, 60-second epochs were commonly used to collect data on habitual physical activity levels in children and adults (Riddoch *et al*., 2007; Davis & Fox, 2007). Recent advances however have enabled shorter epoch lengths to be used over extended periods of time, particularly when the patterning of physical activity or the time spent in different intensities is of interest. Shorter epoch periods have specific relevance in paediatric research. Bailey and colleagues (1995) found, using direct observation and cardiofrequencemeters, that children's MPA bouts lasted for 9-seconds on average, whilst VPA and very vigorous physical activity (VVPA) bouts lasted for 4.7 and 3.9-seconds respectively. Using 60-second epochs may obscure short bursts of VPA and VVPA and underestimate high intensity physical activity (Nilsson *et al*., 2002). Therefore, shorter epochs should provide more detailed information concerning the intensity and duration of children's free-living physical activity (Baquet, Stratton, Van Praagh & Berthoin, 2007). Though the issue of epoch length is under-researched in adults (Trost *et al*., 2005), shorter epoch periods (e.g. 5-seconds; Nilsson *et al*., 2002) should be used where possible to enable researchers to scrutinise children and adults' physical activity in greater detail. Measuring activity using short epochs both in specific contexts and habitually is possible, particularly as the GT1M Actigraph can monitor and record activity and step data using a 5-second epoch for at least 15-days when fully charged (Actigraph, 2007).

Duration of Data Collection.

The duration of data collection should allow collected data to be representative of typical activity levels. Shorter durations may help with compliance and costs, though collected data may have lower reliability than data collected over longer periods of time, which in turn impacts on cost and participant compliance. Adult studies have documented that four to seven days monitoring may be needed to obtain reliable information (intraclass correlation coefficient > 0.8) on habitual physical activity (Matthews, Ainsworth, Thompson and Bassett, 2002), while in children, three to eight days are needed (Mattocks, Ness, Leary, Tilling, Blair, Shield *et al*., 2008; Trost *et al*., 2000). For discrete periods of time such as recess when physical activity may be expected to be less variable, fewer days may be required (Ridgers, Stratton, Clark, Fairclough & Richardson, 2006), though this has not been greatly reported. Generally, seven days of continuous monitoring is recommended to assess habitual physical activity in adults and children, as this provides a trade-off between feasibility, reliability, and acceptable participant burden (Corder, Brage & Ekelund., 2007).

3.3 Data collection process

The data collection process involves preparing for data collection, the distribution of accelerometers and information prior to the participant wearing the monitor, methods for promoting compliance, and collecting the accelerometer. Prior to starting data collection, accelerometers should be fully charged (see Actigraph, 2007). Once charged, the accelerometers are initialised and allocated to an individual using a unique identifying filename. This enables the researcher to know whom the data belongs to when the information is downloaded. In addition, monitors should be marked using numbers, for example, so that the named individual receives the monitor intended for them, and in the event of missing monitors, they can be identified.

Accelerometer Distribution.

Generally, accelerometers are distributed and collected face-to-face. A familiarisation session and an information sheet should be provided to participants to explain monitor wear and placement, how and what data is collected, where and when the monitor should be returned, and provide the contact details of the researchers in case of queries or concerns. Lastly, it is recommended that a recording sheet be provided, enabling the participant to record when they wore the monitor (i.e., on-off times), reasons and times for not wearing it, and specific information that may influence the data collected (e.g., sickness). This will enable the researcher to assess whether the individual may need to be re-assessed, and whether the recorded wear time was reduced due to the legitimate removal of the monitor during activities that may damage it or cause injury to the participant (e.g., bathing, swimming, participation in contact sports, etc; Figure 1). Postal approaches can also be used. Pre-paid and envelopes should be sufficiently padded to protect the monitor from damage, and that recorded delivery should be used so that packages can be tracked and insured in the event of loss or damage.

Participant Compliance.

Compliance is a critical, yet under-researched and under-reported subject. Participants must actively cooperate with the research protocol for data to be collected. Consequently, a number of participant and researcher focused methods are available to encourage and facilitate compliance (see http://www.activelivingresearch.org/conference/2008/wednesday). Methods include providing sufficient information during familiarisation, completing recording sheets, providing incentives (e.g. activity equipment, vouchers), reminders via different media (e.g. telephone calls, SMS messages, emails), and showing examples of previously collected data (Trost *et al*., 2005). It is important to consider the needs of the population and their ability to engage with compliance strategies, as some methods may favour different populations. Most of the methods above can be used in small and large-scale studies, though familiarisation and discussed examples may not be appropriate in large-scale or postal distribution studies. It is likely that a combination of approaches is needed, but there should be a trade-off between feasibility and the burden on the researcher and participant alike.

Compliance strategies that involve incentives should consider the appropriateness and attractiveness of the incentive offered and the associated costs. For studies that employ a longitudinal design, incentives should be provided at all time points to encourage compliance over time. In addition, a feedback system should be in place to explain why someone may not have received the incentive offered.

4. Processing Accelerometer Data.

Figure 1 provides a decision making flow-chart for screening and processing accelerometer data. Some of the main issues concerning these will be discussed below.

Currently, there is no accepted criterion for the length of time an individual needs to have worn an accelerometer for it to represent a valid day (Corder *et al*., 2007). Moreover, there is no set criterion for identifying partial non-compliance; that is, when a monitor was removed during the day for either a specified or non-specific reason. Generally, 10 hours (600 minutes) a day of wear time has been used (Andersen *et al*., 2006; Davis & Fox, 2007; Riddoch *et al*., 2007), though shorter time periods (e.g., 8 hours a day; Cleland, Crawford, Baur, Hume, Timperio & Salmon, 2008) and different wear times for weekdays and weekend days (Rowlands, Pilgrim & Eston, 2008) have also been used. Mattocks and colleagues (2008) found that reliabilities of 0.8 could be achieved through using 420, 480 and 540 minutes a day for 5 days in children. Three hours of wear time a day has provided reliable estimates of activity in young children (Penpraze, Reilly, MacLean, Montgomery, Kelly, Paton *et al*., 2006).

The final daily wear time is influenced by the assessment of partial non-compliance. This is defined prior to data being viewed in a data reduction programme, so that decisions can be made to include or exclude data for the final analysis. Partial non-compliance (i.e., monitor has been removed) has been defined as a sustained period of zero counts recorded, as individuals would be expected to generate even a small number of counts during a period of inactivity such as watching television (Catellier, Hannan, Murray, Addy, Conway, Yang *et al*, 2005). Ten, fifteen, twenty, thirty and sixty minutes of consecutive zeros have been used to identify non-wear time (Andersen *et al.*, 2006; Catellier *et al.*, 2005; Masse, Fuemmeler, Anderson, Matthews, Trost, Catellier *et al.*, 2005). However, true inactivity may be removed using short time frames as it suggests the monitor has been removed, yet non-compliance may be reported as inactivity using longer time frames. Activity logs should help to inform decisions concerning non-wear time during the day, and to set which time frame to use. Logs can identify legitimate removal and inform researchers' decision making about manually adjusting wear time for these periods. However, there is no set guideline on which time frame should be used. Therefore, sustained periods of zero counts used to determine partial non-compliance should be reported (Masse *et al.*, 2005) to provide clarity in the decision making process and to aid cross study comparisons.

It is expected there will be full or partial days that a participant has not worn the accelerometer (i.e. non-compliance). The number of days needed for an individual to be included in the final analyses will depend on the decisions made concerning that particular sample (Esliger, Copeland, Barnes & Tremblay, 2005). A minimum of 3 days (Andersen *et al.*, 2006; Riddoch *et al.*, 2007), 4 days including 1 weekend day (Cleland *et al.*, 2008), 5 days (Davis & Fox, 2007), 5 days including one weekend day (Esliger *et al.*, 2005) and 7 days (Trost, Pate, Sallis, Freedson, Taylor, Dowda, *et al.*, 2002; Matthews et al., 2002) have all been used in child and adult research. Smaller numbers of days are likely to retain a greater number of participants for analysis, but the minimum number of days required for data to be reliable and valid must be considered (Mattocks *et al*., 2008; Trost *et al*., 2000). Complete days that are missing can be modelled on other days that meet minimum wear time requirements (Figure 1). Methods for handling incomplete physical activity data have been detailed by Masse *et al* (2005) and Esliger *et al*. (2005). To aid comparisons across future studies, the minimum number of days required should be specified, and details provided concerning how missing data were handled. These decisions would impact the final data analysis and the physical activity levels obtained and reported (Esliger *et al*., 2005).

5. Outcome Variables and the Research Question.

The raw data collected by the accelerometer is expressed as counts (Welk, 2002). The outcome variable that these data are used to obtain is determined by the initial research question. Typically, raw count data can be used to obtain the following outcome variables: a) time spent in different physical activity intensities, b) time spent in bouts of activity at different intensities, c) total activity (total counts per day), and d) average physical activity intensity (counts per minute per day). Accelerometer raw data need careful interpretation, and some of the issues concerning this are raised below.

When investigating physical activity guidelines or the amount of activity a population engages in, the associated outcome variable is time spent in different physical activity intensities. Derived cut-points or threshold values based on energy expenditure prediction equations are used on the raw accelerometry data, and are specific to the type of monitor used to derive them (Welk, 2002). Prediction equations have been generated for children (e.g., Eston *et al*., 1998; Freedson *et al*., 1997; Puyau, Adolph, Voha, & Butte, 2002; Trost, Ward, Moorhead, Watson, Riner & Burke, 1998) and adults (Freedson *et al*., 1998; Hendelman *et al*., 2000) using different activities that had their associated oxygen cost assessed using indirect calorimetry. Essentially, a cut point applied to the data assumes that an epoch that scores higher than this value is indicative that the individual has been moderately active, for example, for the length of that epoch (be it 1-s or 60-s). These periods of time are then accumulated to give an overall indication of time spent in moderate physical activity for that recorded day.

The use of cut points to analyse accelerometer data is widely debated, as there is considerable variation in the cut points used to define moderate and vigorous physical activity intensity (see Mattocks, Leary, Ness, Deere, Saunders, Tilling, *et al*., 2007), which influences the achievement of physical activity recommendations (Mota, Valente, Alres, Silva, Santos & Riberio, 2007). This variation ultimately affects comparability across studies (Corder *et al*., 2007), introduces error into the data, and may misclassify people as active or inactive (Mota *et al*., 2007). There is no consensus on the cut points that represent sedentary, light, moderate, and vigorous physical activity in children or adults (Freedson, Pober & Janz, 2005; Matthews, 2005), and cut points will be applicable to different populations (Corder et al., 2007). The future use of cut points will depend on the population being studied and how the study sample compares to the population the cut point was derived from. Researchers and practitioners, therefore, should be aware of the impact that different thresholds have on their data, and recognise these as a necessary evil and limitation.

Studies often report accelerometry data as the average physical activity intensity (counts per minute per day). This outcome variable provides an indication as to the intensity of activity; that is, the higher the value, the higher the activity levels (Riddoch *et al*., 2007). This is not influenced by some of the problems discussed above, though has limited use on its own as counts are a dimensionless unit and cannot be compared across different commercial monitors (Corder *et al*., 2008). In addition, average physical activity intensity is affected by the wear time, since the total counts generated are divided by time, and explains why the definition of partial non-compliance should be considered carefully and stated. Expressing accelerometry data in this way may relate more strongly to health outcomes in adults (Corder *et al*., 2007). Overall, average physical activity intensity should be reported, as it provides some indication of the activity levels of the population studied, and will enable comparisons between studies that have used the same brand and model of accelerometers.

Collected accelerometer data is time stamped, which enables an examination of activity patterns across weekdays and weekend days, or between distinct periods of the day. Patterns of activity can be assessed using total counts per hour, average activity intensity, or time spent in different physical activity intensities. In addition, bouts of continuous physical activity can be investigated. This has considerable interest to researchers and practitioners looking to implement and evaluate physical activity interventions, as periods of activity, inactivity, and continuous bouts of physical activity in the population of interest can be established. Despite the limitations of the outcome variables generated from the raw data, accelerometry has the capacity to produce rich data concerning physical activity levels and patterns of physical activity behaviour, and will continue to expand our knowledge in these areas.

6. Summary.

The aim of this paper was to introduce the measurement of field-based physical activity using accelerometry. Recommendations have been made based on the body of literature to date, though other issues are still being widely debated. Specific references have been provided to signpost readers to these debates. Essentially, most important component of physical activity monitoring is participant compliance, because significant non-wear will compromise the validity of the data regardless of how it is processed. Researchers and practitioners should consider the data required, the feasibility of the data collection, the burden of the monitoring protocol on the participants, and methods for encouraging compliance with the resultant protocol. Careful consideration of issues such as participant compliance and clarity in the methods reported should, ultimately, lead to better quality information being available to enhance the existing body of knowledge in the area of physical activity assessment.

References.

Actigraph. (2007). *Actigraph GT1M Monitor/ActiTrainer and ActiLife Lifestyle Monitor Software User Manual.* Pensacola, FL: Actigraph.

Andersen, L.B., Harro, M., Sardinha, L.B., Froberg, K., Ekelund, U., Brage, S. *et al*. (2006). Physical activity and clustered cardiovascular risk in children: A cross-sectional study (The European Youth Heart Study). *Lancet, 368*, 299-304.

Bailey, R.C., Olson, J., Pepper, S.L., Porszasz, J., Barstow, T.J. & Copper, D.M. (1995). The level and tempo of children's physical activities: An observational study. *Medicine and Science in Sport and Exercise*, *27*, 1031-1041.

Baquet, G., Stratton, G., Van Praagh, E. & Berthoin, S. Physical activity assessment in prepubertal children with high frequency accelerometry monitoring. *Preventive Medicine*, *44*, 143-147.

Blair, S.N. & Connelly, J.C. (1996). How much physical activity should we do? The case for moderate amounts and intensities of physical activity. *Research Quarterly for Exercise and Sport*, *67*, 193-205.

Caspersen, C.J., Powell, K.E., & Christenson, G.M. (1985). Physical activity, exercise, and physical fitness: Definitions and distinctions for health-related research. *Public Health Reports*, *100*, 126-131.

Catellier, D.J., Hannan, P., Murray, D.M., Addy, C.L., Conway, T.L., Yang, S., & Rice, J.C. (2005). Imputation of missing data when measuring physical activity by accelerometry. *Medicine and Science in Sports and Exercise, 11*(Suppl), S555-S562.

Chen, K.Y. & Bassett Jr, D.R. (2005). The technology of accelerometry-based activity monitors: Current and future. *Medicine and Science in Sports and Exercise, 11*(Suppl), S490-S500.

Clelend, V., Craford, D., Baur, L.A., Hume, C., Timperio, A., & Salmon, J. (2008). A prospective examination of children's time spent outdoors, objectively measured physical activity and overweight. *International Journal of Obesity, 32*, 1685-1693.

Corder, K., Brage, S., & Ekelund, U. (2007). Accelerometers and pedometers: Methodology and clinical application. *Current Opinion in Clinical Nutrition and Metabolic Care, 10*, 597-603.

Corder, K., Brage, S., Mattocks, C., Ness, A., Riddoch, C., Wareham, N.J. *et al*. (2005). Comparison of two methods to assess PAEE during six activities in children. *Medicine and Science in Sports and Exercise, 39,* 2180-2188.

Corder, K., Brage, S., Wareham, N., & Ekelund, U. (2005). Comparison of PAEE from combined and separate heart rate and movement models in children. *Medicine and Science in Sports and Exercise, 37,* 1761-1767.

Corder, K., Ekelund, U., Steele, R.M., Wareham, N.J. & Brage, S. (2008). Assessment of physical activity in youth. *Journal of Applied Physiology, 105,* 977-987.

Craig, C.L., Marshall, A.L., Sjostrom, M., Bauman, A.E., Booth, M.L., Ainsworth, B.E., *et al.* (2003). International Physical Activity Questionnaire: 12-country reliability and validity. *Medicine and Science in Sports and Exercise, 35*, 1381-1395.

Crouter, S., & Kerr, J. (2008). *An Introduction to Accelerometer Data Reduction and Processing,* Retrieved 9th February, 2009, from http://www.activelivingresearch.org/conference/2008/wednesday.

Dale, D., Welk, G.J. & Matthews, C.E. (2002). Methods for assessing physical activity and challenges for research. In G.J. Welk (Ed.), *Physical Activity Assessments for Health-Related Research* (pp.19-54). Champaign, IL: Human Kinetics.

Davis, M.G. & Fox, K.R. (2007). Physical activity patterns assessed by accelerometry in older people. *European Journal of Applied Physiology, 100,* 581-589.

Department of Health. (2004). *At Least Five a Week: Evidence on the Impact of Physical Activity and its Relationship to Health. A Report from the Chief Medical Officer.* London: Department of Health.

Esliger, D.W., Copeland, J.L., Barnes, J.D., & Tremblay, M.S. (2005). Standardizing and optimizing the use of accelerometry data for free-living physical activity monitoring. *Journal of Physical Activity and Health, 3*, 366-383.

Eston, R. G., Rowlands, A. V., & Ingledew, D. K. (1998). Validity of heart rate, pedometry, and acclerometry for predicting the energy cost of children's activities. *Journal of Applied Physiology, 84*, 362-371.

Freedson, P.S., Pober, D., & Janz, K.F. (2005). Calibration of accelerometer output for children. *Medicine and Science in Sports and Exercise, 11*(Suppl), S523-S530.

Freedson, P.S., Sirard, J., Debold, E., Pate, R., Dowda, M., Trost, S., *et al*. (1997). Calibration of the Computer and Science Applications, Inc (CSA) accelerometer. *Medicine and Science in Sports and Exercise, 29*(Suppl), S45.

Health Survey for England. (2006). *Health Survey for England 2006: CVD and Risk Factors in Adults, Obesity, and Risk Factors in Children.* London: The Information Centre for Health and Social Care.

Hendelman, D., Miller, K., Baggett, C., Debold, E., & Freedson, P. (2000). Validity of accelerometry for the assessment of moderate physical activity in the field. *Medicine and Science in Sports and Exercise, 32*, 442-449.

Janz, K. F. (2002). Use of heart rate monitors to assess physical activity. In G. J. Welk (Ed.), *Physical Activity Assessments for Health-Related Research* (pp. 143-161). Champaign, IL: Human Kinetics.

Mâsse, L.C., Fuemmeler, B.F., Anderson, C.B., Matthews, C.E., Trost, S.G. , Catellier, D.J, *et al.* (2005). Accelerometer data reduction: A comparison of four reduction algorithms on selected outcome variables. *Medicine and Science in Sports and Exercise, 11*(Suppl), S544-S554.

Matthews, C.E. (2005). Calibration of accelerometer output for adults. *Medicine and Science in Sports and Exercise, 11*(Suppl), S512-S522.

Matthews, C.E., Ainsworth, B.E., Thompson, R.W., & Bassett, D.J. (2002). Sources of variance in daily physical activity levels as measured by an accelerometer. *Medicine and Science in Sport and Exercise, 34,* 1376-1381.

Mattocks, C., Leary, S., Ness, A., Deere, K., Saunders, J., Tilling, K., *et al.* (2007). Calibration of an accelerometer during free-living physical activities in children. *International Journal of Pediatric Obesity, 2,* 218-226.

Mattocks, C. Ness, A., Leary, S., Tilling, K., Blair, S.N., Shield, J., *et al.* (2008). Use of accelerometers in a large field-based study of children: Protocols, design issues, and effects on precision. *Journal of Physical Activity and Health, 5*(Suppl), S98-S111.

McKenzie, T. (2002). Use of direct observation to assess physical activity. In G.J. Welk (Ed), *Physical Activity Assessments in Health-Related Research* (pp. 179-195). Champaign, IL: Human Kinetics.

Melanson Jr, E.L. & Freedson, P.S. (1995). Validity of the Computer Science and Applications, Inc (CSA) activity monitor. *Medicine and Science in Sports and Exercise, 27*, 934-940.

Mota, J., Valente, M., Alres, A., Silva, P., Santos, M.P., & Riberio, J.C. (2007). Accelerometer cut-points and youth physical activity prevalence. *European Physical Education Review, 3*, 287-299.

Nilsson, A., Ekelund, U., Yngve, A. & Sjöström, M. (2002). Assessing physical activity among children with accelerometers using different time sampling intervals and placements. *Pediatric Exercise Science, 14,* 87-96.

Ott A.E., Pate, R.R., Trost, S.G., Ward, D.S. & Saunders, R. (2000). The use of uniaxial and triaxial accelerometers to measure children's "free-play" physical activity. Pediatric Exercise Science, 12, 360-370.

Penpraze, V., Reilly, J.J., MacLean, C., Montgomery, C., Kelly, L., Paton, J.Y., Aitchison, T., & Grant, S. (2006). Monitoring of physical activity in young children: How much is enough? *Pediatric Exercise Science,* 18, 483-491.

Puyau, M.R., Adolph, A.L., Vohra, F.A. & Butte, N.F. (2002). Validation and calibration of physical activity monitors in children. *Obesity Research, 10,* 150-157.

Riddoch, C.J., Mattocks, C., Deere, K., Saunders, J., Kirky, J., Tilling, K., *et al.* (2007). Objective measurement of levels and patterns of physical activity. *Archives of Disease in Childhood, 92*, 963-969.

Ridgers, N.D., Stratton, G., Clark, E., Fairclough, S.J. & Richardson, D.J. (2006). Day-to-day and seasonal variability of physical activity during school recess. *Preventive Medicine*, *42*, 372-374.

Rowlands, A.V. (2007). Accelerometer assessment of physical activity in children: An update. *Pediatric Exercise Science, 19*, 252-266.

Rowlands, A.V., Pilgrim, E.L., & Eston, R.G. (2008). Patterns of habitual activity across weekdays and weekend days in 9-11-year old children. *Preventive Medicine, 46*, 317-324.

Sallis, J.F. & Patrick, K. (1994). Physical activity guidelines for adolescents: Consensus statement. *Pediatric Exercise Science, 6*, 302-314.

Sirard, J. R. & Pate, R. R. (2001). Physical activity assessment in children and adolescents. *Sports Medicine, 31*, 439-454.

Trost, S.G., McIver, K.L., & Pate, R.R. (2005). Conducting accelerometer-based activity assessments in field-based research. *Medicine and Science in Sports and Exercise, 11*(Suppl), S531-S543.

Trost S.G., Pate, R.R., Freedson, P.S., Sallis, J.F. & Taylor, W.C. (2000). Using objective physical activity measures with youth: How many days of monitoring are needed? *Medicine and Science in Sports and Exercise, 32*, 426-431.

Trost, S.G. Pate, R.R., Sallis, J.F., Freedson, P.S., Taylor, W.C., Dowda, M., & Sirard, J. (2002). Age and gender differences in objectively measured physical activity in youth. *Medicine and Science in Sports and Exercise, 34,* 350-355.

Trost, S.G., Ward, D.S., Moorhead, S.M., Watson, P.D., Riner, W., & Burke, J.R. (1998). Validity of the Computer Science and Applications (CSA) activity monitor in children. *Medicine and Science in Sports and Exercise, 30*, 629-633.

Tryon, W.W. & Williams, R. (1996). Fully proportional actigraphy: a new instrument. *Behavior Research Methods, Instruments and Computers, 28,* 392-403.

Tudor-Locke, C.E. & Myers, A.M. (2001). Methodological considerations for researchers and practitioners using pedometers to measure physical (ambulatory) activity. *Research Quarterly for Exercise and Sport, 72*, 1-12.

Welk, G. J. (2002). Use of accelerometry-based activity monitors to assess physical activity. In G. J. Welk (Ed.), *Physical Activity Assessments in Health-Related Research* (pp. 125-141). Champaign, IL: Human Kinetics.

Welk, G.J. (2005). Principles of design and analyses for the calibration of accelerometry-based activity monitors. *Medicine and Science in Sports and Exercise, 11*(Suppl), S501-S511