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Measuring physical activity in children and adolescents for dietary surveys: practicalities, problems and pitfalls

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Physical inactivity is an important risk factor for many chronic diseases and contributes to obesity and poor mental well-being. The present paper describes the main advantages and disadvantages, practical problems, suggested uses, and future developments regarding self-reported and objective data collection in the context of dietary surveys. In dietary surveys, physical activity is measured primarily to estimate energy expenditure. Energy expenditure surveillance is important for tracking changes over time, particularly given the debates over the role of the relative importance of energy intake and expenditure changes in the aetiology of obesity. It is also important to assess the extent of underreporting of dietary intake in these surveys. Physical activity data collected should include details on the frequency, duration and relative intensity of activity for each activity type that contributes considerably to overall activity and energy expenditure. Problems of validity and reliability, associated with inaccurate assessment, recall bias, and social desirability bias, are well-known; children under 10 years cannot report their activities accurately. However, despite such limitations, questionnaires are still the dominant method of physical activity assessment in dietary surveys due to their low cost and relatively low participant burden. Objective, time-stamped measures that monitor heart rate and/or movement can provide more comprehensive, quantitative assessment of physical activity but at greater cost and participant burden. Although overcoming many limitations of questionnaires, objective measures also have drawbacks, including technical, practical and interpretational issues.

Physical activity: Measurement: Children: Survey methodology

Regular physical activity is important to promote physical and mental health and well-being[1,2]. Physical activity is associated with reductions in all-cause mortality[3,4] obesity, diabetes[5], hypertension, CVD[3] certain cancers[3,4], osteoporosis[6] and depression[7]. Insufficient physical activity costs about £8·2×10^9 (\$12·7×10^9, €9·7×10^9) annually in England (2002 values)[8]. In children, physical activity is important for maintenance of a desirable weight for height, for well-being and to inculcate lifelong healthy habits. It also has more immediate health benefits, improving motor development and psychosocial health and reducing adiposity in pre-school children[9]. In school-aged children, periodic physical activity increases physical health and attention and improves behaviour, attitudes and educational achievement[10], and mental function in adolescents[11]. Physical activity is important for optimal bone and muscle development[9,11]; activity sufficient to improve aerobic fitness improves cardiometabolic profiles[9,12,13].

Assessment of physical activity in health surveys is undertaken mostly to monitor adherence to recommendations or identify population subgroups to target with interventions. However, in dietary surveys, physical activity data are usually collected to enable energy

Abbreviations: DLW, doubly labelled water; EE, energy expenditure; HSE, Health Survey for England; MET, metabolic equivalent; MVPA, moderate or vigorous physical activity; NDNS, National Diet and Nutrition Survey; PAEE, physical activity energy expenditure.

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expenditure (EE) to be estimated, not monitor physical activity levels *per se*.

Accurate assessment of physical activity is difficult, particularly in children, because frequency, duration and intensity each need to be assessed for a potentially large range of activities. These may be structured exercise or sports; informal activity within daily life, such as active travel (walking or cycling); leisure; occupational activity (e.g. newspaper delivery); and informal play, which accounts for most physical activity in pre-school children and a substantial but diminishing proportion in older children. Additionally, physical activity may be regular or may vary considerably from week to week, including the weather, seasonal sports and whether school term or holiday.

Participant (and parental) burden is an important constraint on measuring physical activity, as dietary surveys generally require considerable effort by participants, which can cause issues both for research ethics and of depressed response rates. Some measures that are feasible in a laboratory-based study involving small numbers of children, such as indirect calorimetry, are impractical in larger population surveys. Direct observation of participants by trained researchers is intrusive and labour intensive (so expensive and unrealistic) but also inaccurate, although it can provide context.

Physical activity can be assessed in two main ways: by self-report (or parental proxy reports for children aged <10 years) or objectively through using equipment that measures movement and/or physiological responses to physical exertion. The advantages and problems of the many subjective and objective methods of assessing physical activity for surveillance and epidemiological purposes have been reviewed comprehensively[14]. Earlier reviews considered assessment of physical activity in children[15] and in pre-school children[16]. The present paper is aimed at people commissioning or conducting dietary surveys in children (defined broadly to indicate non-adults) who are not experts in measuring physical activity. It summarises issues that may occur, and provides some examples from the authors' experience from the Health Survey for England (HSE)[17,18] and the UK National Diet and Nutrition Survey (NDNS)[19] of unexpected practical issues that can arise, and how these may be overcome.

Subjective assessment of physical activity

Self-report recall questionnaires

Questionnaires, asking about past activity over a predefined time frame, may be self-completed or administered by an interviewer. Children younger than 10 years do not have the capacity to report their activities accurately[20]. Parental proxy answers may be no better at accurate reporting: they cannot report school-based activity, and informal play is particularly difficult to assess. In 2006, we undertook a desk-based review of all physical activity questionnaires used in diet and nutrition studies. We concluded that physical activity in children under 11 years could not be measured in sufficient detail by the use of questionnaires to estimate EE. A 2010 review found that no questionnaires for children were both reliable and valid, with worse results in younger children than adolescents[21].

Short questionnaires often enquire about the frequency and average duration of categories of activity (usually light, moderate and vigorous) over a pre-specified time frame, giving examples of typical activities within each group, based on the metabolic equivalent (MET; 1 MET=the rate of energy expenditure while sitting quietly) intensity coding scheme developed by Ainsworth and colleagues[22]. Despite the advantage of less respondent burden, they provide insufficient detail to estimate EE. Detailed questionnaires ask which activities the survey participant have done in a given time frame, and for 'each activity' asks about the frequency and average duration, and questions to ascertain the intensity. For example, whether the activity makes the respondent breathless, hot or sweaty (or not) would categorise cycling as vigorous or moderate, respectively[22].

Questionnaires are relatively quick, inexpensive, and easy to administer but have many important limitations[23]. A major problem is recall bias. Questionnaires asking about habitual activity[24] risks responses reporting 'most active weeks' instead of 'usual' activity or activity in the specified time period, most commonly for children the previous 7 d[18]. Shorter time periods give greater recall accuracy but determine irregular activities less accurately. In some individuals, light activity can be an important component of physical activity energy expenditure (PAEE)[25] but light activity is extremely difficult to define and capture using self-report or proxy methods. In children, physical activity is sporadic in nature, being characterised by short bursts: during informal play up to 96 % of activity may occur in bouts <10 s[24]. Social desirability bias may play a part among adolescents[26].

Physical activity of children aged 2–15 years was first assessed in the HSE in 1997 (by parental proxy interview for children aged 2–11 years and self-report for those aged 13–15 years). Differing instruments were used subsequently; a new questionnaire was developed *de novo* for HSE 2008[18]. For the 2012 HSE, additional questions were added, to assess adherence to national recommendations for muscle strengthening exercises as well as sufficient weekly duration moderate or vigorous physical activity (MVPA)[27]. In older children, self-report questionnaires overestimated activity levels compared with accelerometry[18]; in younger children, parental proxy questionnaires substantially underestimated MVPA (Fig. 1)[18].

For the rolling programme UK NDNS, a new questionnaire for teenagers was developed to attempt to estimate PAEE accurately at the individual level, by including detailed questions on all forms of activity. It performed well at the population level in categorising participants into activity levels but was not accurate at an individual level when compared with doubly labelled water (DLW; an objective measure of EE used in dietary surveys)[19].

For questionnaires there is a trade-off between completeness of the information collected, balancing how

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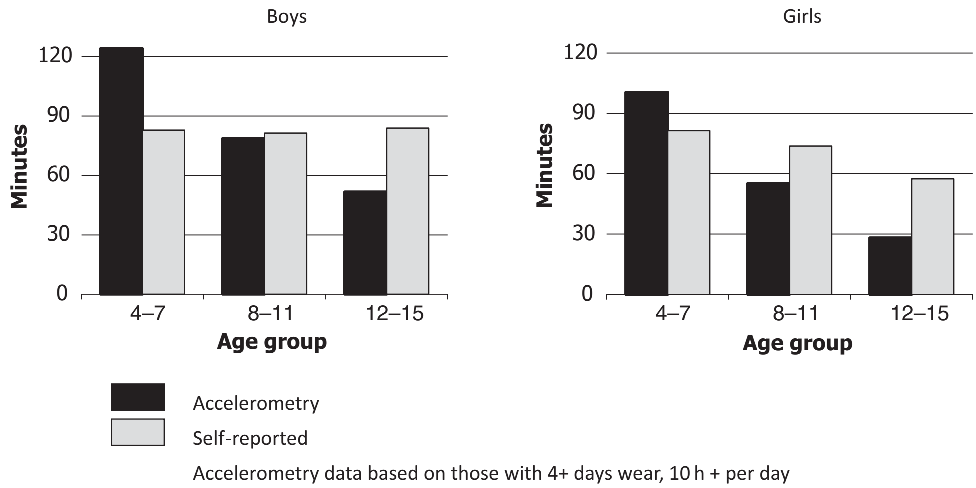

Fig. 1. Comparison of accelerometry data with reported average daily moderate or vigorous physical activity time in children.
Source: Reanalysis from Health Survey for England 2008[18].

comprehensive the questionnaire is with participant burden and the risks of missing data items and/or lack of co-operation on further stages of the dietary survey. In practice, questionnaires have been the most frequently used method for recording physical activity, although there is a trend towards moving to more objective methods for children in population surveys[15,16].

Assessing energy expenditure from physical activity questionnaires

Population-level assessment of EE may be required to compare changes over time with changes in energy intake and obesity prevalence, or to compare population subgroups. Accurate assessment of individuals' EE is generally used in dietary surveys for comparison with recorded intake, to assess the accuracy of reported diet. Where EE assessment is not sufficiently accurate, underreporting can be assessed by grouping participants into EE categories for comparison of reported intake.

Questionnaires that cover all physical activity domains contribute significantly to EE and in sufficient detail to record frequency, duration and intensity of activity, are very long but fail to provide accurate EE measures at the individual level because such precise recording of activity intensity and duration across all levels of intensity is not feasible. EE assessment using questionnaires is still a common technique to assess free living EE, although seldom valid due to inadequate coverage of all activity domains and inaccurate assignment of MET values (EE) to reported activities, particularly in children. In NDNS, the population means derived from the questionnaire and from the DLW data were close but participants could not be assigned into meaningful EE categories because of the large variance in the results[28].

Validation may be hampered by use of different time periods[29]. If the DLW collection period does not overlap fully with the other measurements (other physical activity data, dietary intake), results will contain additional noise among those participants whose activity pattern is unstable with considerable between-day or between-week variation[19,30].

Activity diary or log

Use-of-time tools have moderate validity and reliability for assessing young people's physical activity and EE[31]. An activity log requires the individual, parent or other responsible adult to record at regular time intervals what activity or activities have been undertaken in that time period. As with questionnaires, young children cannot do this and parents are often not present. Despite the theoretical advantage of better completion, as minimal recall is required, there is a trade-off concerning the time interval selected: the shorter the duration, the more accurately physical activity can be recorded but more frequent recordings add considerably to participant burden and therefore reduce completeness and/or accuracy[24].

A diary requires the participant to record specific groups of activities. However, diaries usually collect information on MVPA only as a proxy for EE, which is not ideal as light intensity activities, such as standing and non-brisk walking, may contribute substantially to overall PAEE. Activity diaries, used in the first UK NDNS of children[32], give valid data in adolescents for estimating physical activity category and total EE, assessed by DLW measurement[33] but add to the participant burden. Electronic diaries have been validated against accelerometry in children[34] but are relatively costly and are not commonly used in dietary surveys in children.

Objective measures of physical activity

The gold-standard for measuring EE in dietary surveys is through the use of DLW[35]. Survey participants are asked to drink a measured dose of water labelled with

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two, non-radioactive (stable), naturally occurring isotopes, ^{2}H and ^{18}O, which are assayed in urine in one pre-dose sample and one sample daily for ten consecutive days. Although the most accurate method in regular use, inaccuracies in EE can occur through incomplete consumption of the dose or inaccurate recording of the urine samples, or occasionally poor laboratory techniques. The method is safe but ensuring the entire dose is consumed and collecting the urine samples is difficult in the youngest children.

Monitoring physical activity can be undertaken by recording movement and/or physiological changes[36]. Such devices avoid problems of recall of frequency and duration and subjective assessment of the intensity. However, they are not infallible and have both theoretical and practical difficulties in use. Similarly to DLW, there is no contextual information about what the individual was doing at the time, unless a diary or log is also kept, but this adds to the respondent burden, reducing response or compliance rates, and adds subjective errors to the objective measure. In dietary surveys, the context is generally not crucial, provided the total volume of physical activity is monitored reasonably accurately. Another important issue pertinent to dietary survey methods is the difficulty translating measured activity into EE.

Pedometers

Pedometers measure steps taken. They can be a useful motivational tool to encourage activity[37,38]. Their main advantages are their low cost, compared with other devices, and the simplicity of the data produced: the number of steps taken. They are therefore useful for large population surveys[39], and were used in the Australian National Survey of Children's Diet and Nutrition[40]. However, they cannot capture other forms of activity, including cycling and swimming, nor increased EE from walking on an incline or carrying a load. They have been validated in children[41], including adolescents[42], but are not recommended for pre-school children[43].

Dietary surveys need research-grade pedometers that have adequate performance criteria[44]. They also need to be calibrated, although this is simple, as step size depends on age and speed[15]. While some authors have found pedometer data can estimate children's EE reasonably accurately[24,39], most recommend that the data be analysed only as the number of steps taken[45].

Accelerometers

Accelerometers, introduced in the early 1980s[46], have been used to assess physical activity and to validate self-reported physical activity. They provide objective, standardised data without recall bias and other subjectivity problems but participants' co-operation is required to wear the monitor during waking hours[47] and, if required, to record activities when not worn.

Accelerometers can measure directly the frequency, duration and intensity of most aspects of physical activity. The greater precision of the objective data yields equivalent statistical power with lower sample sizes. Accelerometer counts increase almost proportionally with ambulatory speed[46], so are excellent for recording time being inactive and time spent on dynamic activity such as walking or running up to a certain speed. However, they are less good at recording static activity, often important for overall EE estimation. Non-wear time can also be an important issue. In relation to estimating EE, the main issue is that the equations for conversion from accelerometers to EE perform poorly in non-controlled free-living situations[24].

Accelerometers can measure movement in one, two or three dimensions (uni-, bi- or tri-axial measurements). Uni-axial accelerometers produce data that are the simplest to interpret but are limited by the lack of detection of movement in other directions; for example, rowing and cycling are poorly detected. Uni-axial monitors may also not detect inclines; walking more slowly up a 5 % hill may use more energy than walking faster on the level. No devices detect load-carrying, also underestimating EE while carrying a heavy school bag, for example. Most accelerometers are not water-proof, and must therefore be removed for swimming. Some ethics committees may also impose restrictions, e.g. to instruct participants to remove the device when participating in contact sports, including martial arts.

After the accelerometers have been worn, the devices need to be returned or collected, so that data can be downloaded from the devices and processed. Data processing of accelerometer data includes differentiating between periods of non-wear and low counts indicating inactivity (sedentary behaviour); decisions about minimum wear time for inclusion in analysis (minimum number of hours worn per day ('sufficient wear') and minimum number of days of sufficient wear)[47]; which thresholds to use to categorise activity as sedentary, light, moderate or vigorous[22]; and which equations to use to estimate MET or EE, if that is intended. Data processing has become much more sophisticated over time. For example, probability modelling is replacing a dichotomous decision of whether or not a device was deemed to be worn at any particular moment, and therefore whether that reading should be included.

Accelerometry has been used for population surveillance. The US National Health and Nutrition Examination Survey was the first general population study to use accelerometry in children and adults in a population-wide survey, in 2003/04[48]. They used accelerometers with over 1000 participants, aged 6 years and over, demonstrating the feasibility of objective measurement in large population studies. The first surveys to issue accelerometers 'in the field' occurred in England[18,19,28,47,48]. Both the HSE and NDNS used the Actigraph model GT1M, a lightweight, digital, accelerometer, smaller than a matchbox. Movements outside normal human motion are filtered out electronically[49]. The filtered acceleration signal is digitised and summed over a specified time interval to produce a number of 'counts' for that time period, which is stored and the summing restarts. We used a 1 min period, to maximise data storage, but shorter periods give more detailed assessment of short bursts of activity, characteristic of children. In the NDNS, a subsample of children provided DLW estimates over 10 d, concurrent with accelerometer wear[28].

The choice of Actigraph was based on cost, ease of use and compliance, reliability, adequacy for physical activity assessment[50,51], and a wide comparison base. Participants in the HSE and NDNS were asked to wear the accelerometer on their waist, positioned above the right hip, during waking hours for seven consecutive days.

Practicalities of using accelerometers. Accelerometers need to be charged and initialised (to enable fresh data collection) before being given to participants. Initially, this was done centrally by the operations department then sent to interviewers to issue to eligible participants. The instruments were collected by the survey nurse or interviewer at the next planned visit, or an additional visit, or could be posted back using a pre-paid addressed envelope. On receipt by the operations centre, the instrument was logged against the participant identification, the data downloaded, and the device recharged and reinitialised prior to being sent back to the field staff for use with a new participant. However, where there is a subsequent delay before the accelerometers are reissued, it is better for the devices to be charged and initialised by the field staff, to minimise data loss from inadequate charge remaining during the data collection period.

Accelerometry compliance. In the NDNS Comparison Study, of the sixty-four children aged 4–15 years who agreed to participate in the accelerometry sub-study, 95 % wore the accelerometer for ≥500 min daily for at least 4 d. Variations in the time spent wearing an Actigraph by age were not significant[28].

Participants (or their parents) were asked to keep a log of when they put on and removed a device, what they were doing while it was not worn (e.g. if removed because of swimming or contact sports, thus not measuring significant activity), or when they undertook activity not recorded by the device (e.g. rowing or cycling if using a uni-axial accelerometer). Inclusion of log book information required lengthy and often manual processing and affected EE estimation very little. Larger population studies using accelerometers do not ask participants to complete a log, because of the additional errors added by inaccurate record keeping by participants and the need of researchers to make assumption to use those data[18]. The log was therefore dropped from the NDNS in later years.

Assessing energy expenditure from accelerometry data. EE estimates based on assessment of physical activity differ considerably depending on which equations are used to convert physical activity to EE. There are additional inaccuracies from estimating the individual's BMR[52]: as with all models, this approximation fits population-level data while being inaccurate for individuals, particularly those with extremes of age, body mass or composition. Additional inaccuracies ensue when there is also measurement error in the assessment of physical activity; EE can be assessed more accurately using objective than self-reported physical activity measures.

There are a number of problems with using accelerometers to assess EE, particularly from free-living data. Calibration is usually performed by walking and running at different speeds on a treadmill. Age and leg length affect the relationship[53]. Simulation of 'daily activities' in the laboratory have produced very different equations for estimating EE[24] but about 90 % of the data collected lie outside the laboratory range used in deriving the conversion equations[24]; PAEE is zero for complete inactivity, so mathematical methods adjust the equations to ensure this[54]. Equations used most often for providing estimates of total EE (BMR+PAEE) for children are those by Trost *et al.*[55] and by Puyau *et al.*[56]

For NDNS, the Actigraph data resulted in a greater underestimate of EE than the questionnaire at the population level but with acceptable variance[28]. The Year 4 NDNS report presented counts per minute, to avoid additional errors from assumptions included in converting counts per minute to EE[19].

Heart rate monitors

Heart rate monitors are usually worn on a strap around the chest. Measuring changes in heart rate can be a better assessment of physical activity in relation to cardiovascular impact but is not responsive to low-intensity activity and cannot distinguish between different causes of raised heart rates (activity, pain and other emotional stimuli). This is the main issue in free-living studies, where measurement 'noise' is more of a problem for heart rate than for motion sensors[57]. There are also problems of latency, with the heart rate change lagging behind changes in activity, and heart rate elevation persisting after cessation of activity, particularly in less fit individuals. This may conceal intermittent activity, particularly in children.

Combined heart rate and activity monitors

Monitors that detect both movement and heart rate provide more accurate assessment of energy use[58]. Accelerometry provides accurate data for sedentary and light activity, where heart rate monitors contribute less. Monitoring the heart rate allows the intensity of the activity to be captured more accurately. Such devices can also distinguish well between non-wear and sedentary behaviour, and can help describe the intensity and duration of activity more accurately, although requiring analysis of more complex data. They may provide more accurate assessment of EE[24], including in children[39,59]. However, calibration is required for each individual to optimise data interpretation[60]. Current combined sensor technology can be relatively burdensome for the participant (e.g. certain devices require removal of hair from men's chest) and there is a risk that gains in accuracy may be offset by losses in participant adherence. Furthermore, at the time of preparing this report, combined sensors are still very expensive and beyond the reach of most dietary surveys.

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Discussion

Expected lack of correlation between questionnaire data and objective measures

One criticism levelled at questionnaire data is the low correlation found with objective measures and, in particular, the much lower activity levels recorded by accelerometers than from questionnaire responses (except in young children where the opposite is found, Fig. 1). However, they measure different things. For example, while individuals report the amount of time spent in a session called 'playing football', including time spent organising the game, or moving little while play is elsewhere on the pitch, an accelerometer measures the amount of time during that session that the individual is moderately or vigorously active. For assessment of physical activity against recommendations, questionnaires are valid, given that the heath outcome-based guidance is currently based solely on self-reported activity.

However, for assessing EE, accelerometry is potentially much more accurate, as it can provide information on the amount of time spent in light activity, which contributes substantially to EE because of the much longer accumulated duration in most individuals, and in particular, the great difficulty in recording 'active play' and other informal activities among younger children. This greater accuracy needs to be weighed against the greater capital and running costs of the survey, the adherence to wearing the device required of participants and the more complex data processing.

Recent advances and future prospects

Accelerometers have changed substantially over the past few years. In addition to development of tri-axial monitors, newer devices have been validated for wear on the wrist[61], improving acceptability. Cut-points have been validated for MVPA for children[62] but data from hip-worn accelerometers should not be compared with wrist-worn accelerometers[63], with discrimination between activity intensities better when worn on the hip rather than on the wrist[64]. Newer devices can output raw acceleration signals, offering promise for the future not only for quantification of physical activity but also pattern recognition.

Waterproof devices are now being marketed, so activity while swimming could also be recorded. However, early experience in a survey in Hawaii showed high failure rates: to enable data downloads, the devices cannot be fully sealed and are thus not fully waterproof (C Boushey, personal communication). Devices are being developed that combine motion sensors with other physiological measurements, such as pulse or blood pressure, to increase assessment accuracy for activity and EE.

Computational developments now permit more complex assessment of movement from accelerometry and similar devices. These include non-linear modelling techniques controlled by the investigator, and non-integrated acceleration signals to create an artificial neural network to replace the more limited information from uni-axial accelerometry. A commercially available monitor uses five accelerometers attached to the skin at five locations, with a hip pack[65]. A further development is high-frequency movement sampling, which can differentiate activities not currently distinguishable by accelerometers in general use.

Conclusions

Questionnaires, although inexpensive and practical, are limited in providing reasonably accurate assessments of PAEE. Objective methods, despite their limitations and cost, offer more promise than subjective methods. Where the aim is to categorise participants into activity groups, questionnaires can be cheaper options for teenagers; however, questionnaires cannot be used for pre-school children and are not recommended for primary school children. Despite the expense combined accelerometry and heart rate data appears the most promising method to estimate PAEE in dietary surveys. As technology progresses fast and costs are continually decreasing, we envisage that such methods will be within the reach of dietary studies in the near future.

The MRC Dietary and Physical Activity Assessment toolkit[66] provides further information about these various approaches, including a matrix to aid selection of the appropriate tool(s) given the question(s) to be answered, the sample size, participants' age group and other theoretical and practical aspects.

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Conflicts of interest

None.

Authorship

J. M. drafted the initial version and conducted most of the literature review; E. S. provided advice and reviewed three drafts of the manuscript; N. C. revised manuscript drafts and helped with reference searches; all authors contributed to the final text.

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