Physical Activity Assessment (26 June 2025)

<Reference page> https://www.measurement-toolkit.org/physical-activity/introduction/energy-expenditure
Physical activity is a different construct to physical fitness; exercise is a type of physical activity undertaken in leisure time and should not be used interchangeably with the term 'activity'. Sedentary behavior is not merely the absence of physical activity and is emerging as a potential independent health risk.

Sedentary behavior assessment

Sedentary behaviours may be defined as engagement in pursuits that require expending low amounts of energy i.e. >0.9 (sleeping) but <2.0 (sitting) Metabolic Equivalents (METS). It is a complex area and has been over simplified in the past (Biddle, 2007); it is not merely the absence of moderate or moderate-to-vigorous physical activity (Spanier et al, 2006; Healy et al, 2008a). Importantly, sedentary behaviours can readily coexist with physical activity. There is a frequent assumption in both academic circles and the media that young people are less active than in previous generations, but there is little behavioural or physiological data to support this, although a steep decline in physically active transport to school is apparent (Biddle et al, 2004). Indeed it appears that in the last 50 years the absolute volume of sedentary behaviours undertaken by youth may have remained largely unchanged; the types of activity have changed as TV and small screen use has replaced comic books and music (Biddle, et al, 2004; Marshall et al, 2006). There is increasing interest in sedentary behaviours as an independent health risk factor. It is also apparent that sedentary behaviours may have different correlates to physical activity and that these differ between boys and girls (Leatherdale et al, 2008). The measurement of sedentary behaviour is not a well developed field and many misconceptions exist, e.g. that television viewing is a measure of overall sedentary behaviour in youth. In addition to the promotion of physical activity, reductions in sedenatary behaviour are rapidly becoming a public health focus.

Television viewing

There is evidence of positive, although weak, associations between children's television viewing time and body mass index or percent body fat but few studies have examined whether these associations are independent of physical activity levels (Salmon et al, 2008). In a comprehensive review of health-enhancing physical activity in children and adolescents it was noted that most children and adolescents do not exceed recommended daily hours of TV viewing and that physical activity is unrelated to TV viewing (Biddle et al, 2004). It appears that TV viewing accounts for less than 50% of time spent in sedentary pursuits (Gorley et al, 2007; Gorely et al 2007b). There is virtually no evidence for the displacement hypothesis i.e. TV and other sedentary pursuits will displace more active pursuits (Sallis et al, 2000; Marshall et al, 2004; Marshall et al, 2006). It appears that boys watch more television (or are higher users of computers) than girls (Marhsall et al, 2006).
For adults, it may be that TV viewing is a better marker of sedentary behaviour in women than men (Sugiyama, 2008a).
In recent study, TV viewing more than 4 hrs significantly rises the risk of CVD, but sedentary working (often/always) does not change the risk of CVD, though the data were obtained using JPAC (Garcia et al., 2019).

Measurement of Sedentary Behaviors

Typically, physical activity is assessed and individuals are classified according to their 'score' as being active or not; inactive is said to be sedentary.
There are 4 categories of sedentary behaviors, which ideally, should all be measured; the first two are the most dominant:
1. Technological (screen time)- TV, computer use (leisure), small screen use
2. Socializing – chat, phone, texts
3. Motorized transport
4. Homework (for children) or reading

Ideally, when measuring sedentary behaviour the aim is to capture accurately:
- What was done
- Who with - friends, family, self (social context)
- Where - indoor, outdoor (physical environmental context)
- The frequency of sedentary behaviours
- The duration of sedentary behaviours

Self-report, observation, parental report and real time data capture are the main measurement tools used to assess sedentary behaviours. Self-report can be either by questionnaire or diary. Accelerometers which show total inactivity or the absence of physical activity do not provide the context of the behaviour.
The structure of the questionnaire is important and recalls of activity must be broken down and time bound. Some well known tools in the area are listed:
* Self-Assessed Physical Activity Checklist (SAPAC) - this tool has been psychometrically tested and uses a long list of prompts (Brown et al, 2004);
* Previous Day Physical Activity Recall (PDPAR) - designed to assess physical activity and sedentary behaviours (Pate et al, 1997; Pate et al 1999);
* Multimedia Activity Recall for Children and Adolescents (MARCA) - a computerised 24-hour activity recall linked to a compendium of energy expenditure (Ridley et al, 2002);
* Adolescent Sedentary Activity Questionnaire (ASAQ) - includes five categories: small screen recreation, education, travel, cultural activities and social activities (Hardy et al, 2007);
* A systematic review of questionnaires which included a television assessment component has been published (Bryant et al, 2006).
* Ecological Momentary Assessment (EMA) is an assessment strategy that can simultaneously capture behaviour and the factors that influence it; the method is also known as experience sampling or ambulatory diary assessment (Dunton et al, 2005). Individuals report their current activity, location, and social surroundings at any particular moment. The method has been used

in a small number of studies only, in both adults and adolescents. In the UK, 923 adolescent girls kept pen and paper diaries of free time i.e. outside of school for three weekdays and one weekend day (Gorely et al, 2007; Gorely et al 2007b). A US study in adolescents captured this information by a Personal Device Assistant (PDA) (Dunton et al, 2005). In the EMA diaries individuals recorded WHAT they were doing in 15 minute intervals-NOT what they had been doing in the past 15 minutes as in a typical activity diary or log. Location and details of other people present were also recorded.

The EMA diary method produces rich complex data, time points are aggregated and then reduced to daily summaries and typically reduced further to provide a summary of weekday and weekend behavior. In children there is a reasonable argument for measuring time out of school, the rationale being that options to decrease sedentary behavior in school are limited and it was what children CHOOSE to do which is important and provides a platform to intervene. In younger children a proxy report may be used but this is problematic for parents to do as they are not there all the time. Observational methods are intrusive and may cause reactivity, but technological advances may make this method more feasible.

Measurement of TV viewing

A systematic review of the measurement of TV viewing in children and adolescents urged researchers to consider the level of precision that is required as well as feasibility issues (Bryant et al, 2006).

The 'Robinson school based intervention self-report instrument' (Robinson et al, 1995) had the highest reliability (r=0.94), however the test, re-test was done on the same day (Bryant et al, 2006).

The 'Direct estimate of hours per week of TV' developed by Anderson et al (1985) had the highest validation (r=0.6), and this was undertaken by comparison with a 10-day viewing diary not a criterion method of direct observation.

Often TV viewing was assessed as a component of other questionnaires measuring either physical activity or sedentary behavious. The authors concluded that few of these assessment tools have supportive psychometric evidence for validity or reliability (Bryant et al, 2006). Of the ones that do, none assessed validity with a criterion measure.

The measure which demonstrated the greatest reliability (r=0.98) was the PDPAR (Weston et al, 1997), again reliability was tested on the same day. This tool also had the best validity compared to pedometer counts (r=0.88).

The 'New Moves obesity prevention physical education program' tool (Neumark-Sztainer et al, 2003) which was re-administered a month apart also had good reliability (r=0.8).

Single item tools within a survey to measure TV watching lack content validity and are subject to measurement error relating to memory and social desirability bias; estimates will be crude (Bryant et al, 2006).

Activity or viewing diaries allow more detailed information about the TV programs to be collected and are not subject to error associated with memory. However diaries are intrusive and may cause reactivity.

Direct observation either by video or by researcher are considered a gold standard method for measuring TV exposure but is burdensome for researchers and is likely to affect behavior.

Advances in accelerometry and high frequency movement sampling will contribute to the measurement of sedentary behaviour as motorised transport, for example, can be distinguished. However there is an urgent need for the development of observational tools which are low burden for the individual and researcher.

Sedentary behaviors and health risk

The Australian Diabetes, Obesity and Lifestyle Study (AusDiab) has shown that independent of time spent in moderate to vigorous intensity activity, there were significant associations of sedentary time, light intensity time and mean activity intensity with waist circumference and clustered metabolic risk (Healy et al, 2008b). An Australian survey of over 2000 adults showed that those who spent more time in sedentary behaviours but were sufficiently physically active had a similar risk of being overweight or obese as those who were insufficiently active but spent less time in sedentary behaviour (Sugiyama et al, 2008b). This suggests that reducing leisure time sedentary behaviours may be as important as increasing leisure time physical activity in obesity prevention.

Observational studies of the relationship between TV viewing and health outcomes have been systematically reviewed (Williams et al, 2008). In adults, greater amounts of TV viewing appear to be associated with overweight but the relationship with other health outcomes is not consistent (Williams et al, 2008).

A meta-analysis of studies in children and adolescents investigated the relationships between media use, body fatness and physical activity. A statistically significant relationship was found between TV viewing and body fatness but the magnitude was such that the clinical significance of was irrelevant (Marshall et al, 2004). In an adult prospective population cohort study in the UK, sedentary time was measured by individually calibrated heart rate monitoring. Body mass index, fat mass and waist circumference were associated with sedentary behaviour but sedentary time was not predictive of future obesity (Ekelund et al, 2008).

The association of TV viewing time with other sedentary behaviors has been examined in a large sample of Australian adults (Sugiyama, 2008a). After adjustment for body mass index and socio-demographic variables, women's TV viewing time was associated with time in other sedentary behaviors and negatively with leisure time physical activity; these associations were not present in men (Sugiyama, 2008a).

The dose response associations of television viewing have been examined in Australian adults who met the public health guideline for physical activity and a positive association with a number of metabolic risk variables was apparent; the associations were stronger in women (Healy, 2008a).

The term 'inactivity physiology' has been coined to describe the effect of inactivity on muscular ability (Hamilton et al, 2007). The potential role of low energy expenditure and sitting in obesity, metabolic syndrome, Type 2 diabetes and cardiovascular disease has been reviewed (Hamilton et al, 2007). In society today, prolonged sitting time is commonplace for many people who spend their working days largely sitting, and for old people in nursing homes or at home. The benefits in terms of metabolic risk in breaking up sedentary time have been shown (Healy et al, 2008c).

Refs: https://www.measurement-toolkit.org/physical-activity/introduction/sedentary-behaviour

Various methods

- Questionnaire: Self-report methods are the most convenient and cheapest way to collect physical activity data from a large number of people in a short time. Physical activity questionnaires (**PAQs**) are the most widely used self-report instrument to assess physical activity and have been used extensively in research. Self-report measures include self or interviewer administered (Matthews, 2002): Activity diaries or logs; Recall questionnaires; Quantitative history; Global self report
    - Questionnires vary greatly in their detail. Recall questionnaires typically contain 5-15 items and aim to stratify the population into broad categories of physical activity. Some may also try to estimate energy expenditure. The reference time frame varies depending on the objectives of the study but typically tends to be between a week and a month. Examples are the short version of the IPAQ and the Baecke questionnaire.
    - International Physical Activity Questionnaire (IPAQ): This questionnaire is available in a short form for surveillance, and in a longer form when more detailed physical activity information is required, both forms are available in a number of languages (https://sites.google.com/view/ipaq/home). The questionnaire was rigorously tested for reliability and validity (Craig et al, 2003) and this has been replicated in a number of countries; this questionnaire is not designed to provide a detailed assessment of physical activity in all domains.
        - https://doi.org/10.1079/PHN2005898
        - https://doi.org/10.1371/journal.pone.0219193.s010 (https://doi.org/10.1371/journal.pone.0219193)
    - Global Physical Activity Questionnaire (GPAQ): This questionnaire was developed under the auspices of the World Health Organisation and it collects information on participation in physical activity in three domains: activity at work, travel to and from places and recreational activities.
        - https://www.who.int/publications/m/item/global-physical-activity-questionnaire
        - https://www.who.int/docs/default-source/ncds/ncd-surveillance/gpaq-analysis-guide.pdf
    - Both the IPAQ and the GPAQ were developed for surveillance studies and the GPAQ more specifically for surveillance studies in developing countries. These instruments are not recommended for other purposes.
    - Other questionnaires aiming at measuring dose of physical activity by domains have been developed for investigative purposes. One of them is the EPIC Physical Activity Questionnaire 2 (EPAQ2), which has been developed and validated in England (Wareham et al, 2002). The Recent Physical Activity Questionnaire (RPAQ) developed from the EPAQ2 with a shorter time frame of one month instead of one year is currently under validation with promising results (Besson et al, 2006). (Note: in 2010, RPAQ was validated. Besson et al., 2010 https://doi.org/10.3945/ajcn.2009.28432)
    - Self reports for specific populations: Cognitive immaturity or degeneration make self-report of physical activity difficult in the young and elderly. Children's activity is unique in that it is characterised by short bouts rather than more sustained periods of activity (Pate, 1993; Kohl et al, 2000; Sirard & Pate, 2001). For this reason specific recommendations of levels of desirable activity have been made for this age group (Welk et al 2000). Self-report is not viable in the young, (Sallis 1991) and previous day's recall has been suggested as the most appropriate method for children aged 10-11 years (Sallis et al, 1993). Decisions then need to be made on how many days and on which days activity will be measured (Welk et al, 2000). It is necessary to rely on proxy reports for children e.g. parents is difficult as a child gets older and becomes more independent (Pate, 1993).
    - The children physical activity questionnaire (CPAQ; https://www.mrc-epid.cam.ac.uk/wp-content/uploads/2014/08/CPAQ.pdf) and the youth physical activity questionnaire (YPAQ; https://www.mrc-epid.cam.ac.uk/wp-content/uploads/2014/08/YPAQ.pdf) have recently been tested for their validity and reliability. Validation results suggested that these PAQs were unable to accurately estimate time spent at moderate and vigorous intensity physical activity and physical activity energy expenditure. However, they may rank individuals accurately (Corder et al, 2009, https://doi.org/10.3945/ajcn.2008.26739).
    - For the elderly, using physical activity questionnaires which have been designed and validated in younger populations is inappropriate (Washburn, 2000). Four questionnaires have been specifically designed for this segment of the population (Washburn, 2000): Modified Baecke Questionnaire; Zutphen Physical Activity Questionnaire; Yale Physical Activity Survey (https://www.sralab.org/sites/default/files/2019-11/Yale_Physical_Activity_Survey.pdf); Physical Activity Survey for the Elderly.
    - JPAC has been used to assess physical activity in Jackson Heart Study (Dubbert et al., 2005; Smitherman et al., 2009).
    - The elderly are a diverse population group in terms of physical and cognitive function and this is likely to be reflected in a wide range of activity levels and competence to self-report this activity.
    - (cf.) **RAPA** (Rapid Assessment of Physical Activity) → scoring activity level, not intended to estimate quantitative energy expenditure. Available from https://depts.washington.edu/hprc/resources/products-tools/rapa/
- **Diary or log**: Self-reports of physical activity by a diary or log method provide a detailed record of an individual's physical activity on a daily basis; these records are generally completed prospectively as the activities are completed. In a physical activity diary (also known as a record), individuals are instructed to record the individual bouts of activity as they occur during the day. In contrast, logs capture the time individuals spend in broad categories of activity: inactive, sitting, light, moderate, vigorous and very vigorous and examples of activities in each intensity level are provided (Bouchard et al, 1983). In both the diary and log, the 24 hour period is typically broken down into 15 minute segments and individuals record their activity. Completing diaries and logs every 15 minutes may lead to the omission

of some activities, but reducing the period has been shown to be too intensive and lead to non completion (Bratteby et al, 1997). In diaries, individuals are asked to record their activity often from a pre-defined list which is coded, but space is provided for other activities to be recorded. The list of activities is typically grouped according to their metabolic equivalents (MET) value. The intensity of the activity (low, moderate or vigorous) is also recorded. Ainsworth et al (2000a) have developed and tested a logbook which is a page long per day and contains 48 items (7 resting/light; 25 moderate; 16 hard/very hard) organised as home, transport, occupation, conditioning, sports and leisure activities (intensity was not sought in the later version). Individuals are instructed to complete the log book at the end of each day and record only activity with duration of more than 10 minutes. This log book is less burdensome than others. Correlations with accelerometry were moderate and ranged from 0.26-0.54 depending on the comparisons. Diaries produce more detailed information i.e. types of activity, intensity and patterns, than logs but are more burdensome for individuals to complete and the data are more complex to reduce and enter. The recent development of palm-top personal digital assistants has enabled this electronic medium to be utilized for the collection of physical activity data by a diary method (Mathews, 2002).

- **Pedometry:** Pedometers are low-cost motion sensors which are typically worn on a belt or waistband and respond to vertical accelerations of the hip during gait cycles (Welk et al, 2000). Pedometers provide data on steps taken, and therefore, only really measure walking activity. Due to this, they will not capture activities such as cycling, swimming, walking on an incline or weight lifting. Walking however is one of the most common forms of physical activity and pedometers readily measure this. There are wide variations between pedometer models and this is reflected in their cost. Generally the cost of a pedometer is proportional to its accuracy. Several papers have rigorously reviewed and compared commonly available pedometers (Crouter et al, 2003; Schneider et al, 2003; Tudor-Locke et al, 2006). In one study, eight out of 10 electronic pedometers were considered accurate when recorded steps were compared to actual steps, but three models (Kenz-Lifecorder, New Lifestyles NL-2000 and Yamax Digiwalker SW-701) were noted to be superior over a 400-m track walking test, as they were accurate within ±3% (Schneider et al, 2003). Comparison of pedometers over fixed distances or at a variety of treadmill speeds is not reflective of their performance in free-living conditions. The Yamax SW-200 (YX200) has been used widely in the literature and as a criterion pedometer in a comparison study in free-living conditions (Schneider et al, 2004). Pedometers used in research must be of research grade and the following specifications have been recommended (Tudor-Locke et al, 2006): Sensitivity threshold of 0.35Gs; Detection of ± 1 step error on the 20 step test (i.e. within 5%); Detection of ± 1% error most of the time during treadmill walking at $80 m.min^{-1}$; Detect steps/day within 10% of the Actigraph at least 60% of the time, or be within 10% of the Yamax under free-living conditions. The variation in cost and accuracy is due to different internal mechanisms. There are at least three basic mechanisms, including the spring-suspended lever arm with metal-on-metal contact, a magnetic reed proximity switch and horizontal beam, and piezo-electric crystal i.e. an accelerometer-like mechanism (Crouter et al, 2003; Schneider et al, 2003).
- **Accelerometry:** Accelerometry is a direct measure of acceleration of the body or segments of the body. Accelerometry is the most common objective method used to measure physical activity; it has been used extensively in field settings to monitor activity patterns. Technological advances have resulted in devices that can measure activity accurately, over an extended time period (greater than 7 days), and that are small and discrete for people to wear. The device is enclosed in a case and typically attached to the hip (or lower back, ankle, wrist or thigh) by a strap. Acceleration is a change in velocity with respect to time (SI unit: m.s-2). Muscular forces can result in acceleration of body mass. Both the acceleration of the body mass and the amount of body mass being accelerated are in theory related to energy expenditure. In accelerometry, acceleration is measured by piezoelectric or seismic sensors in one (longitudinal body axis, usually vertical), two (vertical and medio-lateral or vertical and anterior-posterior) and three (vertical, medio-lateral and anterior-posterior) directions (Chen et al, 2005). Accelerometers attached to the waist do not capture upper body movement or cycling, and underestimate walking on an incline or carrying heavy loads. The latter are examples of where the energy cost of physical activity may not necessarily be equivalent to body movement. Accelerometers are usually not waterproof although a few models are splash-proof, and should be removed for water-based activities. Classical accelerometers used in the epidemiological field sampled acceleration at some higher frequency (10-32 Hz) but then reduced the information on-the-fly to store local averages on say a minute-to-minute basis. This is due to memory and battery restriction. It is important to acknowledge that these data processing "decisions", made by any given monitor makes the stored information fundamentally different to the original acceleration signal. Current monitors store more data, from which it is possible to make more sophisticated inferences, either on-the-fly or at the post-processing stage. A number of manufacturers produce accelerometers, and studies have shown differences in values both within and between models (Welk et al, 2000; Brage et al, 2003; Welk et al, 2004; Esliger & Trembaly, 2006; Plasqui & Westerterp 2007). Regular mechanical calibration of the sensor is recommended to overcome the former issue. The underlying scientific principles and technical specifications have been comprehensively described (Chen et al, 2005; Pober et al, 2006). Accelerometers used in paediatric studies have also previously been summarised (Reilly et al, 2008). The primary outcome measure of accelerometry is body acceleration, often expressed as a count value. A "count" is an arbitrary unit, which varies across devices and even generations of the same device type (Rothney et al, 2008). It is influenced by the amplitude and frequency of acceleration, also to a varying degree between different types of instrument. Secondary outcomes are estimates of bout frequency, duration and intensity of body movement. Output measures may be presented as: activity counts i.e. counts/min; Units of acceleration (g-force units or $m.sec^2$); Time spent in physical activity with varying intensity i.e. time spent above an intensity threshold pre-determined by a regression equation; Number of bouts of activity i.e. the number of times there was continuous movement above an intensity threshold (pre-determined by a regression equation) and a duration threshold

- **Heart rate monitoring:** Heart rate monitoring is a measure of a direct physiological response to physical activity. The development of minute by minute heart rate monitors with internal capacity for multiple days' storage without displaying heart rate has increased the feasibility of this objective measure of physical activity. A heart rate monitor is commonly configured as a chest strap which is wirelessly connected to a data logger hidden in a watch. The use of electrodes provides an alternative way to obtain heart rate as it can improve compliance, but is sometimes considered less feasible for the individual. The theoretical basis of this measure is the linear relationship that exists between heart rate and energy expenditure (EE) in steady state exercise involving large muscle groups. The method has shown to have high reproducibility within subjects (Strath et al, 2000). The primary outcome measure is heart rate and thereby identify the time spent at different intensity levels using absolute heart rate values or heart rate indices. A secondary outcome measure is physical activity energy expenditure estimated using regression equations derived from individual or group calibrations. The slope and y-intercept of this linear relationship varies within and between individuals (Li et al, 1993); factors such as age, gender, weight and fitness level modulate this relationship (Dugas et al, 2005) as do ambient temperature, body posture and emotional state such as anxiety or stress. Additionally, heart rate response tends lag after changes in movement and remain elevated after movement stops; this means that heart rate may mask sporadic activity; this is of particular relevance in children (Trost, 2008). Assessment of physical activity using heart rate is problematic at low levels of activity as its linear relationship with physical activity is more reliable during higher intensities of activity. A number of techniques have been devised to overcome the limitations of heart rate monitoring including individual calibration, and heart rate indices. Absolute heart rate values have been used to distinguish between activity intensities (Sirard & Pate, 2001). The method is based on using a percentage maximum heart rate and an intensity of ≥140 beats per minutes. It has been suggested as an approximate measure of moderate vigorous physical activity in children (Simons-Morton et al, 1994). In sedentary adults average 24-hour heart rate does not rise much above resting levels of 60-100 beats per minute. Three of the most popular heart rate indices are: Activity heart rate index (AHR) – mean of the recorded heart rate minus resting heart rate; Physical activity (PAHR)-25 – the percentage of heart rate 25% above resting heart rate; PAHR-50 - the percentage of heart rate 50% above resting heart rate.
- **Combination heart sensors:** The first commercially available combined sensor is the Actiheart sensor (Brage et al, 2005) which: has a main component 7mm thick with a 33mm diameter and houses a movement sensor, a rechargeable battery, a memory chip and other electronics; weighs 8g; does not require a chest strap; instead electrodes are attached to the chest; is waterproof; indivduals only remove it to replace pads that have perished; offers a choice of epoch length-15s, 30s, 60s; the memory capacity allows 11-days of continuous monitoring using a 60 s epoch (or 15 s epochs in newest generation which has 4 times enhanced memory capacity); allows collection of additional heart rate variability (HRV) information during free-living which provides useful information on the quality of data; provides advanced analyses to estimate energy expenditure more accurately. The initial reliability and validity study of the Actiheart (UK) was undertaken in 2005 (Brage et al, 2005). In this study, the intra- and inter-instrument reliability and validity of the heart rate and motion sensor during electronically simulated heart rate, mechanical shaking, and also during rest, walking and running activities were demonstrated (Brage et al, 2005). Other combined heart rate and motion sensors are available, e.g. the ickal but there is not yet much literature describing this device (Berntsen et al, 2009). In general, combined heart rate and motion sensing allow relatively accurate estimation of activity energy expenditure across the intensity range. For example, low to moderate activities performed by adults in a laboratory setting were well-captured by branched equation modelling of the two sources of information (Thompson et al, 2006). In a study in children, the validity and predictive accuracy of combined sensing was investigated in 39 children during laboratory based treadmill walking and running. Physical activity energy expenditure was measured continuously using indirect calorimetry. The activity energy expenditure from the combined model had the strongest agreement with measurements from indirect calorimetry and accounted for 86% of the variance (Corder et al, 2005). Another evaluation of branched equation modeling (using Actiheart, US version) validated against indirect calorimetry during a wide range of activities in a laboratory setting also reported that this particular technique produce valid estimates (Crouter et al, 2007).
- **Observation:** A number of systems are available and have been comprehensively reviewed (McKenzie, 2002) and recently specifically in pre-schoolers (Oliver, 2007). McKenzie (2002) reviewed nine protocols, for observing physical activity, eight of which had been validated concurrently with accelerometry, heart rate monitoring, or energy expenditure assessed by indirect calorimetry. Inter-observer reliability was also found to be high in these studies with coefficients of agreement ranging from 84% to 99%. A summary of the established observation systems is given:
  - The Fargo Activity Time sampling Survey (FATS) – was the first attempt to develop a research instrument for describing children's activity and related parent behaviour. The FATS used an interval time sampling procedure; observing behaviour for 10 seconds and then record behaviour for 10 seconds (Klesges et al, 1984).
  - Activity Patterns and Energy Expenditure (APEE) – observes free play by 15 second momentary time sampling and rates activity level into one of 5 categories (Epstein et al, 1984).
  - Children's Physical Activity Form (CPAF) – was designed to measure physical activity during physical activity classes using partial time sampling at 1 minute intervals. There are four activity level categories (O'Hara, 1989).
  - Behaviors of Eating and Physical Activity for Children's Health: Evaluation System (BEACHES) – measures physical activity in a range of settings. It uses momentary time sampling at 1 minute intervals and 5 activity level categories (McKenzie et al, 1991).
  - Children's Activity Rating Scale (CARS) – is a five level scale (resting, low, medium, medium-to-high, vigorous), designed to categorise the intensity of physical activities and discriminate between levels of energy expenditure in

young children. The system uses partial time sampling at 1 minute intervals (Puhl et al, 1990).

- Studies of Children's Activity and Nutrition: Children's Activity Timesampling Survey (SCAN CATS) – measures physical activity in a range of locations with an interval time sampling procedure to observe behaviour for 10 seconds and then record behaviour for 10 seconds. There are four activity categories: stationary, minimal activity, slow movement, rapid movement (Klesges et al, 1990).
- System for Observing Fitness Instruction Time (SOFIT) – measures activity during physical education classes using momentary time sampling; 10 second observe/record intervals. Five activity categories are used (McKenzie et al, 1991).
  https://activelivingresearch.org/sofit-system-observing-fitness-instruction-time
- Level and Tempo of Children's Activity (LETO) – measures physical activity in natural settings including the home using 3 second time sampling. Activity is categorised as 14 postures with 3 intensity levels (Bailey et al, 1995). More recently, two observational systems have been developed which incorporate the previously validated CARS and SOFIT systems:
- System for Observing Play and Leisure Activity in Youth (SOPLAY) – designed to capture behavioural and contextual information in groups of (rather than individual) children and adolescents. The target area is scanned to record the number of boys and girls, their activity level and additional information including, the time, temperature, equipment provision, level of organisation and supervision. This system was validated with self-reported physical activity (r=0.35-0.73); inter-observer reliability was found to be high, with intraclass reliability coefficients for activity levels ranging from 0.76-0.99 and percentage agreement for physical activity context ranged from 88-97% (McKenzie et al, 2000).
- System for Observing Play and Recreation in Communities (SOPARC) has recently been developed from SOPLAY. The aim is to capture physical activity and contextual information in people attending community-based settings such as parks and recreation areas. An area is scanned systematically from left to right. The activity levels and types are recorded for boys and girls, concurrently with contextual information (Brown et al, 2006).
- Observational System for Recording Physical Activity in Children – preschool version (OSRAC-P) – has recently been developed to collect contextual and behavioural information at an individual level in a range of pre-school settings. The OSRAC-P measures: physical activity level using the CARS system; type of activity; location of activity; social context; prompts for activity. The data are entered directly into a personalised digital assistant (PDA) or Pocket PC (McKenzie et al, 2006). Inter-observer agreement for OSRAC-P in three preschoolers was assessed and percentage agreements for each of the major variables ranged from 89% to 100% (Brown et al, 2006).

- **Doubly labelled water method:** Doubly labelled water (DLW) measures total energy expenditure (TEE) by observing the differential rates of elimination of a bolus dose of the stable isotope tracers 2H (deuterium) and 18O. The tracers used are non-radioactive and occur naturally in all waters (including drinking waters), and therefore completely safe to use in any population. The method has been used in adults, children and infants to measure TEE, in many diverse investigations including the energy costs of clinical conditions, and the energy utilisation of people participating in intensive physical activities under extreme conditions. It has also been used widely to validate other methods of assessment of dietary and physical activity. Indeed the application of DLW led to seminal work in the identification of widespread under-reporting in dietary assessment. In physical activity measurement, DLW has been used to validate various methods which estimate energy expenditure e.g. questionnaires, diaries, logs and accelerometers; the combination of DLW and indirect calorimetry provides a robust method of measuring the energy expenditure due to physical activity. The theoretical considerstions and assumptions which underpin the method are complex and comprehensive reviews of these are listed in the reference section. The DLW method was originally developed by Lifson et al (1955) with many refinements since. Schoeller (1983) was the first to use the method in humans when the cost of 18O reduced sufficiently to make this a viable albeit expensive measurement for research. In subsequent years advances in measurement technology and the falling bcost of the isotopes has made the method more accessible and it is now used routinely. The fundamental basis of the DLW technique is that whilst the hydrogen label is lost only as water, the oxygen is lost as both water and carbon dioxide; transference of oxygen between water and carbon dioxide is the consequence of rapid exchange promoted by carbonic anhydrase. Therefore the difference between the turnover of the two labels can be used as a measure of the production of carbon dioxide. In practice the subject is asked to drink a known dose of water enriched in 2H and 18O. Samples of blood, saliva or urine, from which the isotopic composition of the body water can be determined, are collected over the next 5-14days. From the isotope disappearance curves four parameters are deduced, the two pool sizes of hydrogen and oxygen and the fractional rate constants of elimination for each of these species, and these are combined to give an estimate of CO2 production.
- **Indirect calorimetry:** Indirect calorimetry provides an estimation of energy expenditure. The experimental protocol used determines which components of energy expenditure are captured, which also depends upon the definition of these components. **Basal Metabolic Rate (BMR)** is the largest component of **total energy expenditure (TEE)**, typically 60-75% when measured over 24 hours and the thermic effect of food is the smallest at 10%. The measurement of BMR requires strict (and generally impractical), conditions and protocol adherence. Therefore, the more loosely defined Sleeping Metabolic Rate (**SMR**) and Resting Metabolic Rate (**RMR**) are usually used as measures of an individuals' lowest level of energy expenditure, acknowledging they are marginally different from BMR. The difference and the direction of the difference between RMR and BMR depend upon the population of interest (Wouters-Adriaens, 2006). The remaining component of TEE is energy expenditure due to physical activity (physical activity energy expenditure) and this component is the most variable between individuals but typically constitutes 15-30% of TEE when measured over 24 hours. However, in some extreme cases (e.g. elite cyclists during

Tour De France), this could be as high as 70%. Indirect calorimeters use standard equations to calculate TEE (Weir 1949, Elia 1988, Elia 1992). The laws of thermodynamics state that energy is neither created nor destroyed; rather it is transformed from one form (higher) to another (lower). Chemical energy from food (macronutrients, i.e. carbohydrates, proteins, fat and alcohol) is liberated in the presence of oxygen (O2) to produce mechanical work thus enabling the activities of daily living to be undertaken. All energy expended ends up as heat and the heat produced in this conversion is equal to the liberated chemical energy. Indirect calorimetry measures energy expenditure or the capacity of our bodies to do work, by assessing oxygen consumption; direct calorimetry in comparison, assesses heat production. The biochemical principle behind the conversion of O2 consumption to heat equivalents i.e. kilojoules or kilocalories is reliant on knowing the composition of foods being metabolised. The macronutrients are each metabolised in the presence of oxygen to produce CO2, H20 and heat; usually protein does not contribute significantly to energy production except in periods of prolonged negative energy balance, e.g., starvation. The ratio of C02 produced to O2 consumed (i.e. VCO2/VO2) is known as the respiratory exchange ratio and will determine the kJ or kcal equivalent value for each litre of oxygen consumed. When 100% carbohydrate is metabolised the respiratory exchange ratio is 1.0, and when 100% fat is metabolised the respiratory exchange ratio is 0.7; a mixture of the two 50:50 is equivalent to a respiratory exchange ratio of 0.85. Based on individual's respiratory exchange i.e. oxygen consumed and carbon dioxide produced, energy expenditure is calculated by Weir's equation (Weir 1949):

REE = [VO2 (3.94) + VCO2 (1.11)] 1440 min/day

The standard Weir equation therefore defines the relationship between VO2 and CO2 production and energy expenditure. Weir also showed that for a specific measurement technique, energy expenditure could be reasonably well approximated without CO2 measurement. However, during specific conditions, when the body covers a more significant proportion of the work from anaerobic (non-oxygen requiring) sources (e.g. maximal work for a few minutes, such as 400 to 800 meters running) of chemical energy, the proton concentration of the blood (from lactic acid) will shift the carbon dioxide – carbonic acid equilibrium towards an excess release of CO2, the measurement of CO2 will enhance the precision of the estimated energy expenditure.

New methods:

Recent developments in technology have led to, or suggest, important developments in the field of physical activity measurement. Developments of particular note are:

* Global positioning system (GPS);
* High frequency movement sampling;
* Combined motion sensors

Additionally, advances in the analysis of physical activity data e.g. analysing accelerometry data using non-linear modelling techniques and a move away from monitor-based processing to more investigator controlled data handling strategies is a positive step and is likely to increase flexibility and comparison in the field. An artificial neural network of energy expenditure using non-integrated acceleration signals showed improved estimates of energy expenditure when compared to a uniaxial accelerometer and the IDEEA monitor and shows promise when linked with raw acceleration signals to improve estimates (Rothney et al, 2007). The IDEAA monitor commercially available (MiniSun, Frenso, CA) consists of 5 accelerometers attached to the skin with hypoallergenic tape at the sternum, midthigh, bottom of each foot. Each sensor is wired to a hip pack that serves to synchronise the signals from each channel and to store data.

The incorporation of GPS to movement sensors provides objective data about location, domain of activity and may even help assess the determinants of activity (Rodriguez et al, 2005).

High frequency movement sampling has the potential to overcome some of the limitations of accelerometry. The technology is advanced enough to differentiate activities not currently possible.

Advanced analysis of accelerometry data combined with a physiological measure such as heart rate or temperature offers the greatest potential for the accurate estimation of energy expenditure (Corder, et al, 2008).

These technological advances and the development of novel estimation methods are likely to narrow the gap between validity and feasibility of different methods.

References:

Corder K, Ekelund U, Steele RM, Wareham NJ, Brage S Assessment of physical activity in youth Appl Physiol. 2008 doi:10.1152/japplphysiol. 00094.2008

Rodriguez DA, Brown AL, Troped PT Portable global positioning units to complement accelerometry-based physical activity monitors Med Sci Sports Exerc. 2005; 37:11 (suppl):S572-81

Rothney MP, Neumann M, Beziat A, Chen KY An artificial neural network model of energy expenditure using non-integrated acceleration signals J Appl Phyiol. 2007; 103:1419-27

Dowd KP, Szeklicki R, Minetto MA, Murphy MH, Polito A, Ghigo E, et al. A systematic literature review of reviews on techniques for physical activity measurement in adults: a DEDIPAC study. International Journal of Behavioral Nutrition and Physical Activity. 2018 Feb;15(1):15.

Ward D, Evenson K, Vaughn A, Rodgers A, Troiano R. Accelerometer Use in Physical Activity: Best Practices and Research Recommendations. Medicine & Science in Sports & Exercise [Internet]. 2005 Nov 1 [cited 2019 Jul 2];37(11). Available from: insights.ovid.com

Thijs I, Fresiello L, Oosterlinck W, Sinnaeve P, Rega F. Assessment of Physical Activity by Wearable Technology During Rehabilitation After Cardiac Surgery: Explorative Prospective Monocentric Observational Cohort Study. JMIR mHealth and uHealth. 2019;7(1):e9865.

Trost S, Mciver K, Pate R. Conducting Accelerometer-Based Activity Assessments in Field-Based Research. Medicine &

Science in Sports & Exercise [Internet]. 2005 Nov 1 [cited 2019 Jul 2];37(11). Available from: insights.ovid.com
Sallis JF, Haskell WL, Wood PD, Fortmann SP, Rogers T, Blair SN, et al. PHYSICAL ACTIVITY ASSESSMENT METHODOLOGY IN THE FIVE-CITY PROJECT. Am J Epidemiol. 1985 Jan 1;121(1):91–106.
Dubbert PM, Carithers TC, Ainsworth BE, Taylor HA, Wilson GB, Wyatt SB. Physical activity assessment methods in the Jackson Heart Study. Ethnicity & disease. 2005;15(4):S6-56–61.
Caspersen CJ, Powell KE, Christenson GM. Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. Public Health Rep. 1985;100(2):126–31.
Diaz KM, Duran AT, Colabianchi N, Judd SE, Howard VJ, Hooker SP. Potential Effects on Mortality of Replacing Sedentary Time With Short Sedentary Bouts or Physical Activity: A National Cohort Study. Am J Epidemiol. 2019 Mar 1;188(3):537–44.
RAPA | Health Promotion Research Center [Internet]. [cited 2019 Jul 2]. Available from: https://depts.washington.edu/hprc/resources/products-tools/rapa/
Montoye AHK, Moore RW, Bowles HR, Korycinski R, Pfeiffer KA. Reporting accelerometer methods in physical activity intervention studies: a systematic review and recommendations for authors. Br J Sports Med. 2018 Dec 1;52(23):1507–16.
Katzmarzyk PT, Powell KE, Jakicic JM, Troiano RP, Piercy K, Tennant B. Sedentary Behavior and Health: Update from the 2018 Physical Activity Guidelines Advisory Committee. Med Sci Sports Exerc. 2019 Jun;51(6):1227–41.
Patterson R, McNamara E, Tainio M, de Sá TH, Smith AD, Sharp SJ, et al. Sedentary behaviour and risk of all-cause, cardiovascular and cancer mortality, and incident type 2 diabetes: a systematic review and dose response meta-analysis. Eur J Epidemiol. 2018 Sep 1;33(9):811–29.
Klurfeld DM, Hekler EB, Nebeker C, Patrick K, Khoo CSH. Technology Innovations in Dietary Intake and Physical Activity Assessment: Challenges and Recommendations for Future Directions. American Journal of Preventive Medicine. 2018 Oct 1;55(4):e117–22.
Turi BC, Monteiro HL, Lemes ÍR, Codogno JS, Lynch KR, Mesquita CAA, et al. TV viewing time is associated with increased all-cause mortality in Brazilian adults independent of physical activity. Scandinavian Journal of Medicine & Science in Sports. 2018;28(2):596–603.
Garcia Jeanette M., Duran Andrea T., Schwartz Joseph E., Booth John N., Hooker Steven P., Willey Joshua Z., et al. Types of Sedentary Behavior and Risk of Cardiovascular Events and Mortality in Blacks: The Jackson Heart Study. Journal of the American Heart Association. 2019 Jul;8(13):e010406.
Smitherman TA, Dubbert PM, Grothe KB, Sung JH, Kendzor DE, Reis JP, et al. Validation of the Jackson Heart Study Physical Activity Survey in African Americans. Journal of physical activity & health. 2009;6(Suppl)