Methodological considerations in large scale accelerometer-based studies of childhood physical activity

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Declaration

I, Carly Rich, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

Abstract

Accelerometers are widely used to measure children's physical activity (PA) in large scale studies. However, the analysis of data from such studies is challenging and several methodological uncertainties remain regarding collection and processing protocols. The aim of this thesis was to investigate some of these issues in relation to a range of child and parental factors using data collected as part of the Millennium Cohort Study (MCS).

The MCS is a UK-wide prospective study of the social, economic and health-related circumstances of children. Accelerometer-determined measurement of activity was introduced into the study when the children were aged seven years. Accelerometers were distributed and returned using a novel postal methodology. Reliable accelerometer data was obtained from 7,105 children. Analyses were conducted to determine: (i) data processing thresholds; (ii) predictors of consent, accelerometer return, and data acquisition, and; (iii) factors associated with intra-individual variation of PA and sedentary behavior (SB) across the four seasons.

Analyses revealed that: (i) using a proposed minimum threshold of 11,715 counts/minute will enable researchers to identify extreme high count values in the ActiGraph GT1M, and using data from children with ≥ two days lasting ≥ six hours/day will provide reliable estimates of children's habitual PA; (ii) a range of factors are associated with non-response, and; (iii) a single-measurement period may not adequately measure children's activity due to substantial intra-individual variation in PA and SB across the seasons. Some children are also less stable in their activity and may therefore be more amenable to change. Interventions aimed at reducing SB and/or increasing PA may be particularly helpful for these groups of children.

These findings highlight the importance of quality control procedures in accelerometer data collection and processing. This thesis addresses methodological issues in large scale accelerometer-based studies of childhood activity and presents important results in this area.

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Thank you to Jane Ahn, Florence Kinnafick and Richard Pulsford for their hard work and support in the data collection phase and to Marco Geraci and Francesco Sera for their invaluable statistical advice. The co-operation of the participating families is also gratefully acknowledged.

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List of abbreviations

ANOVA	Analysis of variance
ALSPAC	Avon Longitudinal Study for Parents and Children
BMI	Body mass index
CHASE	Child Heart and Health Study
CI	Confidence interval
CLS	Centre for Longitudinal Studies
cm	Centimetres
cpm	Counts per minute
EE	Energy expenditure
EHCV	Extreme high count values
EYHS	European Youth Heart Study
g	Grams
G	Gravitational constant
GPS	Global positioning system
HR	Heart rate
ICC	Intraclass correlation coefficient
ICH	UCL Institute of Child Health
IQR	Interquartile range
kcal	Kilocalorie
kg	Kilogram
LPA	Light physical activity
LRT	Likelihood ratio test
MCS	Millennium Cohort Study
MET	Metabolic equivalents
ml	Millilitres
mm	Millimetres
MPA	Moderate physical activity
MVPA	Moderate and vigorous physical activity
n	Sample size
NHANES	National Health and Nutrition Examination Survey
$\mathbf{O_2}$	Oxygen

p	Probability
PA	Physical activity
PAQ	Physical activity questionnaire
r	Correlation coefficient
SB	Sedentary behaviour
SD	Standard deviation
SES	Socio-economic status
SPEEDY	Sport, physical activity and Eating Behaviour: Environmental Determinants in Young People
TV	Television
UK	United Kingdom
USA	United States of America
VIF	Variance inflation factor
VPA	Vigorous physical activity
vs.	Versus
z-score	Standard deviation from the mean

1 Chapter 1: Purpose and structure of thesis

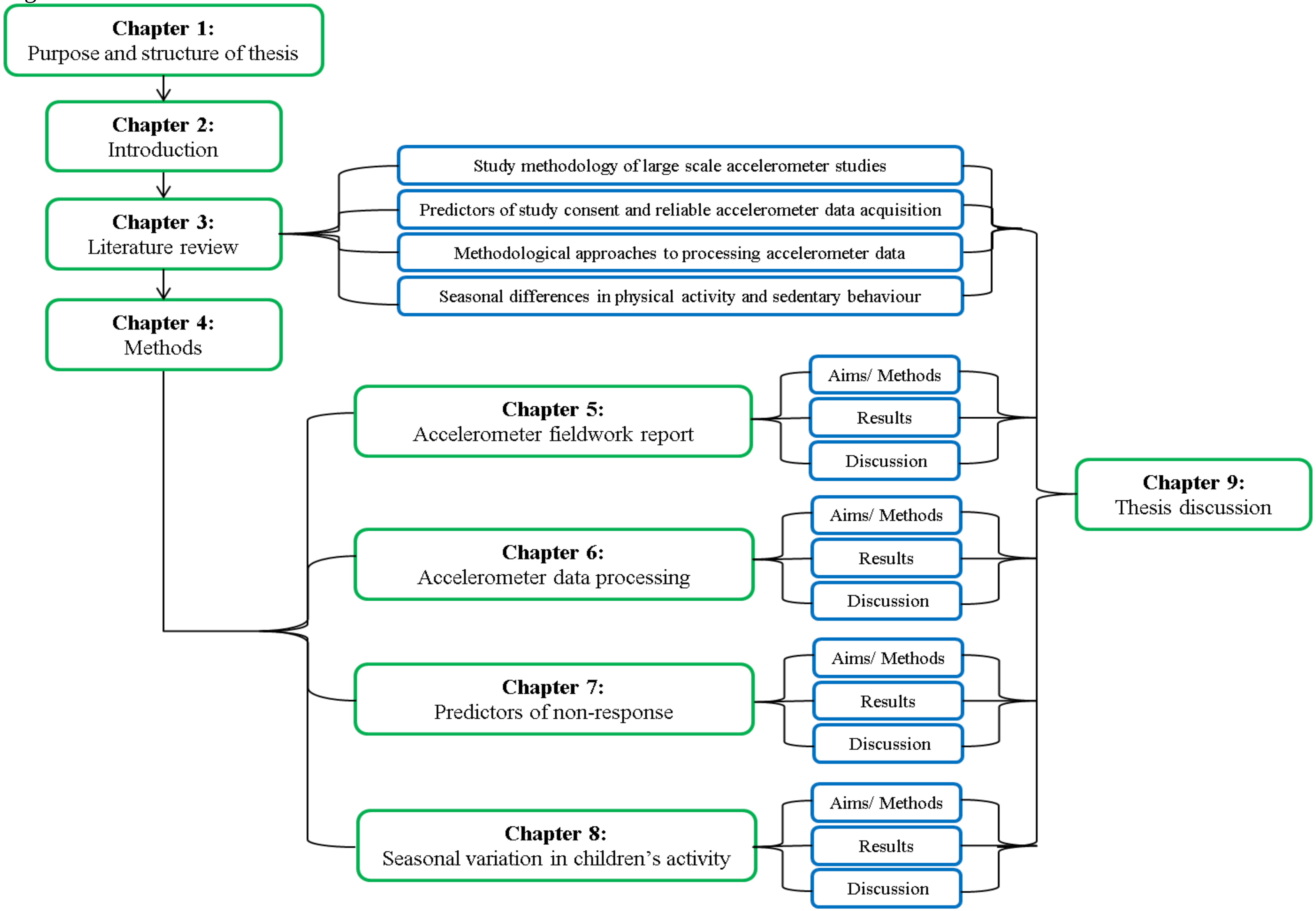
1.1 Purpose of research

The overall purpose of this research was to address some of the major methodological uncertainties in using accelerometers to measure physical activity (PA) and sedentary behaviour (SB) in large scale studies in children. SB in this thesis refers to objectively measured sedentary time. This was achieved by identifying gaps in the research base, providing evidence to address some of these gaps, and proposing the next steps in study practice and research to further reduce these uncertainties. A number of methodological issues were investigated in relation to a wide range of child and parental factors using data collected as part of the Millennium Cohort Study (MCS), a UK (United Kingdom) -wide prospective study of children. These issues included: (i) the use of accelerometer data processing thresholds; (ii) predictors of consent, accelerometer return, and reliable data acquisition, and; (iii) factors associated with intra-individual variation of PA and SB across the four seasons.

1.2 Structure of thesis

This thesis presents a systematic literature review, a detailed report of the MCS accelerometer fieldwork, three original research studies and an overall thesis discussion detailing suggestions for future study practice and additional research. The structure of the thesis is outlined in Figure 1.

Figure 1: Structure of thesis



Chapter 2 provides an introduction to the concepts of PA and SB, and sets the context for the work presented in this thesis. Chapter 3 presents the findings of a structured literature review and reports the study methodology of large scale accelerometer studies in children. This literature review also critically evaluates previous research investigating: 1) factors associated with study consent and/or reliable accelerometer data acquisition in children; 2) different methodological approaches to accelerometer data processing in children, and; 3) seasonal differences in the levels and patterns of children's PA and SB. Consent refers to the provision of approval to participate in the study, and the acquisition of reliable accelerometer data refers to the acquirement of reliable accelerometer data according to the study wear time threshold (the minimum amount of time that the child needed to wear their accelerometer to be included in analyses).

Chapter 4 introduces the MCS, gives a detailed account of the accelerometer protocol used in the MCS, and defines the MCS interview variables used in Chapters 6, 7, and 8. Chapter 5 provides a comprehensive report of the MCS main stage accelerometer fieldwork.

Chapters 6, 7, and 8 are original research studies undertaken by the author. Specific methods, statistical analyses, results and discussions relevant to the specific aims of the study are presented in each chapter. Two quality control procedures that researchers need to consider when processing accelerometer data are explored in Chapter 6. Chapter 7 investigates the child and parental factors associated with study consent, accelerometer return, and reliable data acquisition. Intra-individual variation in children's PA and SB is investigated in relation to a range of child and parental factors in Chapter 8. Finally, Chapter 9 concludes with a summary of the research presented in this thesis, reflects on their limitations and implications, gives advice based on this research for future study practice and interventions, discusses the strengths and limitations of the MCS data and accelerometer fieldwork, and provides general conclusions and reflections on this thesis.

1.3 Role of the researcher

The research presented in this thesis was conducted in collaboration with my supervisors and colleagues; therefore, my role in the research is clarified here.

I contributed towards the Wellcome Trust grant application and design of this large scale accelerometer study and, as part of this, I made a large contribution towards the development of a pilot study and dress rehearsal, of which I was responsible for conducting the fieldwork. The MCS interview data at all sweeps were collected by trained interviewers at the NatCen (MCS4) and managed by the Centre for Longitudinal Studies (CLS). I helped to supervise, and was part of, a team of trained research staff at the ICH (Jane Ahn, Florence Kinnafick and Richard Pulsford) that conducted the MCS main stage and seasonal accelerometer fieldwork, which involved liaison with the survey managers at the CLS and the fieldwork agencies.

The MCS4 accelerometer fieldwork data were cleaned by Jane Ahn (ICH) and myself. The accelerometer data were cleaned and processed using an R package developed by Dr Marco Geraci (ICH)[220]; I played a large part in the design and testing of this software, and helped define the data processing standard operating procedure (Section 4.3.4.3). Francesco Sera and Dr Mario Cortina-Borja (ICH) developed the R functions to detect the observational period for each accelerometer file; I helped design these functions and completed the gold standard experiment to test the software.

The MCS interview variables were cleaned and constructed by either myself, other members of the MCS Child Health Group at the ICH, or the CLS. I was responsible for linking the accelerometer fieldwork data and derived activity variables with the MCS interview data.

Analyses for the data processing chapter (chapter 6) were conducted using functions developed in the R software environment by Dr Mario Cortina-Borja in consultation with myself. I independently conducted all other analyses in this thesis and was also responsible for the generation of the thesis objectives and analysis strategies, which were agreed in consultation with my supervisors (Dr Lucy Griffiths, Dr Mario Cortina-Borja and Professor Carol Dezateux). In addition, I independently conducted all stages of the detailed literature review, and was entirely responsible for writing this thesis.

As well as preparation of reports to the MCS survey team (Appendix A and Appendix B) and manuscripts for publication, I have also presented my work at national and international conferences. I am the first named author on two publications[221 224] that have resulted directly from this thesis (Appendix C and Appendix D), one further manuscript[222] that has been accepted for publication and another that is currently being reviewed by a journal[223]. I was responsible for the conception, analysis, interpretation, and writing of these papers, in collaboration with my co-authors. I was also involved in the conception and study design, and was part of the data collection team for the MCS accelerometer calibration study, and was co-author on the peer-reviewed publication of this study (Appendix E) [213].

2 Chapter 2: Introduction

2.1 Chapter overview

This chapter defines the concepts of PA and SB, describes the methods used to measure these variables in large scale studies, and reports the levels of children's PA and SB in the UK.

2.2 Physical activity

2.2.1 Physical activity definition

The epidemiological study of any concept or event requires the variable under investigation to be defined and measured[1]. "PA", "exercise", and "sport" are terms that are often used interchangeably but all describe different concepts. This thesis focuses on the concept of PA – a complex and multi-dimensional behaviour that is defined as 'any bodily movement produced by skeletal muscles that result in energy expenditure (EE)'[1]. EE is the exchange of energy required to perform biological work[2]. There are three main components of total EE in humans: the basal metabolic rate (approximately 50 to 70% of total energy); the thermic effect of food; and, the EE of PA (activity thermogenesis)[2]. PA is the most variable component of total EE and includes the full range of human movement from structured (e.g. sports, exercise, and transportation) to unstructured activities (e.g. hobbies and play).

Although similar to PA, exercise is defined as 'a subcategory of PA that is planned, structured, and repetitive and has a purpose of improving or maintaining one or more components of physical fitness'[1]. Sport is another subcategory of PA that involves structured activity, an element of competition, and has a framework of institutional organisation[3]. It is evident from these widely accepted definitions that PA is a broad concept that includes both exercise and sport, whilst exercise and sport are more specific terms, i.e. not all PA is accounted for by sport and exercise.

PA is often quantified according to four different dimensions: frequency, duration, intensity, and mode of activity performed. Frequency relates to how often the activity occurs over a specified time period (e.g. five times a week). Duration refers to the amount of time sustained in one bout of activity (e.g. 60 minutes per session). Intensity of PA refers to the level of effort required to perform the activity, and is typically measured in terms of metabolic equivalents (MET). A MET value is defined as the ratio of the working metabolic rate to the resting metabolic rate[4]. The standard adult definition of one MET is equal to a maximum oxygen uptake value of approximately 3.5ml O_2/kg/minute or 1.0kcal/kg/hour. This definition is inappropriate for children as maximum oxygen uptake can decline from 18 years[5]. As a result, Schofield generated child-specific equations that account for gender, age, height, and weight[5]. PA levels are often expressed as the time spent each day in predetermined intensity levels. There are three widely accepted intensity levels: light PA (LPA), moderate PA (MPA), and vigorous PA (VPA). METs can be used to describe the EE of activities at these intensities (Table 1). UK government guidelines recommend that children engage in moderate and VPA (MVPA) for at least 60 minutes and up to several hours every day[60]. The mode of activity refers to the type of PA performed (e.g. running, swimming or gymnastics).

Table 1: Metabolic equivalent definitions and example activities for different intensity levels

Activity intensity	**MET definition[4]**	**Physical activity examples**	**Effect on the body system[6]**
Light	1.1 – 2.9 METs	Self-care, slow walking and playing an instrument	Minimal increase in normal breathing rate
Moderate	3.0 – 5.9 METs	Brisk walking, bike riding and playground activities	Child will feel warm and slightly out of breath, but they should still be able to carry on a conversation
Vigorous	6.0 – 8.9 METs	Running and other sports including swimming or football	Child will feel out of breath and sweaty, making it more difficult to carry on a conversation

2.2.2 Physical activity and health

Health has been defined by the World Health Organisation (1946) as 'a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity'[7]. Regular PA in children is associated with improved health[8], including a decreased risk of developing type 2 diabetes[9] and improvements in cardiovascular risk factors[10], skeletal health[11], and psychological well-being[12 13].

A large scale study investigating the PA levels of children living in the USA (United States of America) with type 1 and type 2 diabetes found that between 17.7% and 35.4% of the study population did not meet the current national PA guidelines[14]. This is particularly important because PA plays a vital role in the management of diabetes, by improving acute and chronic glucose control, and by reducing the risk of cardio metabolic complications[14]. Current guidelines from the National Institute for Health and Clinical Excellence suggest that daily PA is important for the management of type 2 diabetes in paediatric populations[15].

Ekelund *et al*[16] found an association between the clustering of risk factors for cardiovascular disease (waist circumference, insulin, triglycerides, systolic and diastolic blood pressure) and PA independent of adiposity in 1,709 children participating in the European Youth Heart study (EYHS). Andersen *et al*[10] also investigated the association between single and clustered risk factors for cardiovascular disease with PA in children participating in the EYHS. The authors found a clear graded relationship between PA and risk factors for cardiovascular disease: the highest quintile for PA displayed the lowest accumulation of risk factors and there was a steady increase in risk factors with decreasing PA quintiles.

Positive associations between accelerometer-determined PA and lumbar and hip bone mass were found by Janz *et al*[17] in 368 preschool children. Tobias *et al*[11] also found that accelerometer-determined PA was associated with bone health: a dose-response relationship between PA and bone mineral density was observed in 4,457 eleven year old children participating in the Avon Longitudinal Study for Parents and Children (ALSPAC). When analyses were adjusted for height and lean mass, PA was inversely related to bone size, however, when adjusting for fat, lean mass and height, PA was positively related to bone size. As a result, the positive influence of PA on bone size seems to be opposed by the tendency of PA to reduce fat mass, although further research is required to confirm these findings. The positive associations between psychological well-being and PA has been well documented, and a review by Van Der Horst *et al*[13] evaluating 60 published articles found strong evidence for a positive association between self-efficacy and PA in children, and moderate evidence for a positive association between attitude, self-efficacy, and goal orientation with PA in adolescents.

PA may also help to prevent one of today's major public health concerns – childhood obesity[18 19]. Jiménez- Pavón *et al's*[20] review evaluating the associations between objectively measured PA and adiposity supports the hypothesis that higher levels of habitual PA are protective against childhood obesity, although further prospective longitudinal studies are warranted to provide evidence for a dose-response relationship. It has also been suggested that if an individual is physically active during childhood he or she is likely to remain physically active as an adult, and as a consequence, may be less likely to develop heart disease, cancer, stroke and diabetes in adulthood. Telama *et al's*[21] review evaluating tracking of PA from childhood to late adulthood found only a small number of studies that used objective tools to measure PA, but found that PA tracks reasonably well from childhood to young adulthood and beyond.

2.2.3 Measurement of physical activity in epidemiology

2.2.3.1 Introduction

An increased awareness of the importance of PA and SB, combined with technological advances in their measurement, has improved the ability to measure these variables in free living conditions. The ideal measurement tool would capture all dimensions of PA, however, no single method currently exists that measures the frequency, intensity, duration, and type of activity. The choice of method depends on the research question being addressed. The age of the study sample, and whether individual or population level estimates are necessary will also influence the measurement method. Other important considerations include the reliability, validity, and feasibility (e.g. study size and budget) of the measurement tool. For a measurement tool to be considered reliable its results must be replicable and stable under the different conditions in which it is likely to be used[22]. Validity is the extent to which a measurement tool assesses the true exposure of interest[23].

2.2.3.2 Subjective methods

Subjective methods are the cheapest and most convenient way to collect PA data from a large sample of people in a relatively short period of time, and they include self or interview administered questionnaires, activity diaries or logs, and self-report methods.

Questionnaires

PA questionnaires (PAQ) are the most widely used subjective tool to determine PA in children. They are easy to administer, acceptable to study participants, and are often the only feasible way to assess PA in large scale studies due to financial resources. They are also valuable for assessing aspects of PA not measured easily using objective methods, such as the type and location of PA. However, cognitive immaturity can make self-report of PA difficult in children, particularly as young children may lack the ability to think abstractly and perform detailed recall[24]. Self-report is further problematic in children as their activity pattern is more variable and intermittent than that of adults[25]. If parent-proxy reports are used further issues can occur because parents are not present during school time PA.

Numerous questionnaires for children have been developed which vary greatly in length, and the type of activities and recall periods used. Questionnaires developed for children include the following:

- PAQ for Older Children[26]
- Children's Leisure Activities Study Survey[27]
- Girls Health Enrichment Multisite Study Activity Questionnaire[28]
- Youth PAQ[29]
- Children's PAQ[29]
- Swedish Adolescent PAQ[30]

Chinapaw *et al*[31] evaluated previous research investigating the measurement properties (reliability, validity, and responsiveness) of self-report PAQ that are used in children. None of the included versions of PAQs (n=61) showed both acceptable reliability and validity. Reported validity varied with correlations ranging from very low to high (e.g. previous day PA recall r=0.77; p<0.05). Corder *et al*[29] investigated the validity and reliability of several PAQs used in children's studies, and found that they were unable to estimate accurately the time spent in MVPA and PA EE at an individual level.

Diaries/logs

Self-reported PA using a diary or log provides a detailed record of an individual's daily PA. Individuals typically use a PA diary to record individual bouts of PA as they occur during the day, and participants are most commonly asked to record their activity using a predefined coded list. An activity log usually gives examples of PA in specific intensities and require participants to record the time they spend being sedentary, or participating in LPA, MPA or VPA[32].

Diaries and logs provide detailed information on the activity intensity and patterns of PA throughout the day. In addition, they rely on the subject's recall ability less than questionnaires do, and are also relatively inexpensive methods for assessing bouts of PA. However, due to the high level of compliance required to complete PA diaries, this method is less feasible for younger children. Participants may also be inclined to increase their PA level as a result of completing the activity diary.

Few studies have successfully shown the validity of PA diaries or logs in children. Parent-proxy reports of PA diaries in young children have shown low to moderate reliabilities[33 34]. Wen *et al*[34] compared accelerometer-determined PA with parent-proxy report of PA using a seven day activity diary in 34 three to five year olds. The authors reported a moderate association (r=0.44; p<0.05) between the time spent in accelerometer-determined VPA and total PA assessed by the diary. However, accelerometer-determined activity counts, MPA, MVPA and SB were not significantly associated with total PA and SB recorded by the activity diary.

2.2.3.3 Objective methods

Objective methods such as pedometers and accelerometers are being increasingly used in large-scale studies to determine levels and patterns of children's PA and SB. The main advantages of objective measurement compared to subjective methods include the avoidance of bias, greater confidence in the amount of PA and SB measured, and improved ability to relate variation in PA and SB to health outcomes[35].

Pedometers

Pedometers are small, inexpensive, electronic motion sensors which are worn on a belt or waistband and respond to vertical accelerations of the hip during gait cycles[36]. Pedometers measure walking activity by measuring steps and/or distance. They are economically feasible to use in large scale studies in children and offer a cheaper alternative to accelerometers. However, pedometers are unable to measure specific types of activities including swimming, cycling, and upper body movements. They are also unable to determine the intensity, frequency, or duration of movement, and are less accurate at slow walking speeds[37] and very fast running speeds[38]. Furthermore, some pedometers are not able to store data internally for longer than 24 hours and require users to record their daily step readings, which may not be feasible in paediatric studies.

Several studies have investigated the validity of pedometers to measure PA in children. Eston *et al*[39] compared the Yamax Digiwalker (Figure 2) with oxygen consumption during unstructured play activities, and treadmill walking and running in eight to ten year old children. The authors reported good correlations (r=0.81; p<0.001) between step counts and oxygen uptake for all activities. Kilanowski *et al*[40] compared the Yamax Digiwalker with accelerometer- determined PA and directly observed PA in 12 year old children, and reported correlations of 0.99 and 0.96 respectively ($p<0.05$). Crouter *et al*[41] validated ten different pedometers and found that they were most accurate for assessing steps, less accurate for assessing distance, and even less accurate for assessing EE.

Figure 2: Yamax Digiwalker pedometer

Accelerometers

In recent years accelerometers have been regarded as the gold standard method to determine PA in childhood populations[42 43]. Accelerometers are instruments designed to measure time varying differences in acceleration (the rate of change in velocity with respect to time) of body mass. Accelerometers measure accelerations using piezoelectric or seismic sensors in one (longitudinal body axis, usually vertical), two (vertical and medio-lateral or vertical and anterior-posterior) or three (vertical, medio-lateral and anterior-posterior) directions[44]. When applied to PA measurement an accelerometer can assess the frequency, intensity, and duration of movement. There are a wide variety of accelerometers available that vary in cost and functionality, although the most commonly used is the ActiGraph (formerly MTI and CSA) accelerometer (Figure 3). Accelerometers have been validated extensively in children and have compared favourably against observational techniques[45], heart rate (HR) telemetry[46], indirect calorimetry[47], and EE measured by doubly labelled water[48].

Figure 3: ActiGraph GT1M accelerometer

Accelerometers collect and store data over time sampling intervals known as epochs. The epoch sampling period can range from raw data frequencies (e.g. 10 hertz) to several minutes. Modern accelerometers have excellent storage capacity and can capture data for extended time periods using very short sampling frequencies.

Unfortunately, single axis monitors cannot accurately measure all types of PA including upper body movement, cycling, walking on an incline, and carrying heavy loads. In addition, the majority of accelerometers are not waterproof (although the recently developed ActiGraph GT3X-plus model is water resistant up to one metre) and therefore cannot measure water-based activities such as swimming and diving. Furthermore, accelerometers are expensive compared to subjective methods, particularly as software, charging equipment, and maintenance costs also need to be considered.

The primary outcome measure of an accelerometer is body acceleration, expressed as a count value. A count is biologically meaningless, and varies across devices and even across models of the same device[49]. Count values are influenced by the amplitude and frequency of acceleration, and must be derived into biologically meaningful outcome variables such as the number of daily minutes spent in SB or in LPA, MPA, or VPA. Thresholds used to define activity intensities and SB are derived from studies that calibrate accelerometer counts with an objective gold standard measure of EE such as oxygen consumption over a range of exercise intensities. The thresholds used to define activity intensities in children's accelerometer studies vary greatly. ActiGraph accelerometer thresholds used to define SB in five to eight year old children range from at least 25 counts/15 seconds to greater than 397 counts/15 seconds, and definitions for MPVA range from at least 574 counts/15 seconds to greater than 890 counts/15 seconds[50]. Studies have found that the use of different activity intensity thresholds may result in biologically meaningful differences in MVPA[51].

Heart rate monitoring

HR monitoring is a relatively inexpensive, robust, and nonintrusive method to assess PA EE in children. A HR monitor is typically integrated into a chest strap which is connected wirelessly to a data logger hidden in a watch. Adhesive electrodes that can be attached to subjects have also been developed to measure HR. HR monitoring is an attractive approach to measuring PA because of the linear relationship between HR and EE during steady state exercise. The most commonly used method to measure EE using HR monitoring is the Flex HR, especially during LPA[52]. Although there is no consensus regarding the definition of Flex HR, it is normally determined by measuring HR during lying, sitting, standing, and LPA, and computing the mean of the highest resting value and lowest exercise value[53]. HR values that fall below the Flex HR are determined as resting EE, and individual calibration curves are used to predict EE for HR values above the Flex HR. The Flex HR method has been shown to be valid for estimating average daily EE at a group level but not at an individual level in children[54 55].

A major limitation of HR monitoring is that the relationship between HR and EE is uncertain below the Flex HR and, as a result, it does not provide an accurate estimate of PA at this intensity. In addition, other factors can influence HR including age, body size, proportion of muscle mass used, emotional stress, and cardio-respiratory fitness, particularly if below the Flex HR. In addition, HR varies greatly between individuals at specific intensity levels and therefore individual calibration of HR with EE is required. HR monitoring can also fail to measure the sporadic nature of children's PA due to the lag in HR response that occurs momentarily after changes in movement. Furthermore, HR monitoring may not be feasible in children because of the necessity for skin contact.

Combination sensors

The measurement of PA using one or more physiological sensors combined with movement sensors is a developing area of research. Combined devices such as combination HR and movement sensors, combination temperature and movement sensors, and multisensory devices utilise the unique advantages of each method, and reduce some of the disadvantages of each method used alone. Studies have demonstrated increased accuracy in measuring PA using combined HR monitoring and accelerometers rather than using these measures in isolation in preschool (although not for SB)[56] and young children[39 57 58]. The first commercially available combined sensor was the Actiheart (Figure 4), of which the intra- and inter- instrument reliability and validity of the combined HR and motion sensor has been reported[59]. However, combination methods are still relatively expensive to use in large scale studies and they may also cause problems with compliance in paediatric studies.

Figure 4: Actiheart combined heart rate and accelerometer sensor

2.2.4 Physical activity recommendations

A UK-wide consensus from the four nations' Chief Medical Officers on the amount and type of PA at each stage of the life course was launched in July 2011[60]. In light of growing epidemiological evidence, PA recommendations for children living in the UK were revised. It is now recommended that all children engage in MVPA for at least 60 minutes and up to several hours every day, and VPA should also be incorporated at least three days a week.

2.2.5 Physical activity levels in UK children

Relatively few large scale studies have collected accelerometer data in children living in the UK[61-64]. Adherence to guidelines range from 0.4%[61] to 81.5%[63], and boys are consistently more active than girls. Differences between studies are largely attributed to the use of different MVPA intensity thresholds, with these ranging from 2,000[63 64] to 3,600[61] counts per minute (cpm). For example, the ALSPAC reported that only 2.5% of 11 year old children (5% of boys and 0.4% of girls) from the South West of England met the national guidelines. These prevalence estimates contrast with adherence reported by the Sport, PA and Eating Behaviour: Environmental Determinants in Young People (SPEEDY) study who found that 69.1% of British children met the current PA recommendations[61]. The Child Heart and Health Study (CHASE) used the same threshold to define MVPA as that used by the SPEEDY study, and reported similar PA adherence in nine to ten year old children: 64% of children participating in the CHASE met the recommended government guidelines[64]. These estimates are similar to those reported by the Health Survey for England using self-reported PA: 70% of boys and 61% of girls (aged two to ten years) participating in the Health Survey for England met the recommended government PA guidelines[65].

2.3 Sedentary behaviour

2.3.1 Sedentary behaviour definition

SB has been defined as ‘a state in which bodily movement is minimal representing a state where EE approximates resting metabolic rate’[66]. SB is not simply the absence of PA but involves purposeful engagement in activities that involve minimal movement and low EE[67]. SB should be viewed as a separate construct from PA, and although this distinction gets overlooked being ‘insufficiently active’ is different from being sedentary[68]. Sedentary activities include screen-time [television (TV) viewing and computer use], motorised transport, sitting to read, talk, or complete homework, and listening to music. SB includes activities with an EE of 1.0 to 1.5 METs[4].

2.3.2 Sedentary behaviour and health risk

Research has found that SB is associated with an elevated metabolic risk profile in children, independent of PA[69 70]. Martínez-Gómez *et al*[71] also found that children’s TV viewing and screen time were associated with blood pressure independent of body composition. Several studies involving children have also shown that SB is negatively associated with body weight and obesity, although MVPA tends to contribute more significantly to obesity than SB[72 63]. Spinks *et al*[73] found that the odds of children being overweight were increased by 63% if they used electronic media for more than two hours per day. The associations between SB, obesity, and adverse metabolic profiles vary in magnitude, and may not always be independent of PA levels - further research is required to confirm these findings[72].

2.3.3 Measurement of sedentary behaviour in epidemiology

Measurement of SB should ideally capture the frequency, duration, and type of sedentary activity. The frequency and duration of SB can be captured using accelerometers. The benefits of using accelerometers to measure PA have previously been discussed and remain true for their use in measuring SB. However, accelerometers are unable to confirm the type and setting of SB and there is also no consensus on the most appropriate count threshold to define SB. As a result, self-report methods are often used to capture the type of SB, usually via questionnaires or diaries. There are four categories of SB that are typically measured in children[74]:

- Technological (screen time): TV viewing, computer use, small screen use
- Socialising: chat, phone, texts
- Motorised transport
- Homework or reading

There are a wide range of available questionnaires which typically ask subjects to report the frequency and duration of the time spent in different SB over a specific time frame[75]. Researchers have also used recall diaries, where children or parents report their child's behaviour at set time periods over several days. Some common subjective methods used to measure SB in children include:

- Self-Assessed PA Checklist[76]
- Previous Day PA Recall[77]
- Multimedia Activity Recall for Children and Adolescents[78]

- Adolescent Sedentary Activity Questionnaire[75]

The most common SB measured in children is TV viewing. Bryant *et al*[79] reviewed studies that have measured TV exposure in children, and found that relatively few of the measurement tools used had supportive evidence to show their validity or reliability. Direct observation is considered the gold standard method for measuring TV viewing but this is intrusive, burdensome for researchers, and has the possibility to influence behaviour.

2.3.4 Sedentary recommendations

A number of countries (Australia, Canada, USA, New Zealand, France, Denmark, and Finland) have national recommendations for the maximum amount of time children should spend sedentary each day and/or for the maximum amount of daily screen time[80]. For example, the USA government recommend that children should limit their total daily media time to two hours or less[81]. Canada recommend that inactive children should decrease the time they spend watching TV, playing computer games, and using the internet by at least 30 minutes less per day, and over several months, should decrease the time spent in these activities by at least 90 minutes per day[82].

Despite emerging evidence reporting the associations between SB and negative health consequences, the UK does not currently have a specific recommendation for the maximum amount of time children should spend sedentary each day. However, the Department of Health now recommended that children should minimize the amount of time they spend in extended periods being sedentary[60].

2.3.5 Levels of sedentary behaviour in UK children

Findings from large scale UK-based accelerometer studies report varied levels of SB among children. The CHASE study reported that nine to 11 year old children spend approximately 580 minutes in SB (defined as <100 cpm) per day[64]. The ALSPAC reported that children spend, on average, 430 minutes per day in SB (defined as <200 cpm) at 12 years, and even longer periods at older ages[38]. Using a similar definition of SB, the Health Survey for England collected accelerometer-determined measures of SB, and found that children spend about 420 to 460 minutes per day in SB[83].

Several large scale studies have assessed children's SB using self-report measurement tools[84-87]. The Project STIL collected information on SB patterns in 1,371 teenage children living in the UK using self-reported PA diaries for three weekdays and one weekend day. The study found that TV viewing during the week was not excessive: only 3.3% of girls[85] and 8.9% of boys[84] watched more than four hours of TV on weekdays, but this increased to 20.7% and 33.8% in girls and boys respectively at the weekend. Fairclough *et al*[87] used questionnaires to determine levels of SB in 6,337 nine to ten year olds: 36% and 53% of girls and boys respectively watched TV for more than an hour on weekdays, and 42% and 54% of girls and boys respectively watched TV for more than an hour on weekend days. They also reported that boys played computer games more often than girls[87].

2.4 Key points

- PA is a complex and multi-dimensional behaviour that is difficult to measure in children.
- In the UK, children are recommended to engage in MVPA for at least 60 minutes and up to several hours every day.

- The health benefits of regular PA are well established, however, evidence suggests that not all children are meeting the UK guidelines.
- The proportion of children meeting the current PA guidelines depends on the PA measurement tool and the methodological protocol employed.
- SB is a separate construct to PA and involves purposeful engagement in activities that involve minimal movement.
- Emerging evidence has shown the negative health consequences associated with SB, and as a result, the UK government now recommend that children should minimise the amount of time they spend sedentary.
- Accelerometers are considered the most appropriate tool to measure PA and SB in large scale studies in children, however, they have a number of limitations that require further developments.

3 Chapter 3: Literature Review

3.1 Chapter overview

This chapter presents the findings of a structured literature review. This literature review reports the study methodology of large scale accelerometer studies in children and also critically evaluates previous research investigating a number of methodological uncertainties in accelerometer data collection and processing. I independently conducted all parts of this literature review.

3.2 Introduction

The availability of accelerometer-based measures of PA suitable for large scale studies in children creates opportunities for further understanding of the levels of PA, and its determinants and their relation to health outcomes in children. Despite the increasing use of accelerometers for children's PA assessment uncertainties still remain regarding accelerometer protocols. Most published research has focused on the well documented inconsistencies in accelerometer measurement protocols, including accelerometer type[88-91], epoch choice[25 92-96], and accelerometer placement[97-100]; however, these issues do not occur in isolation. Additional considerations such as the willingness of participants to wear accelerometers, and the potential bias that could result from the loss of data from children not consenting to participate, or from consenting children not wearing their accelerometer as required needs to be explored.

Researchers also face a number of important data processing decisions, including defining the minimum wear time threshold, defining accelerometer non-wear time, and identifying extreme high count values (EHCV). The wear time threshold is typically used to determine which children are included in analyses, and is defined as the minimum number of hours per day and the minimum number of days of accelerometer data required per child to provide reliable estimates of children's activity. The identification of non-wear time is particularly problematic due to the difficulty in distinguishing between periods of inactivity and periods in which the accelerometer was not worn. As such, biologically implausible periods of continuous inactivity data need to be identified as non-wear time. This is typically determined by selecting a minimum length of time represented by continuous zero counts that surpass a length beyond which it is deemed unlikely that the accelerometer could have been worn. EHCV may have occurred because of accelerometer malfunction or the participant interfering with the instrument. These count values need to be identified and removed prior to data analysis. Data processing decisions therefore have the ability to influence PA and SB outcome variables. If researchers use the same accelerometer data processing decisions more reliable comparisons could be made between studies.

The influence of accelerometer data collection timing and frequency, particularly the season of data collection also need to be understood fully. Temperature, precipitation levels, and day length vary across seasons in temperate climatic regions of the world, and have the potential to influence levels of PA and SB. The ability to identify specific seasons that are characterised by low PA levels and/or high periods of SB is important for the design of future public health interventions aimed at promoting PA, reducing SB, and reducing seasonal fluctuations in these behaviours. An increasing number of studies[61 64 101-115] have investigated the influence of season on PA in children and it is vital to get a detailed overview of the current research available. Assessment of the existing research on these issues is needed to identify the gaps in the evidence-base so that future research can address these gaps, and standardised accelerometer protocols can be recommended.

3.3 Aim

The overall aim of this review is to identify gaps in the current evidence base and assess critically existing research that has evaluated several methodological uncertainties in accelerometer data collection and processing in children.

The four objectives of the systematic review are:

1. To identify large scale accelerometer-based studies of children's PA and/or SB and report for each study: a) the accelerometer data collection and processing protocol; b) the study consent rate, and; c) the proportion of children returning reliable accelerometer data.
2. To identify and assess critically articles evaluating factors associated with study consent and/or reliable accelerometer data acquisition in children.
3. To identify and assess critically articles evaluating different methodological approaches to accelerometer data processing in children.
4. To identify and assess critically articles evaluating the influence of season on levels of PA and SB in children.

3.4 Methods

3.4.1 Search strategy

A systematic search strategy was developed in PubMed (Appendix F) and four separate searches addressing each of the review objectives were conducted using the following electronic databases: Embase, Medline, PubMed, and Web of Science. Searches were conducted to identify studies with the MeSH terms 'child, preschool' or 'child' or 'adolescent' and 'motor activity' or 'energy metabolism' or 'sedentary lifestyles' or 'television'. To achieve each of the review objectives, the following search terms were combined with the above MeSH terms in Medline:

- *Objective one:* ‘physical or motor activity’ or ‘energy expenditure’ or ‘sedentary’ or ‘television’ or ‘computer’ and ‘accelerometer’.
- *Objective two:* search terms used to address objective one and ‘consent’ (MeSH term) or ‘valid’ or ‘compliance’ or ‘feasibility’ or ‘acceptability’ or ‘adherence’ or ‘predictors’ or ‘response’ or ‘bias’.
- *Objective three:* search terms used to address objective one and ‘biostatistics’ (MeSH term) or ‘data’ or ‘analysis’ or ‘cleaning’ or ‘reduction’ or ‘spurious’ or ‘wear’ or ‘day’ or ‘hour’ or ‘minute’.
- *Objective four:* search terms used to address objective one and ‘season’ (MeSH term) or ‘weather’ (MeSH term) or ‘variation’ or ‘variability’ or ‘wind’ or ‘humidity’ or ‘rain’ or ‘snow’ or ‘sun’ or ‘temperature’ or ‘cold’ or ‘hot’ or ‘month’ or ‘spring’ or ‘summer’ or ‘autumn’ or ‘fall’ or ‘winter’.

Each database was also searched for free text terms. All articles found as a result of these searches were screened to make sure they were relevant to the specific review objective. A citations search was also undertaken on all reviews articles identified from the searches, and on all articles included in the review.

3.4.2 Inclusion criteria

3.4.2.1 Article requirements

Original research articles of any type (e.g. journal articles, theses, conference abstracts) were included in this review provided that an abstract was available, and the article was published in the English language. Review articles obtained as a result of the searches were not discussed in the review but were retained for citation searches.

3.4.2.2 Publication date

The use of accelerometers to measure PA in children is a relatively recent technology with the first portable accelerometer device for measuring human EE being manufactured in the late 1970's[116]. The first validation study of accelerometer use in children was published in 1985[117]. In this review all published articles were included up to and including the end of September 2010.

3.4.2.3 Study design

Articles of any study or methodological design were included provided they reported at least one outcome variable of PA or SB that was derived from accelerometer-determined measurements.

3.4.2.4 Participants

Articles were included in the review if all study participants, or a clearly defined subgroup of participants, comprised preschool children (aged two to five years), children (aged 6 to 12 years) or adolescents (aged 13 to 18 years) that were not selected on the basis of having a specific disease or health problem. To achieve the first review objective, articles were only included if the study had a sample size of at least 250 subjects. Articles included in this review to achieve the second, third, and fourth review objectives were not restricted according to study sample size.

3.4.2.5 Setting

Articles from all countries were included in this review provided that they addressed at least one of the research objectives and met all other inclusion criterion.

3.4.3 Data extraction

3.4.3.1 Objective one

Articles were grouped according to the study in which subjects participated in. Author(s) and publication date(s) of all included articles were reported. If studies were cross-sectional, only one article per study was used to obtain the relevant information using a modified data extraction sheet (because all data extracted would be identical). If studies were longitudinal and different measurement sweeps were discussed in separate articles, one article for each observational measurement was used to obtain the relevant information using the modified data extraction sheet. The following information was extracted for each study: study details (name and country of study); study aim(s); accelerometer data collection protocol (date of data collection, accelerometer model, number of wear days, epoch, distribution and return protocol); accelerometer data processing protocol (minimum number of days required per child for inclusion in data analyses, minimum daily wear time, definition of non-wear and EHCV, and definition of activity intensity thresholds); sample size calculations; study recruitment; study consent rate; sample characteristics (size, gender, age, ethnicity, and weight status), and; reliable accelerometer data acquisition.

3.4.3.2 Objectives two, three and four

A standard data extraction sheet was developed and used by the author to obtain relevant information for all articles that addressed objectives two, three and four. The following information was extracted: author; study name and country; article publication date; aim(s) of the article; date of data collection; sample characteristics (size, gender, age, ethnicity, and weight status); accelerometer measurement protocol (accelerometer model, epoch, accelerometer wear protocol, accelerometer data processing protocol); outcome variable(s); explanatory variables (where relevant); statistical methods; main article findings; article conclusions, and; study limitations. The National Health Service Centre for Reviews and Dissemination proposed a simple assessment to guarantee a minimum level of quality based on study design[118]. However, a preliminary review of abstracts suggested that nearly all of the studies included in this review were observational studies and therefore poorly differentiated by the study hierarchy. Nevertheless, information relevant to the methodological quality of each article were also extracted, including study recruitment and sampling procedures, study design, sample size calculations, representativeness of the study sample to the wider population (i.e. external validity), and representativeness of the achieved sample to the study population (i.e. internal validity). The most important influence on study quality was considered to be the internal validity because the degree to which the results of the study are likely to be free of bias is dependent on whether children consent to participate in wearing an accelerometer, and also whether consenting children return and wear their accelerometer. As a result, this review assesses both sources of potential bias.

3.4.4 Analysis

The results of the review are presented as a qualitative review discussing each research question in turn with a descriptive analysis of outcomes. No attempt has been made to synthesise statistical outcomes as the heterogeneity across research methodologies was judged too large to permit this.

3.4.5 Searches and abstract review

3.4.5.1 Search results

The number of abstracts identified in the electronic searches for each review objective according to the database used is specified in Table 2.

Table 2: Number of abstracts identified in the final searches for each review objective according to the database used

Objective	**PubMed**	**Embase**	**Medline**	**Web of Science**	***Total****
One	729	628	534	947	*2838*
Two	382	310	259	450	*1401*
Three	610	531	489	789	*2419*
Four	219	157	134	309	*819*

* Includes duplicates

3.4.5.2 Articles included

Unique abstracts were reviewed against the inclusion criteria and screened to make sure they were relevant to the research question. A citations search was undertaken on all review articles, and on all original articles selected for inclusion. All articles selected for inclusion were obtained and reviewed in full.

Objective one

A total of 2,838 articles were identified from the electronic searches addressing review objective one, of which 2,140 were duplicates, leaving 698 unique articles (Figure 5). Abstracts were reviewed against the inclusion criterion, of which 397 articles were removed (leaving 301 articles); primarily because the sample size was lower than 250 subjects. Abstract review for relevancy of these studies to review objective one led to a further 231 studies being excluded. A citations search was undertaken on the 46 retained original research articles and on 24 relevant review articles, from which a further 12 articles were added. A total of 58 articles (from 23 studies) were selected for inclusion of the review.

Figure 5: Flowchart of studies and articles selected for objective one

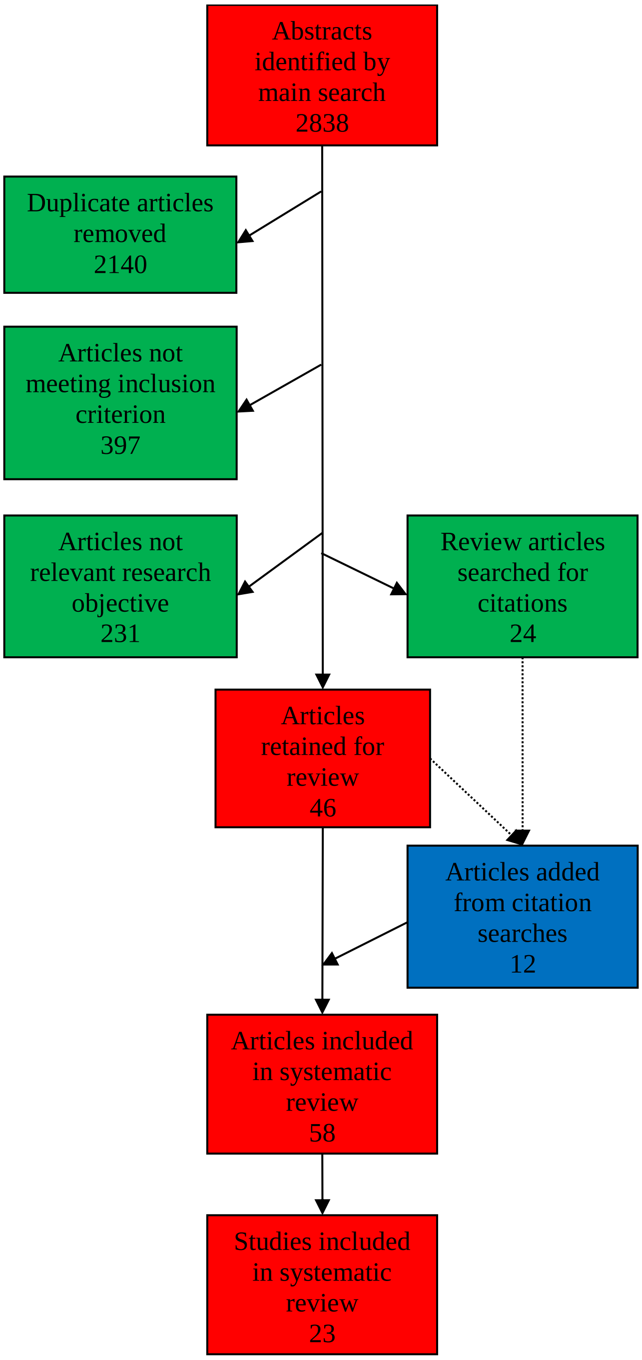
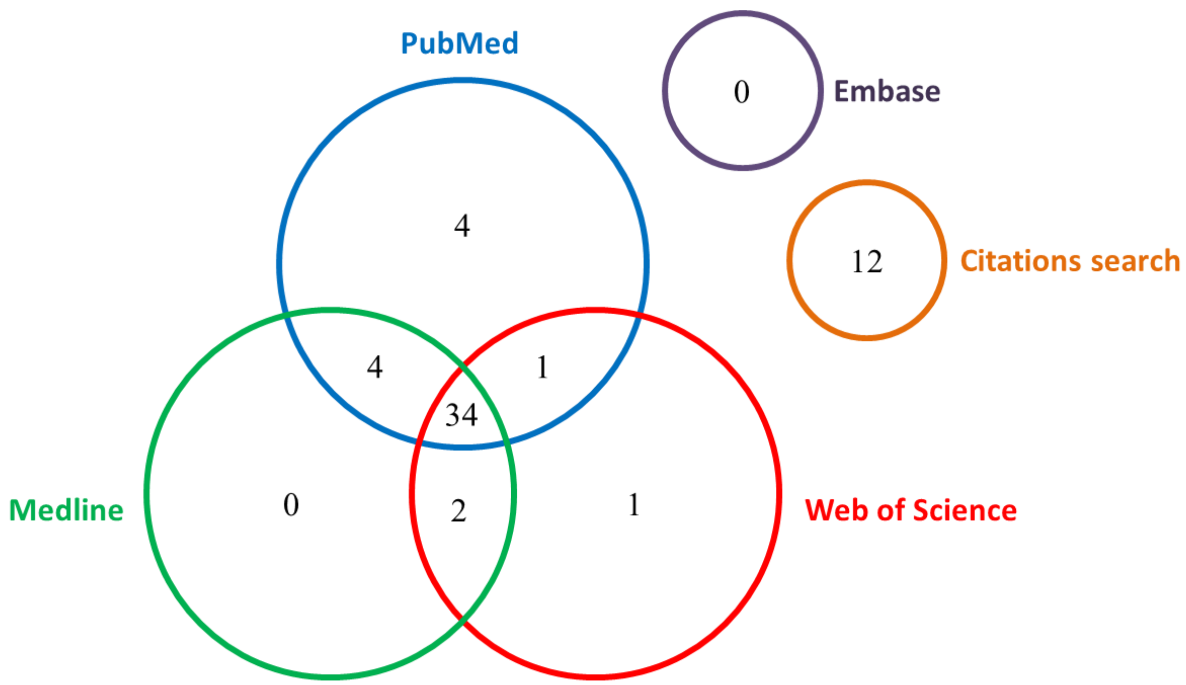


Figure 6 shows the derivation of articles included in the review to address review objective one. There were no relevant articles found using the pharmacological and biomedical search engine (Embase) for any of the review objectives, but there was a vast amount of overlap between the medical and scientific search engines (PubMed, Medline and Web of Science).

Figure 6: Articles (n=58) included in the review identified by each electronic database for objective one



Objective two

A total of 1,401 articles were identified from the electronic searches addressing review objective two, of which 1,020 were duplicates, leaving 381 unique articles (Figure 7). Abstracts were reviewed against the inclusion criterion, of which only 46 articles were removed, and reviewed for relevancy to review objective two which led to a further 308 studies being excluded. A citations search was undertaken on the 12 retained original research articles and on 15 relevant review articles, from which a further two articles were added. A total of 14 articles were selected for inclusion of the systematic review, all of which were reviewed in full. Figure 8 shows the derivation of articles included in the review to address review objective two.

Figure 7: Flowchart of articles selected for objective two

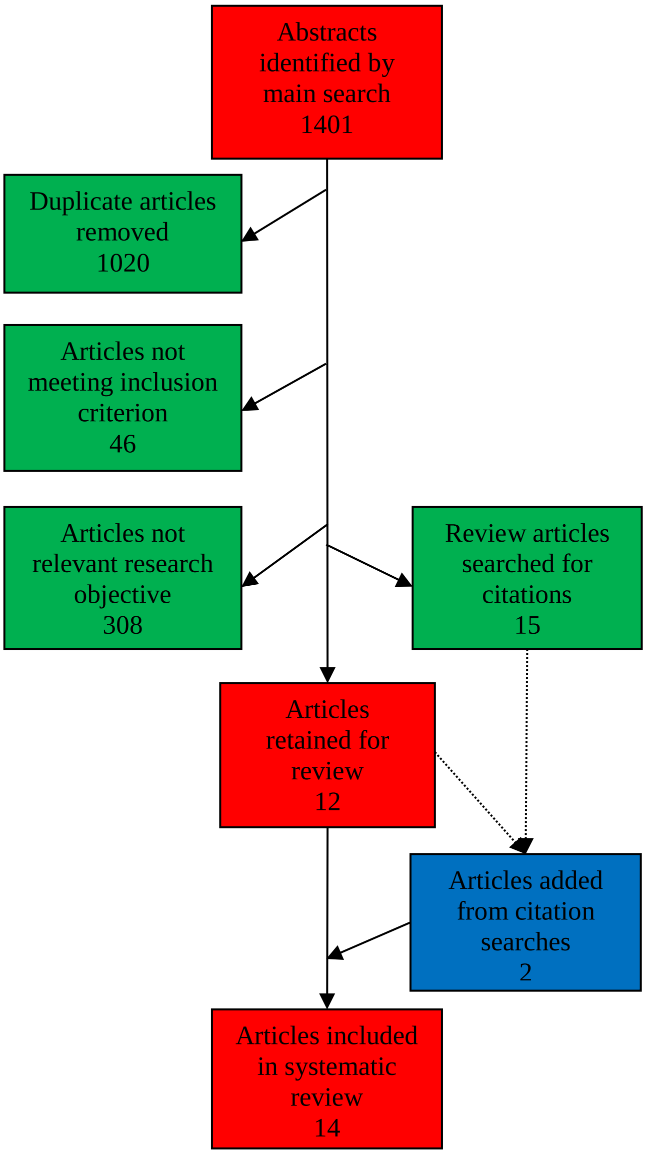
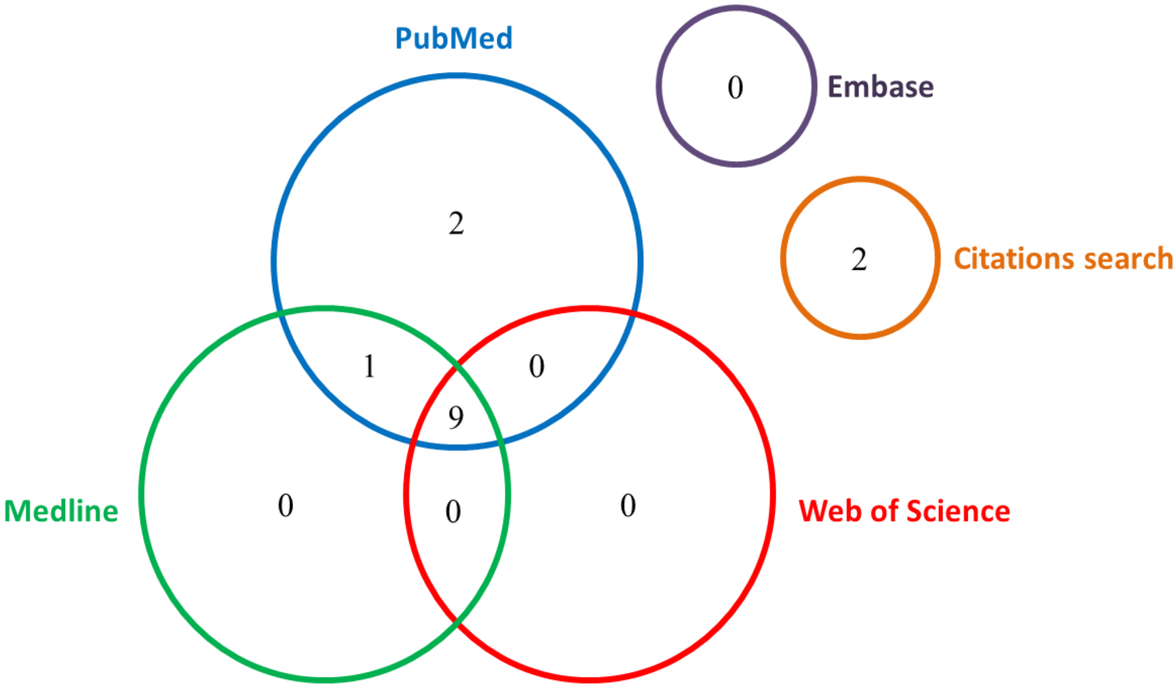


Figure 8: Articles (n=14) included in the review identified by each electronic database for objective two



Objective three

A total of 2,419 articles were identified from the electronic searches addressing review objective three, of which 1,790 were duplicates, leaving 629 unique articles (Figure 9). Abstracts were reviewed against the inclusion criterion, of which 97 articles were removed, and reviewed for relevancy to review objective three which led to a further 498 studies being excluded. A citations search was undertaken on the 13 retained original research articles and on 21 relevant review articles, from which one further article was added. A total of 14 articles were selected for inclusion of the systematic review, all of which were reviewed in full. Figure 10 shows the derivation of articles included in the review to address review objective three.

Figure 9: Flowchart of articles selected for objective three

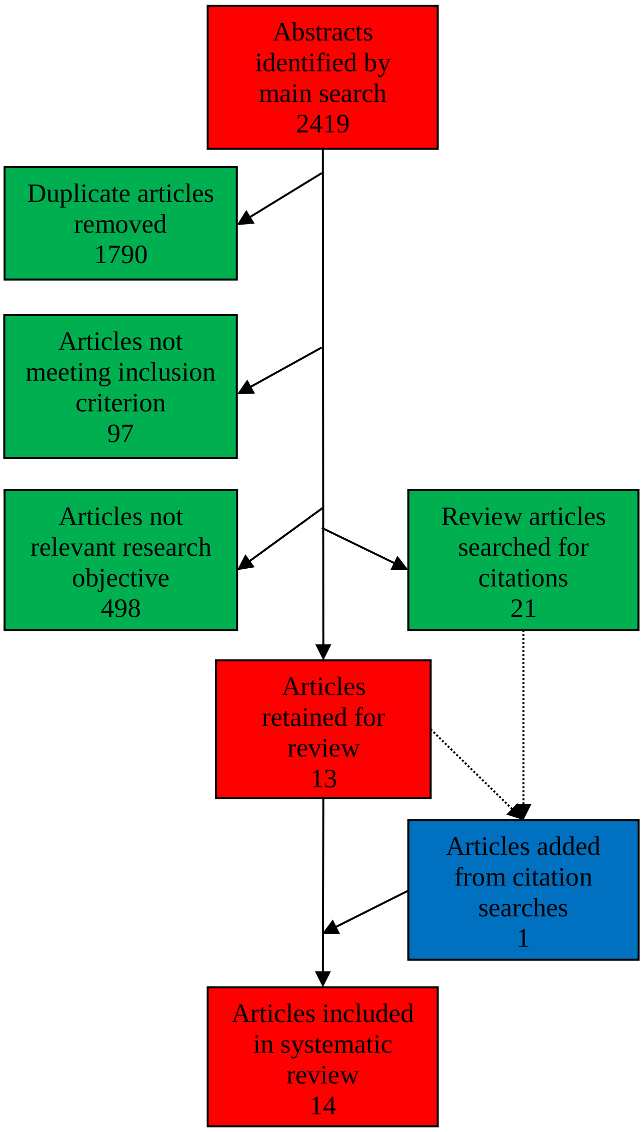
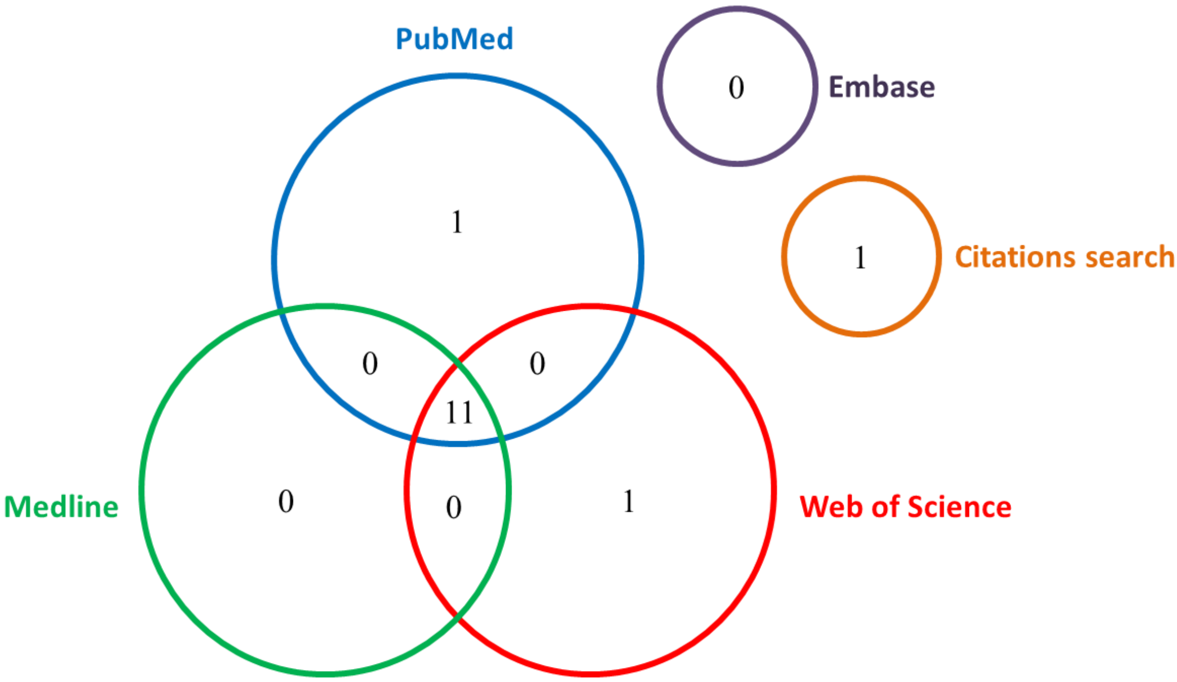


Figure 10: Articles (*n*=14) included in the review identified by each electronic database for objective three



Objective four

A total of 819 articles were identified from the electronic searches addressing review objective four, of which 585 were duplicates, leaving 234 unique articles (Figure 11). Abstracts were reviewed against the inclusion criterion, of which only 45 articles were removed, and reviewed for relevancy to review objective four which led to a further 158 studies being excluded. A citations search was undertaken on the 17 retained original research articles and on 14 relevant review articles, from which no further articles were added. A total of 17 articles were selected for inclusion of the systematic review, all of which were reviewed in full. Figure 12 shows the derivation of articles included in the review to address review objective four.

Figure 11: Flowchart of articles selected for objective four

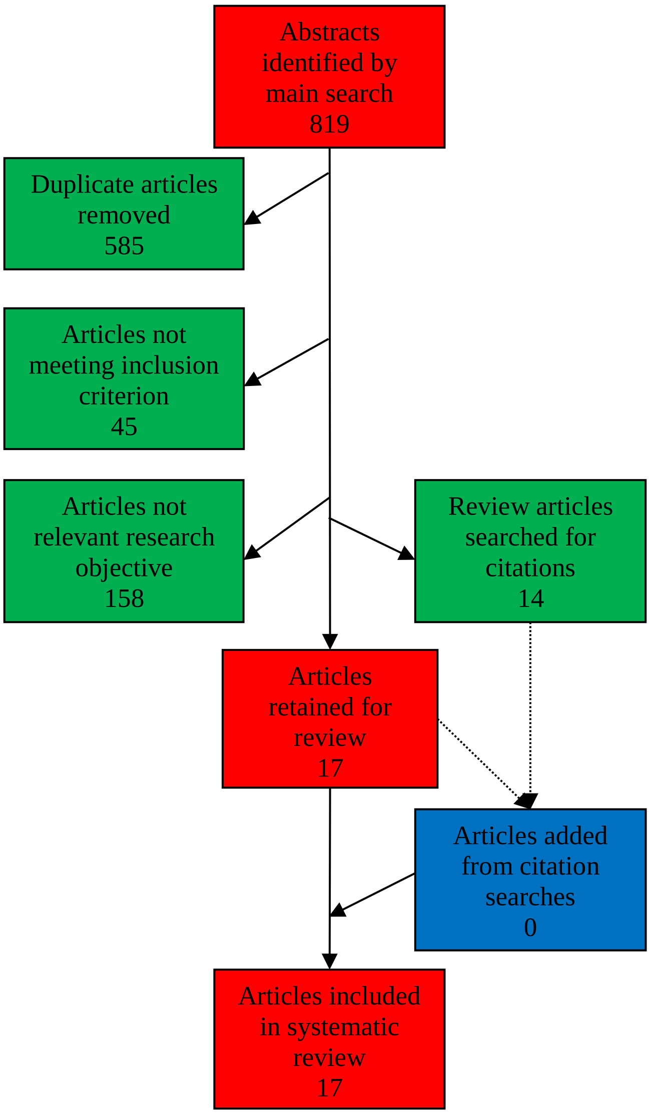
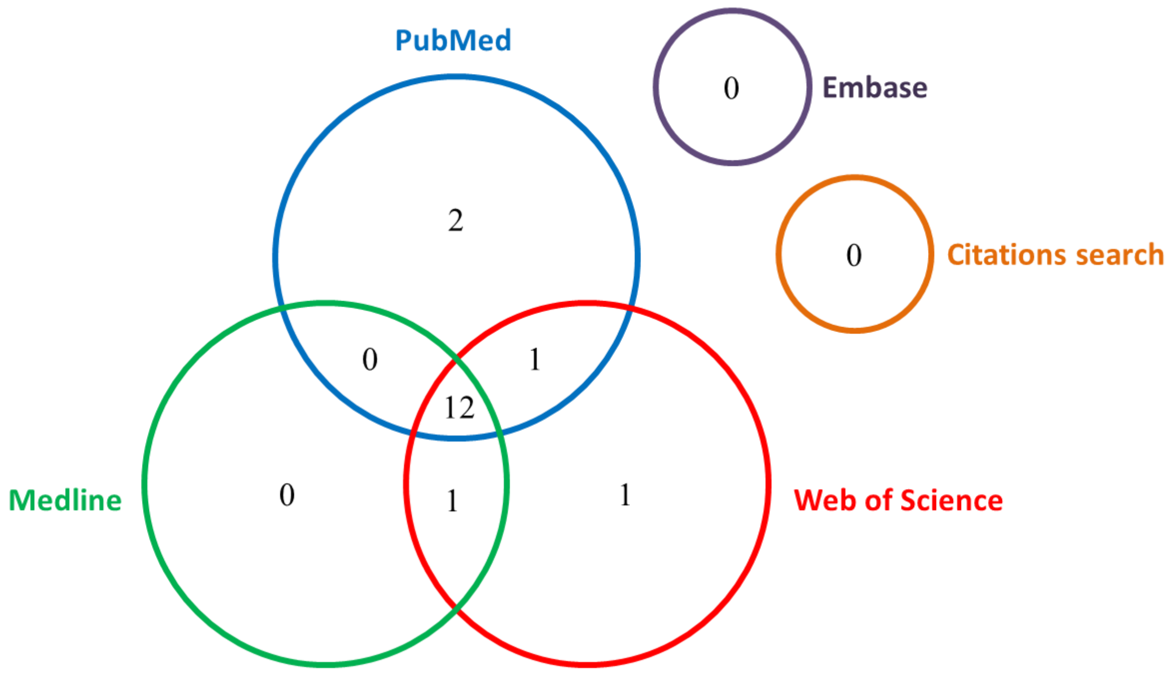


Figure 12: Articles (*n*=17) included in review identified by ach electronic database for objective four



3.4.6 Presentation of results

The results of this review are separated into four sections according to each of the review objectives. Section 3.5.1 discusses all articles that were included in the review to address objective one. Articles are grouped according to the study (*n*=23) that subjects participated in, and discussed in alphabetical order according to study name. Sections 3.5.2, 3.5.3, and 3.5.4 discusses all articles that were included in the review to address objectives two, three, and four, respectively. Articles are discussed in detail according to information obtained from the data extraction sheet. The main findings of each article are discussed in chronological order according to publication date - information is not repeated if already discussed in section 3.5.1.

3.5 Results

3.5.1 Objective 1: Study methodology of accelerometer studies in children

3.5.1.1 Summary of studies

3.5.1.1.1 Study overview

The study abbreviations used throughout this review chapter are listed in Table 3. A total of 23 large scale ($n \geq 250$) accelerometer-determined studies of children's PA and/or SB were identified (Table 4).

Table 3: Study abbreviations

Abbreviation	Study name
AHA	Amherst Health and Activity Study
ALSPAC	Avon Longitudinal Study of Parents and Children
Bristol 3P's	Bristol 3P's (parents, peers and physical activity) project
CHAMPS UK	Children's Health and Activity Monitoring Programme in Schools
CHAMPS USA	Children's Activity and Movement in Preschool Study
CHASE	Child Heart and Health Study
CLASS	Children's Leisure Activities Study Survey
CoSCIS	Copenhagen School Child Intervention Study
EYHS	European Youth Heart Study
FLAME	Family Lifestyle, Activity, Movement and Eating Study
IBDS	Iowa Bone Development Study
KOALA	Child, Parent and Health: Lifestyle and Genetic Constitution (in Dutch)
NICHD	National Institute of Child Health and Human Development Study of Early Child Care and Youth Development
NHANES	National Health and Nutrition Examination Survey
PACY-2	Physical Activity and Dietary Intake of Children and Youth Study
Pathways	Pathways Study
PEACH	Personal and Environmental Associations with Children's Health

PEACHES	Physical Exercise and Appetite in Children Study
PRESTYLE	Preschool , Body Composition and Lifestyle Study
Project EAST	The Eating and Activity Survey Trial
SPEEDY	Sport, Physical Activity, and Eating Behaviour: Environmental Determinants in Young People
TAAG	Trial of Activity for Adolescent Girls

A total of 58 articles analysed accelerometer data collected by these studies. Date of publication ranged from 2001 to 2010. Eight studies were from the USA (AHA[119-122], CHAMPS USA[123], IBDS[17 124-128], NICHD[129], NHANES[130], Pathways[131], Project EAST[132], and TAAG[133-137]), eleven from Europe [including seven from the UK (ALSPAC[61 72 108 138-142], Bristol 3P's[143 144], CHAMPS UK[123], CHASE[64], PEACH[62 145-148], PEACHES[149 150], and SPEEDY[151 152])] (CoSCIS[153-155], EYHS[156-159], KOALA[160], and PRESTYLE[161 162]), two from Canada (PACY-2[163], and Esliger *et al*[164]), one from New Zealand (FLAME[113]), and one from Australia (CLASS[165 166]). Only four studies reported longitudinal data (ALSPAC, FLAME, NICHD, and TAAG) and the remainder reported cross-sectional data. Eighteen articles stated the date of data collection, which ranged from 1995 to 2009.

Sample sizes for the 23 studies ranged from 255[132] to 5,595[61]. Studies included just children (6 to12 years; *n*=8; ALSPAC, Bristol 3P's, CHAMPS UK, CHASE, CoSCIS, PEACH, PEACHES, and SPEEDY), children and adolescents (6 to 18 years; *n*=8; AHA, EYHS, NICHD, NHANES, PACY-2, Project EAST, TAAG, and Esliger *et al*[164]), or preschool children (two to five years; CHAMPS US, IBDS, KOALA, and PRESTYLE). The CLASS study included samples of preschool children and children. Nearly all included both boys and girls; only one study included samples of girls only (TAAG).

Table 4: Table summarising large scale ($n \geq 250$) accelerometer-based studies (n=23) of children's physical activity and/or sedentary levels

Study; country	**Authors; year of publication**	**Study accelerometer sample [Size; gender; mean age (±SD)]**	**Period of data collection**	**Accelerometer protocol (model; days wear; epoch)**	**Minimum no. of days per child required reliable data**	**Minimum daily wear time (min)**	**Definition of non-wear time**	**Extreme count value definition**	**Accelerometer distribution protocol**	**Accelerometer return protocol**	**Consent rate (%)**	**Reliable accelerometer data acquisition rate (%)**
AHA; USA	Pate *et al*, 2002[119]; Trost *et al*, 2000[120]; Trost *et al*, 2002[121]; Trost *et al*, 2003[122]	*n*=375; 185m; 190f; 7.2 (1.4)y, 10.4 (1.0)y, 12.9 (0.9)y, 15.8(1.1)y	Oct 1996-Apr 1997	ActiGraph 7164; 7d wear; 60 sec epoch;	7	NS	zero counts must be indicative of sleeping time	NS	School	School	38.0	93.8
ALSPAC (age 11 sweep); England	Riddoch *et al*,2007[61]; Mattocks *et al*, 2008[138]; Deere *et al*, 2009[139]; Mitchell *et al*, 2009[72]; Riddoch *et al*, 2009[140]; van Sluijs *et al*, 2009[141]; Jago *et al*, 2010[142]	*n*=5595; 2662m, 2933f 11.8 (range 11.6-11.9)y	Jan 2003-Jan 2005	ActiGraph 7164; 7d wear; 60 sec epoch;	≥ 3	≥ 600	≥ 10 min zero counts	Day excluded if cpm > 3 SDs above mean (1665 cpm)	Research laboratory	UK mail	92.5	84.5
ALSPAC (seasonal sub-study); England	Mattocks *et al*, 2007[108]	*n*=315; 148m, 167f; 11.65 (0.19)y	NS	ActiGraph 7164; 7d wear; 60 sec epoch	≥ 3	≥ 600	≥ 10 min zero counts	NS	UK mail (except first measurement)	UK mail	64.0	*1st season*: 90.0; *2nd season:* 86.0; *3rd season:* 81.0; *4th season:* 70.0; *all 4 seasons:* 70.0
Bristol 3P's; England	Brockman *et al*, 2010[143];	*n*=940; 436m, 504f; 10-11y (range)	Feb 2008-Mar	ActiGraph GT1M; 5d wear (inc.	≥ 3	≥ 500	≥ 60 min zero counts	NS	School	School	60.9	74.2

Study; country	Authors; year of publication	Study accelerometer sample [Size; gender; mean age (±SD)]	Period of data collection	Accelerometer protocol (model; days wear; epoch)	Minimum no. of days per child required reliable data	Minimum daily wear time (min)	Definition of non-wear time	Extreme count value definition	Accelerometer distribution protocol	Accelerometer return protocol	Consent rate (%)	Reliable accelerometer data acquisition rate (%)
	Jago et al., 2010[144];		2009	2d w/e); 10 sec epoch								
CHAMPS UK; England	Gidlow *et al*, 2008[123]	*n*=503; 250m, 253f; 10.4 (3.7)y	Nov 2006-May 2007	ActiGraph GT1M; 7d wear; 60 sec epoch	≥ 2 (w/d) ≥ 1 (w/e)	≥ 600 (w/d), ≥ 480 (w/e)	NS	NS	School	School	67.0	82.5 (w/d) 66.2 (w/e)
CHAMPS USA; USA	Pfeiffer *et al*, 2009[167]	*n*=331; 168m, 163f; 4.3 (0.6)y	Aug 2003-Jan 2006	ActiGraph 7164; 8-10d wear & 1d w/e; 15 sec epoch	≥ 7 (inc. 1 w/e)	≥ 300 & ≤ 1080	≥ 60 min zero counts	NS	Preschool	Preschool	NS	NS
CHASE; England	Owen *et al*, 2009[64]	*n*=2071 994m, 1077f; 9.9 (range 9.2-10.7)y	Jan 2006-Feb 2007	ActiGraph GT1M; 7d wear; 5 sec epoch	≥ 1, 1st & last day removed	≥ 600	≥ 20 min zero counts,	NS	School	School	62.0	96.6
CLASS; Australia	Telford *et al*, 2005[165]; Timperio *et al*, 2004[166]	*Age 5-6y sample:* *n*=296; 151m, 145f; 6.1 (0.48)y *Age 10-12y sample:* *n*=919; 423m, 496f; 11.5 (0.63)y	2001-2002	7164 ActiGraph; 8d wear; 60 sec epoch	≥ 4 (inc. 1 w/e), 1st & last day removed,	NS	> 360 min vigorous activity removed	NS	School	School	*Age 5-6y sample:* 27.0; *Age 10-12y sample:* 45.0	*Age 5-6y sample:* 80.1; *Age 10-12y sample:* 96.7
CoSCIS; Norway	Eiberg *et al*, 2005[153]; Hansen *et al*, 2005[154]; Hasselstrom *et al*, 2006[155]	*n*=592; 309m, 283f; m: 6.8 (0.4)y, f: 6.7 (0.4)y	Dec 2001-May 2002	ActiGraph 7164; 3d + 19hr wear; 10 sec epoch	≥ 3	≥ 480	≥ 10 min zero counts, 22:30-06:00 sleep time	NS	School	School	69.0	94.9
EYHS; Denmark, Portugal,	Brage *et al*, 2004[156]; Brage *et al*,	*n*=2185; m: 9.7 (0.4)y & 15.5 (0.5)y,	NS	ActiGraph 7164; 4d wear;	≥ 3	≥ 600	≥ 10 min zero counts	NS	School	School	70.0	75.2

Study; country	Authors; year of publication	Study accelerometer sample [Size; gender; mean age (±SD)]	Period of data collection	Accelerometer protocol (model; days wear; epoch)	Minimum no. of days per child required reliable data	Minimum daily wear time (min)	Definition of non-wear time	Extreme count value definition	Accelerometer distribution protocol	Accelerometer return protocol	Consent rate (%)	Reliable accelerometer data acquisition rate (%)
Estonia, Norway	2004[157]; Riddoch *et al*, 2004[158]; Cooper *et al*, 2006[159]	f: 9.6 (0.4)y & 5.4 (0.6)y		60 sec epoch								
FLAME; New Zealand	Taylor *et al*, 2009[113]	*Total n*=574; 319m, 255f; *Age 3y sample: n*=208; 113m, 95f; *Age 4y sample: n*=180; 101m, 79f; *Age 5y sample: n*=186; 105m, 81f;	2004 - 2007	Mini Mitter Actical; 5d wear; Epoch: NS	≥ 3	length of day calculated from parental report	NS	NS	Clinic	Clinic	*59.0*	*Age 3y sample: 85.0; Age 4y sample: 76.0; Age 5y sample: 83.0*
IBDS; USA	Janz *et al*, 2001[17]; Janz et *al*, 2002[124]; Janz *et al*, 2004[125]; Janz *et al*, 2005[126]; Janz *et al*, 2008[127]; Janz *et al*, 2009[128]	*n*=368; 179m, 189f; m: 5.18 (0.39)y, f: 5.26 (0.39)y	Sep 1995- Nov 1995	ActiGraph 7164; 4d wear (inc. 1d w/e); 60 sec epoch	≥ 2	≥ 480	NS	NS	US mail	US mail	NS	87.0
KOALA; Netherlands	Eijkemans *et al*, 2008[160]	*n*=305; 152m, 153f; 4.9 (range 4.1-5.6)y	NS	ActiGraph GT1M; ≥5d wear; 15 sec epoch	≥ 3 w/d & ≥ 1 w/e	≥ 400	NS	NS	Community building	Community building	39.1	84.0
NICHD; USA	Nader *et al*, 2008[129]	*Age 9 y sample: n*=839; 408m, 431f; 9.0 (0.3)y	2000, 2002, 2003 &	Caltrac accelerometer; 7d wear; 60 sec epoch	≥ 4	first count after 05:00 until one	NS	NS	Home	NS	*Age 9y sample:* 80.1; *Age 11y*	*Age 9y sample*: 95.4; *Age 11y sample*: 96.0;

Study; country	Authors; year of publication	Study accelerometer sample [Size; gender; mean age (±SD)]	Period of data collection	Accelerometer protocol (model; days wear; epoch)	Minimum no. of days per child required reliable data	Minimum daily wear time (min)	Definition of non-wear time	Extreme count value definition	Accelerometer distribution protocol	Accelerometer return protocol	Consent rate (%)	Reliable accelerometer data acquisition rate (%)
		Age 11y sample: *n*=850; 416m, 434f; 10.7 (0.3)y *Age 12y sample:* *n*=699; 532m, 532f; 11.9 (0.3)y *Age 15y sample:* *n*=604; 280f, 324f; 15.0 (0.2)y	2007			of the following: ≥60min zero counts after 21:00, ≥30min zero counts after 22:00, last zero count before 00:00					*sample*: 81.6; *Age 12y sample:* 70.7; *Age 15y sample:* 68.9	*Age 12y sample:* 93.0; *Age 15y sample:* 86.9
NHANES; USA	Troiano et *al*, 2008[130]	*n*=1778; 879m, 899f; *Age 6-11y sample:* m: 8.4 (0.1)y, f 8.5 (0.1)y *Age 12-19y sample:* m:15.3 (0.2)y, f: 15.0 (0.1)y	2003-2004	ActiGraph 7164; 7d wear; 60 sec epoch	≥ 4	≥ 600	≥ 60 min zero counts (with allowance for 12 min between 0-100 counts)	NS	Mobile examination centre	Express mail	68.0 (all ages)	*Age 6-11y sample:* m*: 70.9,* f*: 69.3;* *Age 12-19y sample:* m: 62.1, f: 62.0
PACY-2; Canada	Thompson *et al*, 2009[163]	*n*=1790; 802m, 982f; 8.3 (0.5)y, 12.3 (0.5)y, 16.5 (0.6)y	NS	ActiGraph 7164; 7d wear; 60 sec epoch	≥ 5 (inc. 1 w/e)	≥ 240	NS	NS	School	School	NS	76.5
Pathways; USA	Stevens *et al*, 2004[131]	*n*=574; 233m, 221f; 7.5 (0.6)y	Spr 1997	Tritac R3D; 1d wear; Epoch: NS	1	NS	NS	NS	School	School	NS	NS
PEACH; England	Page *et al*, 2009[145];	*n*=1300; 639m, 661f;	Sep 2006-	ActiGraph GT1M;	NS	≥ 480 (w/d)	≥ 10 min zero	NS	School	School	70.5	*w/d*: 91.7; *w/e:* 70.0

Study; country	**Authors; year of publication**	**Study accelerometer sample [Size; gender; mean age (±SD)]**	**Period of data collection**	**Accelerometer protocol (model; days wear; epoch)**	**Minimum no. of days per child required reliable data**	**Minimum daily wear time (min)**	**Definition of non-wear time**	**Extreme count value definition**	**Accelerometer distribution protocol**	**Accelerometer return protocol**	**Consent rate (%)**	**Reliable accelerometer data acquisition rate (%)**
	Cooper *et al*, 2010[146]; Griew *et al*, 2010[147]; Page *et al*, 2010[148]; Wheeler *et al*, 2010[62]	10.95 (0.41)y	Jul 2008	7d wear; 10 sec epoch			counts					
PEACHES; England	Purslow *et al*, 2008[149]; Fisher *et al*, 2010[150];	*n*=301; 155m, 146f; 8.31 (0.65)y	NS	ActiGraph GT1M; 5d wear (inc. 2d w/e); 60 sec epoch	≥ 3 (inc. 1 w/d)	≥ 600	≥ 10 min zero counts	NS	School	School	65.0	88.0
PRESTYLE ; Portugal	Vale *et al*, 2010[161]; Vale *et al*, 2010[162]	*n*=281; 157m, 124f; 5.03 (0.81)y	Apr 2009-Nov 2009	ActiGraph GT1M; 5d wear (inc. 2d w/e); 5 sec epoch	≥ 3 (inc. 1 w/e)	≥ 600 (07:00-19:00)	≥ 10 min zero counts	NS	School	School	NS	NS
Project East; USA	Van Coevering *et al*, 2005[132]	*n*=255; 106m, 146f 11-14y (range)	Jan 2001-May 2001	ActiGraph 7164; 7d wear; 60 sec epoch	NA	NS	≥ 180 min zero counts (08:00-21:00)	NS	Home	Home	52.9	50.2
SPEEDY; England	Van Sluijs *et al*, 2008[152]; Corder *et al*, 2010[151]	*n*=2064; 926m, 1138f; 10.3 (0.3)y	Apr 2007-Jul 2007	ActiGraph GT1M; 7d wear; 5 sec epoch	≥ 3, 1st day removed	≥ 500	≥ 10 min zero counts,	NS	School	School	57.0	90.5
TAAG; USA	Catellier *et al*, 2005[133]; Murray *et al*, 2006[134]; Webber *et al*, 2008[135]; Evenson *et al*, 2010[136]; Voorhees	*Spr 2003 sample:* *n*=1603; 1603f; 11-12y (range) *Spr 2005 sample:* *n*=3085; 3085f;	Spr 2003, Spr 2005, Spr 2006	ActiGraph 7164; 7d wear; 30 sec epoch	≥ 1d (imputed up to 6d)	≥ 360	≥ 20 min zero counts	NS	School	School	*Spr 2003 sample*: 79.7; *Spr 2005 sample:* 85.0; *Spr 2006 sample:* 89.5	*Spr 2003 sample*: 93.1; *Spr 2005 sample:* 88.0; *Spr 2006 sample:* 88.0

Study; country	Authors; year of publication	Study accelerometer sample [Size; gender; mean age (±SD)]	Period of data collection	Accelerometer protocol (model; days wear; epoch)	Minimum no. of days per child required reliable data	Minimum daily wear time (min)	Definition of non-wear time	Extreme count value definition	Accelerometer distribution protocol	Accelerometer return protocol	Consent rate (%)	Reliable accelerometer data acquisition rate (%)
	et al, 2009[137]	13-14y (range) *Spr2006 sample:* *n*=3378; 3378f; 13-14y (range)										
Study NS; Canada	Esliger *et al*, 2010[164]	*n*=413; 204m, 209f; 8-13y (range)	NS	ActiGraph 7164; 7d wear; 60 sec epoch	≥5	≥ 600	NS	NS	In person	In person	*OOM sample:* 40.0; *OOA sample:* 100.0; *RSK sample:* 59.0; *USK sample:* 62.0	*OOM sample:* 100; *OOA sample:* 86.1; *RSK sample:* 80.0; *USK sample:* 84.5

Abbreviations: *n*=sample size; m=males; f=females; y=years; mth=months; spr=spring; sum=summer; aut=autumn; win=winter; NS=not specified; Jan=January; Feb=February; Mar=March; Apr=April; Jun=June; Jul=July; Aug=August; Sep=September; Oct=October; Nov=November; Dec=December; d=days; hr=hours; min=minutes; sec=seconds; w/d=weekday; w/e=weekend; RSK=rural Saskatchewan; OOM=Old Order Mennonite; OOA=Old Order Amish; USK=urban Saskatchewan.

3.5.1.1.2 Accelerometer measurement protocol

Accelerometer model

The ActiGraph accelerometer was used in 20 studies (12 used the 7164 model[17 61 120 130 132 133 153 158 163 164 166 168], and eight the GT1M model[64 123 143 145 149 152 160 161]), one used the Tritac R3D[131], one used the Mini Mitter Actical[113], and the remaining study used the Caltrac accelerometer[129]. The ActiGraph is thus the most widely used accelerometer, and has been extensively validated in children and has been compared favourably against observational techniques[45], HR telemetry[46], indirect calorimetry[47], and EE measured by doubly labelled water[48]. In addition, there is a large body of evidence on the calibration of the ActiGraph[47 50 98 169-172]. The Actical[50 168 169]and Caltrac[90] accelerometers have also been shown to be a valid tool for assessing PA in children, but there has been some potential concerns reported with reliability of the Tritac R3D[89]. The ActiGraph is reported to be the most appropriate accelerometer to measure PA in children due to its good reproducibility, validity and feasibility[90].

Epoch

Almost half of all (*n*=12) studies[17 61 119 123 129 130 132 149 158 163 164 166] used a 60 second epoch; this is likely to be because most of these studies used the older ActiGraph 7164 model, which is only capable of storing data collected using epoch lengths of greater than 60 seconds for a limited number of days due to limited battery life and data storage capacity. However, children's activity has been shown to be sporadic, spontaneous and intermittent, with the majority of PA bouts lasting between 3 and 22 seconds[25]. Longer epochs may therefore be inappropriate when measuring children's PA and may underestimate levels of MVPA. Recent advances in accelerometer design have meant that researchers can now select shorter epochs whilst still being able to measure for a sufficient number of days. The FLAME study[113] did not state which sampling epoch they used. It is important to know the epoch length used so that reliable comparisons between study findings can be made: recent research suggests that epoch lengths of 5 and 60 seconds should not be compared in children, and epochs of 5, 10, 15, 30 and 60 seconds should not be compared in adolescent samples[93].

Accelerometer wear protocol

All studies reported the number of days subjects were asked to wear their accelerometer, which ranged from one[131] to ten[167] days. The most common (*n*=12[61 64 120 123 129 130 132 133 145 152 163]; 23% of studies) number of days that children were asked to wear their accelerometer was seven. There are various estimates for the minimum number of wear days required by each child to provide reliable measures of habitual PA[120]. In nearly all (*n*=22) studies participants were asked to wear the accelerometers during waking hours only, although subjects participating in the FLAME study[113] were not asked to remove their accelerometers when sleeping.

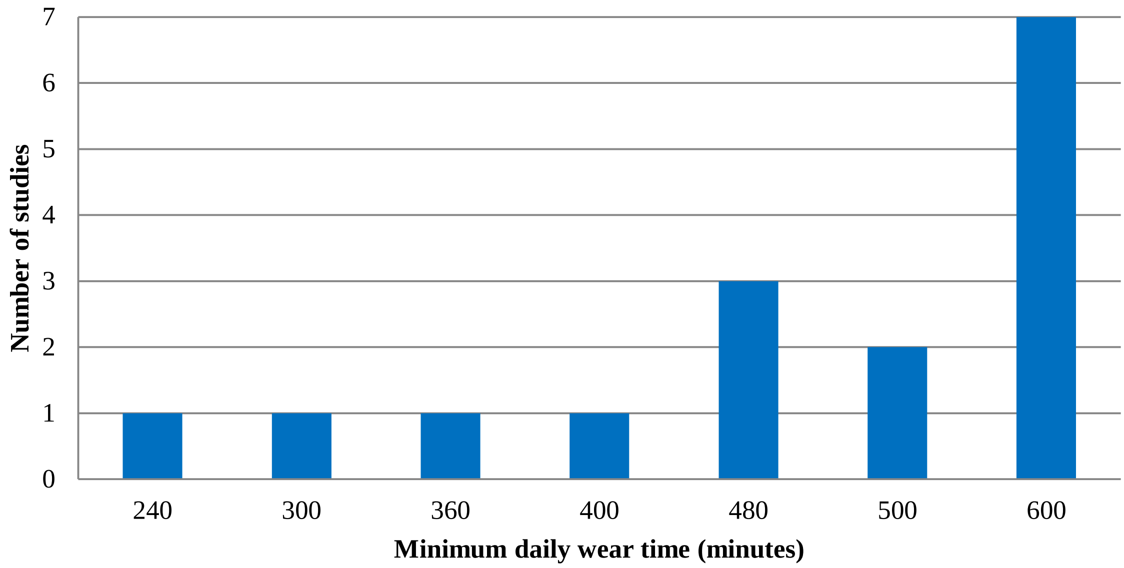
Most studies (65%; *n*=15[64 120 123 131 133 143 145 149 152 153 158 161 163 166 167]) distributed accelerometers through school visits. Other accelerometer distribution methods included home visits (*n*=2[129 132]), posting the accelerometers to subjects (*n*=1[17]), and by participant collection from a research setting (e.g. a research laboratory, clinic or mobile examination centre; *n*=5[164 160 61 113 130]). In two (8%) studies[61 130] a different method was used for returning accelerometers than their distribution method: the ALSPAC[61] and NHANES[130] required subjects to return their accelerometers by UK Royal Mail and USA Express mail respectively. Only one study (NICHD)[129] did not report the accelerometer return method.

Accelerometer data processing

Only 15 (65%) articles reported the methods used to identify periods of non-wear time. In these, periods of at least 10[61 145 149 152 153 158 161], 20[64 133], 60[130 143 167], or 180[132] minutes of continuous zero counts were used to estimate periods in which the accelerometer was not worn. The NHANES[130] defined non-wear time as an interval of at least 60 minutes of consecutive zero counts, with an allowance for one to two minutes of activity counts between 0 and 100.

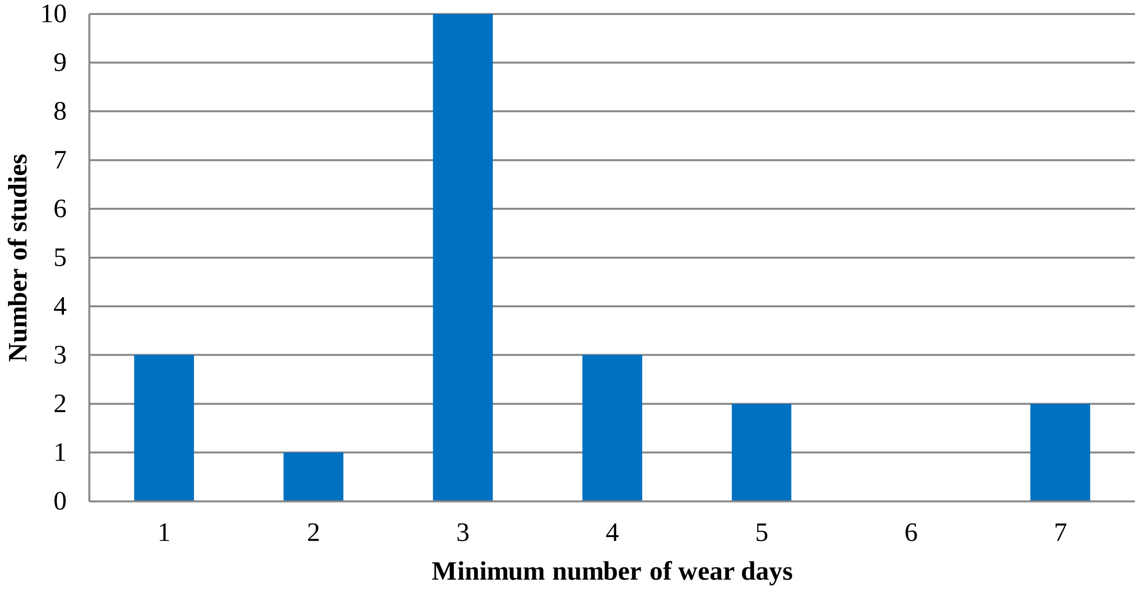
Eighteen out of 23 (78%) studies reported the minimum daily wear time used to determine whether the accelerometer was worn for a sufficient proportion of the day. The CHAMPS UK study[123] defined minimum daily wear time as at least 600 minutes on weekdays, and at least 480 minutes on weekend days. The NICHD study[129] defined minimum daily wear time as the first count after 05:00 until one of the following: at least 60 minutes of zero counts after 21:00, at least 30 minutes of zero counts after 22:00 or, the last zero count before 00:00. The remaining studies (*n*=16) used varying thresholds, including at least 240[163], 300[167], 360[133], 400[160], 480[17 145 153], 500[143 152], and 600[61 64 130 149 158 161 164] minutes per day (Figure 13). The most common threshold used to define minimum daily wear time was at least 600 minutes per day: seven out of 18 (39%) studies[61 64 130 149 158 161 164] chose this criterion.

Figure 13: Graph summarising the minimum daily wear time threshold used by large scale studies of childhood physical activity (*n*=16)



The minimum number of wear days required by each child for inclusion in data analyses was not reported in two studies[132 145]. Project EAST[132] assessed compliance rates according to varying numbers of wear days and as a result a criterion was not necessary. The minimum number of wear days (total weekend and weekday) required by each child to be included in data analyses in each study is summarised in Figure 14. The CHAMPS UK[123] and KOALA[160] studies required at least two weekdays to characterise children's weekday PA, and at least one weekend day to characterise children's weekend PA. Most studies (*n*=10[61 113 123 143 149 152 153 158 160 161]; 48%) required at least three days of accelerometer data per child to represent habitual PA. The TAAG study[133] used a threshold of at least one wear day, however, data were imputed so that all children had at least six days of data. The Pathways Study[131] were only able to analyse children with one day of data as their sample were only asked to wear their accelerometer for a single day. Seven studies (CHAMPS UK[123], CHAMPS USA[167], CLASS[166], KOALA[160], PACY-2[163], PEACHES[149], PRESTYLE[161]) required children to have at least one weekend day of data. Three studies (CHASE[64], CLASS[166], SPEEDY[152]) excluded the first day of accelerometer data, and two studies (CHASE[64], CLASS[166]) excluded the last day of data from analyses. The identification of EHCV was reported in only one study: the ALSPAC removed a day's worth of data if the average cpm for that day were more than 3 SD (SD:1,665 cpm) above the mean for the total sample[61].

Figure 14: Graph summarising the minimum number of wear days required by each child for inclusion in analyses in large scale studies of childhood physical activity (*n*=21)



3.5.1.1.3 Study consent and reliable accelerometer receipt

Eighteen studies[61 64 113 120 123 129 130 132 133 143 145 149 152 153 158 160 164 166] (78%) reported the proportion of children who consented to participate in wearing an accelerometer for their study: consent rate ranged from 27% (CLASS[166]) to 100% (Esliger *et al*[164]). Only two studies[131 167] did not report the proportion of consenting children who returned reliable accelerometer data: reliable data acquisition ranged from 50% (Project EAST[132]) to 100% (Esliger *et al*[164]), but this was highly dependent on the study wear time threshold.

The large scale studies relevant to this review which address objectives two (section 3.5.2), three (section 3.5.3) or four (section 3.5.4) will now be described in alphabetical order, detailing the following information for each: accelerometer data collection and processing methods, study recruitment procedures, study consent rate, and reliable accelerometer data acquisition rate.

3.5.1.2 Amherst Health and Activity Study

3.5.1.2.1 Study overview

The AHA[119-122] is a cross-sectional observational study. The main aim of the study was to examine determinants of PA in school-aged children and youth living in the USA.

3.5.1.2.2 Accelerometer data collection and processing

Children were asked to wear the ActiGraph 7164 accelerometer for seven days; a 60 second epoch was selected. Accelerometers were distributed by researchers visiting the school and were collected back at the school after the monitoring period. Data collection took place in two sweeps. The first sweep (*n*=267) took place in autumn 1996 (late October to mid-December), and the second sweep (*n*=108) took place in spring 1997 (April).

The study only used children who provided all seven days of accelerometer measurement in data analyses. The minimum daily wear time was not specified in any of the included articles but any calculations undertaken on the data assumed that subjects wore their accelerometers for the entire waking period and that continuous zeros counts were indicative of sleeping. Study articles do not state if, and if so, how they identified EHCV. Age-specific count thresholds for each intensity level were derived from the EE prediction equation developed by Freedson *et al*[173].

3.5.1.2.3 *Study recruitment and consent*

Subjects were recruited from seven elementary schools, one junior high school, and one senior high school in Amherst, Massachusetts, USA; 38% of children (*n*=1,379) provided consent from a parent/guardian. Subjects involved in the PA monitoring were sampled by randomly selecting 100 children from four age group categories. If a student refused to participate (*n*=4), a replacement was randomly selected from the same grade and gender group.

3.5.1.2.4 *Reliable accelerometer data acquisition*

Following deletions for monitor failure (*n*=14), monitor loss (*n*=1), participant tampering (*n*=4), and outliers (*n*=6), the final sample consisted of 375 (93.8% of consenting children) children who returned reliable accelerometer data (at least seven days). Sample characteristics of the children who returned reliable data in the AHA are summarised in Table 5.

Table 5: Amherst Health and Activity Study subject characteristics by gender and age for children returning reliable data; mean (SD)

	Boys				**Girls**			
Age(years)	6-9	9-12	12-15	15-18	6-9	9-12	12-15	15-18
n	42	51	48	44	48	46	48	48
Age (years)	7.2 (0.9)	10.1 (1.0)	12.0 (1.0)	15.7 (1.0)	7.3 (0.9)	10.4 (1.0)	12.8 (1.0)	15.5 (1.1)
Height (cm)	128.3 (10.9)	141.7 (10.8)	159.5 (10.4)	176.6 (7.5)	126.4 (10.4)	144.3 (8.6)	159.3 (8.7)	164.9 (5.4)
Body mass (kg)	27.3 (7.2)	39.6 (9.2)	50.7 (11.5)	66.2 (11.6)	25.8 (6.9)	37.7 (8.3)	49.4 (11.0)	57.7 (7.4)
% white	66.0	79.6	85.4	73.3	65.9	67.4	85.4	77.3

(Data taken from Trost et al, 2000[120])

3.5.1.3 Avon Longitudinal Study of Parents and Children

3.5.1.3.1 Study overview

The ALSPAC[61 72 138-142] is a longitudinal birth cohort study which recruited more than 14,000 pregnant women from Bristol base health districts with estimated delivery dates between April 1991 and December 1992. These women, the children arising from the pregnancy and the women's partners have been followed up since. Detailed data have been collected via questionnaires from pregnancy onwards, and from the age of seven, all children were invited to attend regular research clinics. The overall aim of the ALSPAC was to determine which biological, environmental, social, psychological, and psychosocial factors are associated with the survival and optimal health and development of the foetus, infant and child, and the ways in which causal relationships might vary with the genetic composition of the mother and/or child. The ALSPAC has collected accelerometer-determined measurements of PA at the age 11 and 15 year sweeps in order to measure the levels and patterns of children's activity. The ALSPAC has also conducted a sub-study that collected repeated accelerometer measurements in children for a full calendar year to assess the seasonal and intra-individual variation in PA.

3.5.1.3.2 Accelerometer data collection and processing

Children were asked to wear the ActiGraph 7164 for seven days; a 60 second epoch was selected. Children received their accelerometer at a clinic visit and were asked to return their accelerometer by post after the monitoring period using a pre-paid envelope. Children were asked to complete a timesheet throughout the monitoring period, and those who returned their accelerometer received a certificate and a graph summarising their activity levels for one day that they wore their monitor. The accelerometer data collection protocol for the seasonal sub-study was identical to the main study, except children were asked to wear their accelerometer for seven days in each season during the course of a year. Children were sent their accelerometers for the seasonal measurements.

The ALSPAC used children with at least three days of data lasting at least 600 minutes per day in analyses, and determined non-wear time as at least ten minutes of consecutive zero counts. The study used their own activity intensity count thresholds: MVPA was defined as at least 3,600 cpm[170].

3.5.1.3.3 Study recruitment and consent

At the age 11 and 15 year clinics all children participating in the ALSPAC were asked to take part in wearing an accelerometer. A high study consent rate (93%) was achieved at the age 11 sweep. Children who came to the age 11 ALSPAC clinic were also asked whether they would be willing to take part in one of three unspecified sub-studies. Of those who were willing to take part (n=1,393) and had successfully worn their accelerometer on the first occasion, 548 children were randomly selected for inclusion in the seasonal study.

Mattocks *et al*[138] investigated the power of the main ALSPAC study after data collection. They tested the power to detect a difference of 0.07 SD (p<0.05) in cpm between any two groups using various combinations of minimum wear days and day lengths. The selected wear time threshold (at least three days lasting at least 600 minutes per day) gave reasonable reliability (0.7) and a power of at least 90%.

3.5.1.3.4 Reliable accelerometer data acquisition

At the age 11 sweep, the ALSPAC obtained reliable data (≥ 3 days, ≥ 600 minutes per day) from 85% of consenting children (n=5,595). The sample included approximately equal numbers of boys (n=2,662) and girls (n=2,933). Sample characteristics of children who returned reliable data in the age 11 year sweep of the ALSPAC are summarised in Table 6.

Table 6: Avon Longitudinal Study of Parents and Children subject characteristics across gender for children returning reliable data [median (IQR)]

	All	**Boys**	**Girls**	***p*- value**
n	5595	2662	2933	NS
Age (years)	11.8 (11.6-11.9)	11.7 (11.6-11.9)	11.8 (11.6-11.9)	<0.001
Height (cm)	150.5 (145.7-155.4)	149.6 (144.9-154.6)	151.3 (146.3-156.2)	<0.001
Weight (kg)	41.6 (36.2-49.0)	40.4 (35.6-47.2)	42.8 (37.0-50.4)	<0.001
BMI (kg/m^2)	18.7 (16.6-20.7)	18.5 (6.4-20.4)	19.0 (16.7- 21.1)	<0.001

(Data taken from Mattocks et al, 2008[138])

In the seasonal ALSPAC study, 90%, 86%, 81%, and 78% of consenting children provided reliable accelerometer data in the first, second, third, and fourth seasons respectively. Reliable data in all four seasons was obtained from 70% (n=315) of consenting children.

3.5.1.4 Children's Health and Activity Monitoring Programme in Schools

3.5.1.4.1 Study overview

The CHAMPS UK[123] is the school-based component of a research project exploring the ecological determinants of PA and health in communities and schools within deprived inner-city areas of Stoke-on-Trent in the UK. The overall aim of the CHAMPS UK was to inform the design and implementation of a multi-component 'whole school' approach to increasing PA levels.

3.5.1.4.2 Accelerometer data collection and processing

Children were asked to wear the ActiGraph GT1M accelerometer for seven days; a 60 second epoch was selected. Data collection took place between November 2006 and May 2007. Accelerometers were distributed and returned via school visits. No incentives or reminder methods were stated in the study articles.

The CHAMPS UK required children to have at least two weekdays and at least one weekend day of data to be included in weekday and weekend analyses respectively. The minimum daily wear time required was at least 600 minutes on week days and at least 480 minutes on weekend days. The authors justified the difference in daily wear time threshold due to the shorter mean duration of PA measurement observed on weekend days compared to weekdays[174]. Age-specific thresholds for each PA intensity level were derived from the EE prediction equation developed by Trost *et al*[121].

3.5.1.4.3 Study recruitment and consent

The CHAMPS UK used a representative sample of nine primary schools and two secondary schools located in Stoke on Trent, UK. Computerised randomisation was used to select pupils from the register of each school in order to obtain a representative random sample of children living in Stoke on Trent. Consent was obtained from 610 out of 913 invited children (67%).

The CHAMPS UK study based their sample calculation on the power to detect differences of 55 cpm, assuming an effect size of 0.35 and using a within cluster (school) population of 35 (for logistical reasons related to delivery and evaluation), an intraclass correlation coefficient (ICC) of 0.027 (which they estimated from pilot data from ten schools), a type I error probability of 0.05, and a power of 0.8, which calculated that a total of 16 clusters (8 intervention and eight control) would be required[123]. The authors reported that a difference of 55 cpm would be biologically meaningful for a ten year old as this would equate to approximately 20 minutes of MVPA based on age specific thresholds[121].

3.5.1.4.4 Reliable accelerometer data acquisition

The CHAMPS UK study obtained reliable weekday data (≥ 2 days, ≥ 600 minutes per day) from 83% of consenting children, and reliable weekend data (≥ 1 day, ≥ 480 minutes per day) from 66% of consenting children. The mean (SD) age of the sample was 10.4 (±3.7) years, and the sample consisted of equal proportions of girls and boys.

3.5.1.5 Child Heart and Health Study

3.5.1.5.1 Study overview

The CHASE[64] study is a large scale study of primary school children from London, Birmingham, and Leicester in the UK which was designed to investigate the health of white, European, South Asian, and Black African Caribbean children.

3.5.1.5.2 Accelerometer data collection and processing

Children were asked to wear the ActiGraph GT1M accelerometer for seven days between January 2006 and February 2007; a five second epoch was selected. Parents and children were invited to a communal building to have a range of physical measurements taken and to also receive their accelerometer. They were also asked to return to this building after the monitoring period to return their accelerometer. No incentives or reminder methods were reported in the study articles.

The CHASE required children to have at least one day of data lasting at least 600 minutes to be included in analyses. Non-wear time was defined as at least 20 minutes of consecutive zero counts. The first and last days of data were removed from data analyses. Study articles do not state if, and if so, how they identified EHCV. The CHASE defined SB as less than 100 cpm, LPA as 100 to 1,999 cpm, MPA as 2,000 to 3,999 cpm, and VPA as greater than or equal to 4,000 cpm.

3.5.1.5.3 Study recruitment and consent

The school sampling frame included all state primary schools in London, Birmingham, and Leicester with 15 to 50% of pupils being of White European origin. The study included two separate random samples, each of 100 schools; one sample included schools with a high prevalence (30 to 80%) of South Asian pupils, and the second included schools with a high prevalence (30 to 80%) of African-Caribbean pupils. Depending on the size of the school, one or two classes of year five pupils were invited to participate. The study achieved a 62% consent rate (*n*=2,144).

3.5.1.5.4 Reliable accelerometer data acquisition

The CHASE obtained reliable data (≥ 1 day, ≥ 600 minutes per day) from 97% of consenting children (*n*=2,071). The high proportion of reliable data acquisition is likely to be due to the low wear time threshold used by the study. The study sample was 27.1% white, 23.9% South Asian, 29.3% Black-African Caribbean, and 19.7% of children were from other ethnic groups. The mean age of the sample was 9.9 years and 52% were girls.

3.5.1.6 European Youth Heart Study

3.5.1.6.1 Study overview

The EYHS[156-159] is an international cohort study investigating the personal, environmental, and lifestyle factors that influence cardiovascular disease risk factors in children. Six countries (Denmark, Norway, Estonia, Portugal, Iceland and Spain) currently participate.

3.5.1.6.2 Accelerometer data collection and processing

Children were asked to wear the ActiGraph 7164 accelerometer for four days (including both weekend days); a 60 second epoch was selected. Accelerometers were distributed and returned via school visits. No incentives or reminder methods were reported in any study articles. The date of data collection was not stated.

The EYHS used a wear time threshold of at least three days lasting at least 600 minutes per day to determine which children were included in analyses. Non-wear was defined as ten or more minutes of consecutive zero counts. Study articles do not state if, and if so, how they identified EHCV. The EYHS used age-specific activity intensity count thresholds[121].

3.5.1.6.3 Study recruitment and consent

Subjects were recruited from a minimum of 20 schools from local authority lists in Odense (Denmark), Madeira (Portugal), Tartu (Estonia), and Oslo (Norway). Children from these schools were randomly selected using a two stage cluster sampling method. The primary sampling unit was the schools and the secondary units were the school registers.

The EYHS based their sample size calculation on the comparison of two independent groups of equal size using a two-tailed test ($1-\beta=0.80$; two-tailed $\alpha=0.05$). At each study location 200 children within each of the four age and gender groups (total *n*=800 per country) gave an acceptable level of power for the projected analyses. A total of 200 children gave the EYHS the ability to detect subgroup differences of 50 cpm using a two-tailed test. As cluster (school) sampling was used, a design effect of 1.25 was incorporated, giving a final target sample of 250 children per age and gender group in each of the four countries. However, their sample size calculation did not take into account losses to follow up due to non-consent or missing data from non-return of reliable accelerometer data. Although over 4,000 children were invited to participate in the EYHS, only 70% consented, of whom 75% returned reliable accelerometer data: the final sample size was 2,185, almost half that specified in the sample size calculation.

3.5.1.6.4 Reliable accelerometer data acquisition

A total of 2,185 (75%) consenting children provided reliable accelerometer data (≥ 3 days, ≥ 600 minutes per day). The mean (SD) age of participants was 9.7 (±0.4) and 15.4 (±0.5) years for boys, and 9.6 (±0.4) and 15.4 (±0.6) years for girls.

3.5.1.7 Family Lifestyle, Activity, Movement and Eating Study

3.5.1.7.1 Study overview

The FLAME study[113] is a longitudinal birth cohort study in New Zealand that followed 240 families with three year old children over a four year period until their children turned seven to determine the lifestyle factors associated with childhood obesity.

3.5.1.7.2 Accelerometer data collection and processing

Children were asked to wear the Mini Mitter Actical accelerometer for five days. Participants were measured annually at three, four, and five years between 2004 and 2007. The sampling epoch used was not reported in any articles. Children received their accelerometer at a clinic visit and were asked to return their accelerometer at the clinic after the monitoring period. No incentives or reminder methods were reported in any study articles, although parents were asked to complete a PAQ regarding their child's PA and SB.

The FLAME study used children with at least three days of accelerometer data in analyses. Daily wear time was based on parental reports of the time the children put on, and took off their monitors. Study articles did not state the methods used to identify periods of non-wear or EHCV. MVPA was determined using the 0.04 kcal/kg/minute threshold provided by Actical which corresponds to the moderate cut off (20 ml/kg/minute or 715 counts/15 seconds) developed by Pfeiffer *et al*[168].

3.5.1.7.3 Study recruitment and consent

The FLAME study recruited children born in Dunedin, New Zealand, at the Queen Mary Unit between 19th July 2001 and 14th July 2002 just before their third birthday. A total of 413 children were eligible for the study, of which consent was obtained from 244 (59%).

3.5.1.7.4 Reliable accelerometer data acquisition

The FLAME study obtained reliable data (≥ 3 days) from 85% (*n*=208) of children at three years, 76% (*n*=180) of children at four years, and 83% (*n*=186) of children at five years. The retention of participants was high, with 97% of the original sample participating at four years and 92% of children participating at five years. The sample consisted of 319 (56%) boys and 255 (44%) girls. A high proportion of the sample were white (87%), 10.8% were Maori, and 3.7% were Pacific Islanders.

3.5.1.8 Iowa Bone Development Study

3.5.1.8.1 Study overview

The Iowa Bone Development Study[17 124-128] is a longitudinal study in the USA that investigates the association of dietary, genetic, and PA factors with bone growth.

3.5.1.8.2 Accelerometer data collection and processing

Children were asked to wear the ActiGraph 7164 accelerometer for four days (including one weekend day) between September 1995 and November 1995; a 60 second epoch was selected. Children received their accelerometer in the post after their parents gave consent at a clinic visit. Accelerometers were also returned by USA mail. Parents were instructed to complete a short data recording sheet stating the time the accelerometer was put on and taken off.

The study used children with at least two days of data lasting at least 480 minutes per day in analyses. Study articles did not state the methods used to identify periods of non-wear time and EHCV. The study investigated the amount of daily time children spend in VPA (defined as 2,972 counts or higher). For locomotive movement in children this threshold is equivalent to six METs[173].

3.5.1.8.3 Study recruitment and consent

Participants of the Iowa Bone Development study were already participants of the Iowa Fluoride Study, a longitudinal study of fluoride intake and dental fluorosis. Participants in this study were recruited from eight Iowa hospitals between 1992 and 1995. A total of 368 children participated in the accelerometer study. The mean (SD) age of participants was 5.10 (±0.39) years for boys, and 5.26 (±0.39) years for girls.

3.5.1.8.4 Reliable accelerometer data acquisition

The Iowa bone Development Study obtained reliable accelerometer data (≥ 2 days, ≥ 480 minutes per day) from 87% of participating children.

3.5.1.9 Child, Parent and Health: Lifestyle and Genetic Constitution

3.5.1.9.1 Study overview

The KOALA[160] is a cross-sectional birth cohort study in the Netherlands. The main aim of the study was to identify factors that influence the clinical expression of atopic disease and overweight.

3.5.1.9.2 Accelerometer data collection and processing

Children were asked to wear ActiGraph 7164 accelerometer for five days; a 15 second epoch was selected. Parents and children were invited to a communal building to have a range of physical measurements taken and to receive their accelerometer. They were also asked to return to this building after the monitoring period to return their accelerometer. No incentives or reminder methods were reported in any study articles. The date of data collection was also not stated.

The study used children with at least three week days and at least one weekend day of data lasting at least 600 minutes per day in analyses. Study articles did not state the methods used to determined non-wear time or EHCV. The KOALA study defined SB as less than 363 counts/15 seconds, LPA as 364 to 811 counts/15 seconds, MPA as 812 to 1,234 counts/15 seconds, and VPA as greater than 1,234 counts/15 seconds[175].

3.5.1.9.3 Study recruitment and consent

The study consisted of two recruitment groups, women with ‘alternative’ and ‘conventional’ lifestyles. Healthy pregnant women with conventional lifestyles were recruited from an on-going study on pregnancy related pelvic girdle pain. In total, 2,359 pregnant women were included. The selection procedure of the 929 children who were invited to participate in the KOALA accelerometer study was not reported. Consent was obtained for 363 (39%) children.

3.5.1.9.4 Reliable accelerometer data acquisition

The KOALA study obtained reliable data (≥ 4 days, ≥ 600 minutes per day) from 84% of consenting children. The mean age of the sample was 4.9 years, and the sample consisted of equal amounts of boys and girls.

3.5.1.10 National Institute of Child Health and Human Development Study of Early Child Care and Youth Development

3.5.1.10.1 Study overview

The NICHD study[129] is a longitudinal birth cohort study of children from ten geographic locations in the USA. The overall aim of the NICHD Study was to investigate how differences in child care experiences relate to children’s social, emotional, intellectual, and language development, and also to their physical growth and health.

3.5.1.10.2 Accelerometer data collection and processing

Children were asked to wear the ActiGraph accelerometer (CSA model) for seven days; a 60 second epoch was selected. Research staff distributed accelerometers at subjects’ homes: the return method was not stated. No incentives or reminder methods were reported in any study articles. Data was collected in 2000, 2002, 2003 and 2007 when the children were aged 9, 11, 12, and 15 years respectively.

The study used children with at least three days of accelerometer data in analyses. Nader *et al*[129] determined wear time independently for each child based on the first non-zero count after 05:00 until one of the following criteria was met: 60 consecutive zero counts after 21:00, 30 consecutive zero counts after 22:00, or the last non-zero count before midnight. Study articles did not state the methods used to identify non-wear time or EHCV. The NICHD study used age-specific activity intensity thresholds[173].

3.5.1.10.3 Study recruitment and consent

Study participants were recruited in 1991 from designated community hospitals at ten university based data collection sites across the USA. Consent rate was 80% at the age 9 year sweep, 82% at 11 years, 71% at 12 years, and 69% at 15 years. Nader *et al*[129] provided a detailed flow chart reporting how many children consented, how many children dropped out subsequent to consenting, and how many children provided reliable data.

3.5.1.10.4 Reliable accelerometer data acquisition

The NICHD study obtained reliable data (≥ 3 days) from 95% of consenting 9 year olds, 96% of consenting 11 year olds, 93% of consenting 12 year olds, and 87% of consenting 15 years olds. A total of 1,032 children provided reliable accelerometer for at least one of the four sweeps (9, 11, 12, and 15 years). The sample consisted of almost equal proportions of boys and girls, 76.6% were white, and 24.5% lived in low income families.

3.5.1.11 National Health and Nutrition Survey

3.5.1.11.1 Study overview

The NHANES[130] is a longitudinal study designed to assess the health and nutritional status of adults and children living in the USA. Accelerometer data was first collected in the NHANES during 2003 to 2004. The NHANES were the first study to provide objective measures of PA for the USA population.

3.5.1.11.2 Accelerometer data collection and processing

Children were asked to wear the ActiGraph 7164 accelerometer for seven days using during 2003 to 2004; a 60 second epoch was selected. The NHANES distributed accelerometers at local mobile examination centres and asked subjects to return them by post. No incentives or reminder methods were reported in the study articles.

The NHANES used children with at least four days of data lasting at least 600 minutes per day in analyses. They defined non-wear time as at least 60 minutes of consecutive zero counts, with an allowance for one to two minutes of activity counts between 0 and 100. Study articles do not state if, and if so, how they identified EHCV. Age-specific PA intensity count thresholds were used[121].

3.5.1.11.3 Study recruitment and consent

The NHANES sample was selected to represent the USA population of all ages, with over sampling of those who were 60 years and older, African American, or Hispanic. The NHANES population was selected with a complex, multistage probability sampling design. Consent rate was 60% for the total NHANES sample (consent for children was not reported).

3.5.1.11.4 Reliable accelerometer data acquisition

The NHANES obtained reliable data (≥ 4 days, ≥ 600 minutes per day) from 70.9% (n=309) and 69.3% (n=288) of 6 to 11 year old boys and girls respectively, and from 62.1% (n=570) and 62.0% (n=611) of 12 to 19 year old boys and girls respectively.

3.5.1.12 Personal and Environmental Associations with Children's Health

3.5.1.12.1 Study overview

The PEACH project[62 145-148] is a longitudinal study designed to investigate the environmental and personal determinants of PA, eating behaviours, and obesity in UK children as they transition from the final year of primary school (aged 10 to 11 years) to the first year of secondary school (aged 11 to 12 years).

3.5.1.12.2 Accelerometer data collection and reduction

Children were asked to wear the ActiGraph GT1M accelerometer for seven consecutive days between September 2006 and July 2008; a ten second epoch was selected. Children received and returned their accelerometer at school, and all children that successfully returned their accelerometer received a certificate and small toy.

The PEACH study used the MAHUffe software (http://www.mrc-epid.cam.ac.uk/Research/PA/Downloads.html) to process their accelerometer data. The articles don't state the minimum number of wear days required by each child to be included in analyses, but at least 480 minutes per day on weekdays were required. Non-wear time was defined as at least ten minutes of consecutive zero counts. Study articles do not state if, and if so, how they identified EHCV.

3.5.1.12.3 Study recruitment and consent

Subjects were recruited from 23 schools in Bristol, UK. These primary schools were selected as they had the highest transition rates (>40%) to one of eight urban state funded secondary schools selected on the basis of the Index of Multiple Deprivation and geographic location to represent Bristol. If a school agreed to participate, all year six children were invited to take part in the study. Consent was obtained from 1,340 out of 1,899 invited children (71%).

3.5.1.12.4 Reliable accelerometer data acquisition

The PEACH study obtained reliable weekday (≥ 1 days, ≥ 480 minutes per day) data from 92% (*n*=1,229) of consenting children, and reliable weekend (definition not stated) data from 70% (*n*=911) of consenting children. The mean (SD) age of the accelerometer sample was 10.95 (±0.41) years.

3.5.1.13 Physical Exercise and Appetite in Children Study

3.5.1.13.1 Study overview

The PEACHES[149 150] is a longitudinal study in London, UK investigating the associations between eating behaviours, PA, and weight gain during childhood.

3.5.1.13.2 Accelerometer data collection and processing

Children were asked to wear the ActiGraph GT1M accelerometer for five consecutive days (including two weekend days); a 60 second epoch was selected. Accelerometers were distributed and returned via school visits. Children who wore their accelerometer every day were given a ticket for a prize draw to win a £25 gift voucher, and girls and boys competed against each other to win a £5 gift for the gender team with the highest amount of reliable accelerometer data.

The PEACHES used the MAHUffe software (http://www.mrc-epid.cam.ac.uk/Research/PA/Downloads.html) to process their accelerometer data. The study used children with at least three days (including at least one weekend day) of data lasting at least 600 minutes per day in analyses. Non-wear time was defined as at least ten minutes of consecutive zero counts. Study articles do not state if, and if so, how they identified EHCV. The PEACHES defined SB as less than 100 cpm, LPA as 100 to 1,999 cpm, MPA as 2,000 to 3,999 cpm, VPA as 4,000 to 6,999 cpm, and very VPA as greater than 7,000 cpm.

3.5.1.13.3 Study recruitment and consent

Subjects were recruited from five schools in London, UK. Information on how and why these schools were chosen was not reported. Invitations were sent to parents of all children in years three and four in all five schools. A total of 345 (65%) children took part in the activity monitoring.

3.5.1.13.4 Reliable accelerometer data acquisition

The PEACHES obtained reliable data (≥ 3 days, ≥ 600 minutes per day) from 88% of consenting children (*n*=301). The mean (SD) age of the sample was 8.6 (±0.4) years, and the sample included 155 boys and 146 girls. The sample consisted of 46% white children, and 54% non-white children.

3.5.1.14 The Eating and Activity Survey Trial

3.5.1.14.1 Study overview

Project EAST[132] aimed to develop reliable and valid nutrition and PA assessment questionnaires for use in children. The questionnaires included six questions on PA that asked about weekly PA over the past year and distinguished between the school year and summer holidays. Accelerometers were used to validate the questionnaire.

3.5.1.14.2 Accelerometer data collection and processing

Children were asked to wear the ActiGraph 7164 accelerometer for seven consecutive days between January 2001 and May 2001; a 60 second epoch was selected. Distribution and return of accelerometers was achieved via home visits. Children who completed all study measurements (two questionnaires at two time periods, accelerometer measurements, height and weight measurement, and three 24 hour dietary recall questionnaires) were given a $50 gift card from a local shopping centre. Children were also given a cinema pass if they returned their accelerometer on time. Research staff visited the school twice to remind children to wear the accelerometers at all times and return them one week later.

Project EAST assessed compliance in wearing the accelerometer according to varying numbers of wear days so a wear time threshold was not needed. Non-wear was defined as 180 minutes or more of consecutive zero counts in a single day between 08:00 to 21:00 on weekdays, and between 12:00 to 21:00 on weekend days.

3.5.1.14.3 Study recruitment and consent

Subjects were recruited from one urban middle school (grades six to eight) in Minneapolis, USA. The school was selected due to its ethnic diversity (the population was 48% White Non-Hispanic, 3% Native American, 5% Asian, 40% Black Non-Hispanic, and 4% Hispanic) and previous history of successfully conducting research. The research staff visited 28 (out of 35) classes to invite all children to participate; seven classes chose not to participate. Consent was obtained from 316 (52.9%) students.

3.5.1.14.4 Reliable accelerometer data acquisition

Project EAST obtained seven days of reliable data from 50% of consenting children (*n*=128). Reliable data acquisition was low due to the stringent wear time threshold; however, only 13.7% of consenting children did not wear their accelerometer for at least four days. The age range of the sample was 11 to 14 years.

3.5.1.15 Sport, PA and Eating Behaviour: Environmental Determinants in Young People

3.5.1.15.1 Study overview

The SPEEDY study[151 152] is a large population based study that was established to investigate the factors associated with PA levels and dietary behaviour.

3.5.1.15.2 Accelerometer data collection and reduction

Children were asked to wear the ActiGraph GT1M accelerometer for seven consecutive days; a five second epoch was selected. Data collection took place between April 2007 and July 2007. Children received their accelerometer at school and returned it after the monitoring period to research staff returning to the school. Children were asked to complete a timesheet throughout their monitoring period and parents received a reminder letter two days before they were due to return their accelerometer.

The SPEEDY study used the MAHUffe software (http://www.mrc-epid.cam.ac.uk/Research/PA/Downloads.html) to process their accelerometer data. The study used children with at least three days of data lasting at least 500 minutes per day in analyses. The first day of data was removed from all files and non-wear time was defined as an interval of at least ten minutes of consecutive zero counts. Study articles do not state if, and if so, how they identified EHCV. The SPEEDY study defined MVPA as greater than 2,000 cpm[176].

3.5.1.15.3 Study recruitment and consent

Schools in Norfolk, South East England were sampled purposively to achieve heterogeneity in location. If the school agreed to participate all year five children were invited to participate in the study. An average of 168 children was recruited into the study each week with an aim of recruiting 2,000 children over a 12 week period. A total of 101 out of 157 (64%) schools agreed to participate in the study. Of the 3,619 students invited to participate, consent was obtained from 2,064 (52.9%). Van Sluijs *et al*[152] provided a detailed flow chart documenting the recruitment of schools and children into the SPEEDY study.

3.5.1.15.4 Reliable accelerometer data acquisition

The SPEEDY study obtained reliable data (≥ 3 days, ≥ 500 minutes per day) from 91% of consenting children. The mean age of the sample was 10.3 (±0.3) years, and the sample consisted of 926 (44.9%) boys and 253 (55.1%) girls.

3.5.1.16 Trial of Activity for Adolescent Girls

3.5.1.16.1 Study overview

The TAAG[133-137] was a multicentre randomised trial designed to test an intervention to reduce the age related decline in MVPA in middle school girls living in the USA. A two year intervention was implemented between autumn and spring 2005 which targeted schools, community agencies, and girls to increase opportunities, support, and incentives for PA participation.

3.5.1.16.2 Accelerometer data collection and reduction

Children were asked to wear the ActiGraph 7164 accelerometer for seven consecutive days; a 30 second epoch was selected. Accelerometer data collection took place in spring 2003, spring 2005, and spring 2006. Children received their accelerometer at school and returned it after the monitoring period to research staff returning to the school. No incentives or reminder methods were reported in the study articles.

Accelerometers were initialised to start collecting data at 05:00 on the day after they were distributed; thus, data for six complete days were available for analyses. The TAAG study replaced missing accelerometer data within a girls six day record via imputation. Girls were included in analyses if they had at least one full day of data lasting at least 360 minutes. Non-wear time was defined as at least 20 minutes of consecutive zero counts. Study articles do not state if, and if so, how they identified EHCV. TAAG defined MVPA as greater than 1,500 counts/30 seconds, which represented approximately 4.6 METs, which separates slow (<4.6 METs) and brisk (≥ 4.6 METs) walking[177].

3.5.1.16.3 Study recruitment and consent

Public middle schools from six geographically diverse areas of the USA (Arizona, California, Louisiana, Maryland, Minnesota and South Carolina) were eligible to participate. TAAG schools represented the demographic and socioeconomic make up of their school districts, with preference given to schools with greater ethnic and socioeconomic diversity. A total of 68 schools were invited to participate, of which, 41 agreed, and the 36 most conveniently accessed from the university based research centres were selected. All 36 schools participated in the grade six measurements during spring 2003 and in the grade eight measurements during spring 2005. However, only 34 schools participated in the grade eight measurements in spring 2006. During spring 2003, 60 girls per school were randomly chosen: consent was obtained from 1,721 out of 2,160 (79.7%) eligible girls. During spring 2005, 3,504 out of 4,123 (85.0%) eligible girls consented to participate in the study, and in spring 2006, 3,502 out of 3,915 (89.5%) girls consented. Sample size calculations were detailed for the TAAG study. In contrast to the EYHS[158], they allowed for a 15% drop out in their sample size calculations.

3.5.1.16.4 Reliable accelerometer data acquisition

The TAAG study obtained a high (spring 2003: 93.1%; spring 2005: 88.0%; and spring 2006: 88.0%) proportion of reliable data from consenting children. This is likely due to the low wear time threshold of at least one day lasting at least six hours per day.

Participants were 11 to 12 years old in spring 2003, and 13 to 14 years old in spring 2005 and spring 2006. The spring 2003 sample were 46.1% white, 23.5% African-American, 12.3% Hispanic, and 18.0% of children were from other ethnicities. The spring 2005 sample were 45.0% white, 22.0% African-American, 21.1% Hispanic, and 11.9% of children were from other ethnicities. The spring 2006 sample were 46.4% white, 17.6% African-American, 22.6% Hispanic, and 13.4% of children were from other ethnicities.

3.5.1.17 Key points

- Relatively few large scale accelerometer studies in children have been conducted worldwide (*n*=23 between 1995 and 2009); sample sizes ranged from 255 to 5,595 and nearly all included boys and girls.
- The ActiGraph is the most commonly used accelerometer, and a 60 second epoch was most commonly selected. Studies are therefore using reliable and validated tools but may not capture the sporadic nature of children's PA.
- Accelerometers were most often distributed and returned through school visits which may be the most feasible method in children.

- Studies most often asked children to wear their accelerometer for seven days in order to measure all days of the week.
- 65% of studies reported the methods used to identify periods of non-wear and these ranged from 10 to 180 minutes of consecutive zeros.
- 91% of studies reported the minimum number of wear days required from each child to be included in data analyses, and even fewer reported the minimum daily wear time. At least three wear days and at least 600 minutes per day were the most common requirement.
- Study consent rate ranged from 27% to 100%. Reliable accelerometer data acquisition ranged from 50% to 100% and was highly dependent on the wear time threshold defined by the study.

3.5.2 Objective 2: Predictors of consent and reliable data acquisition

3.5.2.1 Overview of articles

Fourteen articles[17 64 123 130 132 138 145 149 152 160 178-181] (Table 7) were identified that investigated predictors of consent and/or reliable accelerometer data acquisition in children's PA studies using accelerometers. Date of publication ranged from 1992[179] to 2009[64 141 181]. Three articles[64 152 160] investigated differences between consenting and non-consenting children, and 11 articles[17 64 123 130 132 138 145 149 180 181 152] investigated differences between children who did, and did not, return reliable accelerometer data. Eight articles[123 132 138 145 160 178-180] also reported the reasons for data loss that were due to factors such as monitor malfunction and battery failure. Six articles included studies from the UK[64 123 138 145 149 152], six from the USA[17 130 132 179-181], one from Canada[178] and one from the Netherlands[160]. Only one article included a quasi-experimental study[181] and the remainder were cross-sectional. In only two articles[17 149] the date of data collection was not reported, and in the remainder this ranged from 1987[179] to 2008[145].

Table 7: Table summarising papers (*n*=14) investigating the factors associated with study consent and/or reliable accelerometer data acquisition in children's accelerometer-determined physical activity studies

Authors	Year; country	Sample [Size; gender; mean age (±SD)]	Period of data collection	Accelerometer protocol [model; days wear; epoch; reliable data; intensity cut point]	Accelerometer distribution; return methods	Reminder/ incentive methods	Consent rate (%)	Reliable data (%)	Useable data (%)	Data loss reasons	Differences between consenters & non-consenters	Differences between those who do and do not return reliable data
Crocker *et al*[178]	2001; Canada	*n*=79; 33m, 46f; 11.0 (1.4)y	Mar-Jun 2000	Tritac R3D; 7d wear; ≥ 1d	School; school	Reminder calls every evening; staff visited school every morning	NS	84.8	NS	Battery malfunction (*n*=4), monitor software failure (*n*=4), forgot (42d), discomfort (27d), not allowed (74d), aquatics (35d), embarrassed by appearance (11d), travel (5d)	NS	NS
Curtis Ellison *et al*[179]	1992; USA	*n*=103; 3-7y (range)	1987-1989	Caltrac; 5d wear (twice)	Home; clinic or home	NS	NS	82.0	NS	Monitor malfunction (37d), forgot to wear (189d), information on report insufficient (102d), monitor malfunction (73d)	NS	NS
Eijkemans *et al*[160]	2008; Netherlands	*n*=305; 152m, 153f; 4.9 (range 4.1 -5.6)y	2006	ActiGraph GT1M; ≥ 5d wear; 15 sec epoch; ≥ 3d w/d &	Community building; community building	NS	39.1	84.0	NS	Refusal to wear (*n*=3), lost monitor (*n*=1), monitor malfunction	No differences by gender, parental asthma, parent obesity, birth	

Authors	Year; country	Sample [Size; gender; mean age (±SD)]	Period of data collection	Accelerometer protocol [model; days wear; epoch; reliable data; intensity cut point]	Accelerometer distribution; return methods	Reminder/ incentive methods	Consent rate (%)	Reliable data (%)	Useable data (%)	Data loss reasons	Differences between consenters & non-consenters	Differences between those who do and do not return reliable data
				≥ 1d w/e, ≥ 400min/d						(*n*=8)	weight, smoking during pregnancy, parental smoking near child, breastfeeding, educational level of mother, wheezing (*p*=NS)	
Gidlow *et al*[123]	2008; England	*n*=503 250m, 253f; 10.4 (3.7)y	Nov 2006-May 2007	ActiGraph GT1M; 7d wear; 60 sec epoch; ≥ 2d, ≥ 600min/d (w/d) ≥ 1d, ≥ 480min/d (w/e),	School; school	NS	67.0	82.5 (w/d); 66.2 (w/e)	NS	No longer at school (*n*=26), absent on day of data collection (*n*=122)	NS	Girls more likely than boys to provide data ($p<0.05$); No differences by age, BMI ethnicity and deprivation of child ($p>0.05$)
Janz *et al*[17]	2001; USA	*n*=368; 179m, 189f; m: 5.18 (0.39)y, f: 5.26 (0.39)y	NS	ActiGraph 7164; 4d wear inc. 1d w/e; 60 sec epoch; ≥ 4d, ≥ 480min/d	US mail; US mail	NS	NS	87.0	2d: 2.0; 3d: 11.0; 4d: 87.0	NS	NS	No ($p>0.05$) differences by gender
Mattocks *et al*[138]	2008; England	*n*=5595; 2747m, 2848f; 11.77 (0.23)y	2002-2003	ActiGraph 7164; 7d wear; 60 sec epoch;	Research laboratory; UK mail	Certificate & graph showing activity for returning	92.5	84.5	3d: 5.6; 4d: 9.4; 5d: 17.0; 6d: 28.3; 7d: 39.6	Broken or malfunctioning monitor (*n*=171)	NS	Girls more likely than boys, (81% vs. 76%; $p<0.001$), younger ($p<0.001$), lighter ($p<0.001$), & lower

Authors	Year; country	Sample [Size; gender; mean age (±SD)]	Period of data collection	Accelerometer protocol [model; days wear; epoch; reliable data; intensity cut point]	Accelerometer distribution; return methods	Reminder/ incentive methods	Consent rate (%)	Reliable data (%)	Useable data (%)	Data loss reasons	Differences between consenters & non-consenters	Differences between those who do and do not return reliable data
				≥ 3d, ≥ 600min/d		completed timesheet						BMI (p<0.001) children more likely to provide data; No differences in height (p=0.097) & birth weight (p=0.42)
Owen *et al*[64]	2009; England	n=2144; 1029m, 1115f; 9.9 (range 9.2-10.7)y	Jan 2006-Feb 2007	ActiGraph GT1M; 7d wear; 30 sec epoch; ≥ 1d, ≥ 600min/d	School; school	Gift voucher for returning, completed timesheet	62.0	96.6	≥3d: 85.9	NS	No differences in ethnic groups (p=0.11)	No differences in ethnic groups (p=NS)
Page *et al*[145]	2009; England	n=1300; 639m, 661f; 10.95 (0.41)y	Sep 2006-Jul 2008	ActiGraph GT1M; 7d wear; 10 sec epoch; ≥ 480 min/d (w/d)	School; school	Certificate & small toy for returning	70.5	94.5 (w/d); 70.0 (w/e)	NS	Absent from school (n=33), non-returned or broken monitors (n=23)	NS	*Weekdays:* No differences in age, deprivation, BMI & pubertal status (p>0.05); Data receipt less likely (p=0.011) from those with higher area independent mobility *Weekends:* No difference in age, IMD, BMI, pubertal status (p>0.05); Data receipt less likely from children with higher local independent mobility (p=0.003), area independent mobility (p=0.001) & living in less deprived neighbourhoods (p=0.001)
Purslow	2008;	n=345;	NS	ActiGraph	School;	Entered prize	65.0	88.0	NS	NS	NS	Data receipt more

Authors	Year; country	Sample [Size; gender; mean age (±SD)]	Period of data collection	Accelerometer protocol [model; days wear; epoch; reliable data; intensity cut point]	Accelerometer distribution; return methods	Reminder/ incentive methods	Consent rate (%)	Reliable data (%)	Useable data (%)	Data loss reasons	Differences between consenters & non-consenters	Differences between those who do and do not return reliable data
et al[149]	England	176m, 169f; 8.31 (0.65)y		GT1M; 5d wear (inc. 2 w/e); 60 sec epoch; ≥ 3d (inc. 1d w/e), ≥ 600 min/d (07:00-19:00)	school	draw to win £25 gift voucher for reliable data, gender reliable data teams- each child in winning team received £5 gift voucher						likely from those with higher PA (cpm: p=0.003; MVPA: p=0.006); No differences by age, gender, BMI, SES or ethnicity (p>0.05)
Sirard *et al*[180]	2008; USA	n=65; 38m, 27f; 16.7 (1.34)y	Aut 2006	ActiGraph GT1M; 7d wear; 30 sec epoch; ≥ 4d, ≥ 600 min/d	School; school	$5 gift card p/d for reliable data, $10 for returning	NS	95.4	0d: 0.0; 1d: 0.0; 2d: 3.1; 3d: 1.5; 4d: 6.2; 5d: 13.9; 6d: 30.8; 7d: 44.6	Insufficient battery (n=44), monitor failure (n=2)	NS	No gender differences (p=0.98) in number of hr worn or with reliable data (p=0.37); 14-15y olds more likely than 18-19y olds (p=0.05) & students receiving free or reduced meals more likely to return data (p=0.02)
Sirard *et al*[181]	2009; USA	n=87; 28m, 59f; *Control sample:* 17 (1.5)y, *Phone sample:* 18 (0.9)y, *Journal sample:* 17 (1.4)y, *Contingent sample:* 16 (1.0)y	Mar -May 2007	ActiGraph 7164; 7d wear; 60 sec epoch; ≥ 4d, ≥ 600 min/d	School; school	*Control:* none; *Phone:* 2 phone calls during week; *Journal:* completed time sheet; *Contingent:* PA graph prior & $5 p/d for reliable data, $10 for	35.0	*Total*: 81.6; *Control:* 70.0; *Phone*: 72.0, *Journal:* 85.0; *Contingent*: 96.0	0-3d: 18.4; 4-6d: 47.1; 7d: 34.5	NS	NS	*Total sample:* No gender or ethnic differences (p>0.05); younger more likely than older to provide data (p=0.0007); no differences in PA (cpm: p=0.69; or activity intensities p=0.16 to 0.97); *Experimental:* Contingent group higher data receipt than all other groups

Authors	Year; country	Sample [Size; gender; mean age (±SD)]	Period of data collection	Accelerometer protocol [model; days wear; epoch; reliable data; intensity cut point]	Accelerometer distribution; return methods	Reminder/ incentive methods	Consent rate (%)	Reliable data (%)	Useable data (%)	Data loss reasons	Differences between consenters & non-consenters	Differences between those who do and do not return reliable data
						returning						(p=0.04)
Troiano *et al*[130]	2008; USA	n=1844; 879m, 899f; *Age 6-11y sample:* m: 8.4 (0.1)y, f : 8.5 (0.1)y; *Age 12-19y sample:* m: 15.3 (0.2)y, f: 15.0 (0.1)y	2003-2004	ActiGraph 7164; 7d wear; 60 sec epoch; ≥ 4d, ≥ 600 min/d	Mobile examination centre; US express mail	NS	68.0 (all ages)	*Age 6-11y:* m: 70.9, f: 69.3; *Age 12-19y:* m: 62.1, f: 62.0	*Age 6-11y (m,f)* 0d : 4.9, 4.7; 1d: 9.4, 6.5; 2d: 6.2, 7.4; 3d: 8.6, 12.1; 4d: 13.3, 11.0; 5d: 12.8, 17.5; 6d: 21.4, 22.2; 7d: 23.4, 18.6 *Age 12-19y (m,f)* 0d: 9.0, 10.2; 1d: 7.4, 8.2; 2d: 10.8, 9.2; 3d: 10.7, 10.3; 4d: 12.1, 14.1; 5d: 15.0, 12.5; 6d: 18.2, 18.6; 7d: 16.8, 16.8	NS	NS	Data receipt lower for adolescents than children (61.1% vs. 70.1%; p=NS) & lower for females compared to males (6-11y: 69.3% vs.70.9%; 12-19y: 62.0% vs. 62.1%; p=NS)

Authors	Year; country	Sample [Size; gender; mean age (±SD)]	Period of data collection	Accelerometer protocol [model; days wear; epoch; reliable data; intensity cut point]	Accelerometer distribution; return methods	Reminder/ incentive methods	Consent rate (%)	Reliable data (%)	Useable data (%)	Data loss reasons	Differences between consenters & non-consenters	Differences between those who do and do not return reliable data
Van Coevering *at al*[132]	2005; USA	*n* =255; 106m, 146f; 11-14y (range)	Jan 2001-May 2001	ActiGraph 7164; 7d wear; 60 sec epoch; ≥ 7d, *non-wear:* ≥ 180min zero counts (between 08:00-21:00)	Home; home	Staff visited school twice during week, $5 if returned on correct date	89.2	50.2	0d: 2.7; 1d: 3.1; 2d: 2.4; 3d: 5.5; 4d: 11.4; 5d: 8.2; 6d: 16.5; 7d: 50.2	Unable to download (*n*=27), returned after 1d (*n*=1), lost (*n*=1), transferred to another school (*n*=1)	NS	Data receipt higher for overweight subjects than non-overweight ($p<0.006$); No gender ($p=0.54$), ethnic ($p=0.29$) or school grade differences ($p=0.10$)
Van Sluijs *et al*[152]	2008; England	*n*=2064; 926m, 1138f; 10.3 (0.3)y	Apr -Jul 2007	ActiGraph GT1M; 7d wear; 5 sec epoch; ≥ 3d, ≥ 500 min/d	School; school	Letter 2d prior to return, completed timesheet	57	90.5	NS	NS	Girls more likely than boys to participate ($p<0.05$)	Girls less likely than boys to provide data ($p<0.05$); No differences in BMI, overweight status or parental education ($p>0.05$)

Abbreviations: *n*=sample size; m=males; f=females; y=years; aut=autumn; NS=not specified; Jan=January; Feb=February; Mar=March; Apr=April; Jun=June; Jul=July; Sep=September; Nov=November; d=days; min=minutes; sec=seconds; cpm=counts per minute; SB=sedentary behaviour; w/d=weekday; w/e=weekend; PA=physical activity; IMD=index of multiple deprivation

3.5.2.2 Analytical aim

The primary aim of six articles[178 179 181 132 138 180] was to understand the feasibility of using accelerometers in large scale studies of childhood PA. Data for all other articles were collected for another purpose, and the article evaluated differences between consenters and non-consenters, and/or between children who did and did not return reliable data, in addition to the primary statistical analysis. For example, Eijkemans *et al*[160] evaluated whether wheezing in the first two years of life resulted in lower PA levels at age five years. However, to confirm that there was no bias in their findings, they investigated differences between children who did and did not return reliable data. Janz *et al*[17] evaluated the associations between PA and measures of bone mineral content, density, and total area in children participating in the Iowa Bone Development Study. They also reported gender differences between children who did and did not reliable data. The primary aim of Purslow *et al's*[149] article was to evaluate associations between SB, PA, and weight in pre-adolescent children participating in the PEACHES study. They also investigated differences in gender, body mass index (BMI), SES, ethnicity and PA between children who did and did not return reliable accelerometer data.

3.5.2.3 Recruitment and sampling procedures

All of the included articles (*n*=14[17 64 123 130 132 138 141 145 149 160 178-181]) reported how their study participants were recruited. Sampling procedures were reported in only six studies[64 123 132 138 145 181]. The majority of articles (*n*=10[17 64 123 130 132 138 141 145 149 160]) analysed data from subjects recruited to take part in large scale studies (detailed in section 3.5.1), and eight studies[64 123 141 145 149 178 180 181] recruited children through schools.

3.5.2.4 Sample size calculations

Sample size calculations were reported in two articles[123 138]. Both of these articles included subjects recruited to take part in large scale studies (section 3.5.1).

3.5.2.5 Accelerometer measurement protocol

Accelerometer model

The ActiGraph accelerometer was used in twelve studies (five using the 7164 model[17 130 132 138 181] and seven using the GT1M model[64 123 145 149 152 160 180]), one used the Caltrac[179] and the remaining article the Tritac R3D[178] accelerometer.

Epoch

The epoch lengths selected by the included studies were 5[152], 10[145], 15[160], 30[64 180] and 60[17 123 130 132 138 149 181] seconds. Seven studies[64 123 145 149 152 160 180] used the ActiGraph GT1M so they were able to select a shorter epoch sampling period whilst still being able to measure for a sufficient number of days.

Accelerometer wear protocol

Subjects were asked to wear their accelerometer for between four[17] and seven days[64 123 130 132 138 145 152 178 180 181], with most (*n*=10; 71%) articles requiring seven days wear.

Accelerometer data processing

Eleven articles reported the criteria used to determine whether the accelerometer was worn for a sufficient amount time each day: periods of at least 400[160], 480[17 145], 500[152]or 600[64 130 138 149 180 181] minutes per day were used to determine the minimum daily wear time. Gidlow *et al*[123] required at least 600 minutes on weekdays and at least 480 minutes on weekend days.

The minimum number of wear days required by each child to be included analyses was at least one[64 178], three[123 138 149 152], four[17 130 160 180 181] or seven[132] days. At least four days of accelerometer data was the most common (*n*=5[17 130 160 180 181]; 45%) number of wear days required.

3.5.2.6 Predictor variables

A wide range of predictors variables were used to investigate differences between consenting and non-consenting children, and between children that did and did not return reliable data. The most common factors investigated were gender (*n*=10[17 123 130 132 138 149 152 160 180 181]), age (*n*=7[123 130 138 145 149 180 181]) and BMI (*n*=6[123 132 138 145 149 152]). Other common variables investigated were: ethnicity, height, weight, birth weight, parental education, and SES. Two articles[26 179] did not investigate predictors of consent or reliable data acquisition but reported the reasons for accelerometer data loss.

3.5.2.7 Sample characteristics

Study sample sizes ranged from 65[180] to 5,595[138]. The majority of studies (*n*=7[64 123 138 145 149 152 178]) included children (6 to 12 years). Only two[17 160] included samples of preschool children (two to five years), two[180 181] included only adolescents (13 to 18 years), two[130 132] included children and adolescents (6 to18 years), and two included preschool children and children (2 to12 years)[17 179]. All studies included boys and girls.

Child ethnicity was reported in only nine[17 64 123 130 132 149 152 180 181](50%) articles, and in these the participants were predominantly white (28%[181]to 96.7%[60]). Studies were more likely to report a measure of weight status than ethnicity, with eight studies[17 123 130 132 138 145 149 152] reporting the weight or BMI of their study sample.

3.5.2.8 Statistical methods

The statistical test(s) used to investigate differences in predictor variables between groups was reported in nine[17 123 130 132 138 152 160 180 181] out of twelve (75%) articles. Articles used either chi-squared tests to determine differences between categorical variables, or two samples *t*-tests to determine differences between continuous variables. In only three articles[17 64 160] was the data reported to be tested for normality. Three articles[64 145 149] did not report which statistical tests they used to determine differences between consenting and non-consenting children, or between children who did and did not return reliable data.

3.5.2.9 Main findings

Summary of articles

Ten articles[64 123 130 132 138 145 149 152 160 181] provided information on study consent rate which ranged from 35.0%[181] to 92.5%[138]. All of the included articles stated the proportion of children that returned reliable accelerometer data, which ranged from 50.2%[132] to 96.6%[64] depending on the wear time threshold and the age of subjects. The most common accelerometer distribution method was via school visits (n=8)[64 123 145 149 152 178 180 181]. Two studies[132 179] distributed their accelerometers by visiting subjects at their home, three studies required subjects to visit a community building[160], research laboratory[138] or examination centre[130] to receive their accelerometers, and one study[17] posted the accelerometers to subjects via USA mail. All studies[64 123 145 149 152 178 180 181] that distributed accelerometers via school visits collected the accelerometers at school after the monitoring period. Three studies[17 130 138] required children to return their accelerometers after the monitoring period via postal methods. Staff collected the accelerometers back at the subject's home in two studies[132 179], and one study required children to re-visit to the community building[160] to return their accelerometer. Reminder methods or incentives to encourage the return of reliable accelerometer data were used in nearly all studies (*n*=9[64 132 138 145 149 152 178 180 181]). The reminder methods employed included the completion of PA timesheets, reminder calls, reminder letters, and staff visits to the schools throughout the monitoring period. Studies offered a number of incentives to encourage children to wear and return their accelerometers including certificates, toy prizes, money, vouchers, and graphs showing the child's activity throughout the monitoring week.

The main findings of all articles included in this review to address objective two will now be described individually in chronological order.

Curtis Ellison et al (1992)

Curtis Ellison *et al*[179] evaluated the feasibility and costs of PA monitoring during a seven day monitoring period in 103 children aged three to seven years using the Caltrac accelerometer. Researchers visited participant's homes to distribute accelerometers, and parents returned them by visiting the study office or by a staff member picking the accelerometer up from the child's house. Parents were asked to keep a daily log sheet throughout the monitoring period. The authors reviewed a random set of 500 days to assess the reasons for unusable data.

The article did not report the study consent rate, however, reliable accelerometer data (at least one day) was obtained from 82% of consenting children[179]. The monitor malfunctioned on average once every 45 days. An additional 189 days of accelerometer monitoring were lost due to the parent forgetting to attach the monitor to their child. Data collection took place between 1987 and 1989. The Caltrac is one of the earliest manufactured accelerometers, and as a result, it is likely that developments in accelerometer design would mean these findings are not applicable to current models.

Crocker et al (2001)

In a similar article, Crocker *et al*[178] evaluated the feasibility of the Tritac R3D accelerometer over a seven day monitoring period in 79 children aged 9 to 13 years. Accelerometers were distributed and returned in a school setting. The article investigated reliable accelerometer data acquisition, and reported any accelerometer hardware or software problems. Children were interviewed after the monitoring period to determine any problems encountered whilst wearing the accelerometer. Children received home phone calls every evening throughout the monitoring period, and a member of staff visited the school every morning to remind children to wear their accelerometers and to answer any relevant questions.

Consent rate was not reported, but reliable accelerometer data (at least one day) was obtained from 85% of consenting children[178]. Although reliable data acquisition was high, there were problems reported with the accelerometers including the children forgetting to wear the monitor, physical discomfort, being embarrassed by the appearance of the monitors, and not being allowed to wear it during organised sports or water sports.

Neither Curtis Ellison *et al*[179] or Crocker *et al*[178] evaluated differences between children who did and did not return reliable data despite both articles reporting a range of subject characteristics (e.g. gender, age, child ethnicity, parental education) that could have been investigated. As a result, both studies can only apply their findings to their study population of school aged children. However, Curtis-Ellison *et al*[179] apply their findings to other populations, reporting that Caltrac accelerometers may be less expensive to use than other methods in large scale studies. This cannot be deduced from the current study as additional costs associated with large scale accelerometer studies were not considered. Additional costs include the extra staff required to charge, programme, distribute and download data from accelerometers, the increased reminder methods required to ensure timely return of monitors, accelerometer maintenance costs, and costs associated with the purchase of data processing software that is essential when cleaning and analysing large volumes of accelerometer data.

Janz et al (2001)

Janz *et al's*[17] article included 368 children aged between four and six years participating in the Iowa Bone Development Study. The authors investigated the internal validity of the study by looking at the representativeness of children returning reliable data compared to those who did not return reliable data. In contrast to other studies[138 123 130], they found no significant differences by gender in the number of reliable days of data provided by children or the number of minutes the monitor was worn each day ($p>0.05$).

Van Coevering et al (2005)

Van Coevering *et al*[132] investigated the feasibility of using accelerometers to measure PA in young children participating in Project EAST, and in particular, the extent to which they could collect reliable accelerometer data (at least seven days wear without 180 minutes of consecutive zero counts between 08:00 and 21:00). The authors found no gender, ethnic, or school grade differences between children who did and did not return reliable accelerometer data ($p=0.54$, $p=0.29$ and $p=0.10$ respectively). However, overweight children were more likely to return reliable data than non-overweight children (65.6% vs. 45.7%; $p=0.006$).

The authors concluded that wearing an accelerometer was an acceptable method to measure PA in middle school children as evidenced by the low numbers ($n=5$) of students who dropped out of the study because they did not want to wear the monitors. However, they reported that because only 50% of consenting children had complete data for all seven days, reliable data acquisition may be a problem in this age group. However, they did not take into account their strict wear time threshold. If Project EAST[132] used a less strict wear time threshold, such as at least three days of accelerometer data, 91.8% (n=234) of consenting children would have returned reliable data. They also report that their findings may lack generalisability to other geographic, ethnic, or socioeconomic groups as their sample were taken from an urban middle school in a large Midwestern city.

Eijkemans et al (2008)

Eijkemans *et al*[160] investigated 305 children participating in the KOALA study. The authors evaluated differences in sample characteristics between children participating in the KOALA study and children that returned reliable data, and they found no major differences in terms of gender, parent obesity, birth weight, smoking during pregnancy, breast feeding, educational level of mother, and wheezing status.

Eijkemans *et al*[160] reported that their low consent rate (39%) was a potential limitation of their study. The authors felt that the low consent rate was because parents had to visit a communal building twice to collect and return the accelerometer. They also suggested that because the invitation letter was strongly focused on PA and overweight, rather than wheezing or asthmatic conditions it was unlikely that bias occurred as a result of a higher response rate from wheezing children.

Gidlow et al (2008)

Gidlow *et al*[123] investigated 503 children participating in the CHAMPS UK study. The authors investigated differences between children who did and did not provide reliable data. Girls were more likely to provide reliable weekday data (63.6% vs. 36.4%; $p<0.001$), and reliable week and weekend data combined (61.2% vs. 38.8%; $p<0.01$) than boys. Differences between all other variables (age, BMI, ethnicity and deprivation quintile) were modest and not significant.

The CHAMPS UK study[123] sample were predominantly white British, and almost half the sample lived in areas within the bottom 20% for national deprivation rankings, which is typical of the sampling area of Stoke on Trent. Although the gender and weight status of the sample were representative of national averages, Gidlow *et al*[123] reported that ethnicity and SES were not representative of the UK, and as a result conclusions cannot be generalised to the national population as a whole. Study findings can only be applied to white British children and those of similar socioeconomic backgrounds.

Mattocks et al (2008)

The ALSPAC[138] found gender differences between children who did (n=5,595) and did not provide reliable data (n=1,564). In agreement with Gidlow *et al*[123], girls were more likely to return reliable data than boys (81% vs. 76%; $p<0.001$). They also found that children who returned reliable data were more likely to be lighter (44.9kg vs. 43.5kg; $p<0.001$), have lower BMIs (19.5 vs. 19.0; $p<0.001$), and be slightly younger than children who did not return reliable data (11.81 vs. 11.71; $p<0.001$). No significant differences in the child’s birth weight, pubertal stage, and all parental variables were found between children who did and did not return reliable data.

The ALSPAC[138] apply their findings to children in general despite their sample including children from a very close geographic region in the UK (Bristol), and finding differences between children who did and did not return reliable accelerometer data. However, they do discuss the external validity of their study data by recognising that their large sample size (n=5,595) will maximise study power, and therefore, studies with smaller samples should take caution when applying the ALSPAC findings.

Purslow et al (2008)

Purslow *et al*[149] investigated associations between PA and weight in 235 pre-adolescent children participating in the PEACHES. The authors investigated differences in gender, BMI, SES, ethnicity, and PA levels between children who did and did not return reliable accelerometer data. The only significant differences reported were for total PA and minutes of MVPA, with higher levels of these variables found in children who returned reliable data compared to those who did not (p=0.003 and p=0.006 respectively).

Sirard et al (2008)

Sirard *et al*[180] investigated reliable accelerometer data acquisition in 65 children aged between 14 and 17 years. Children received their accelerometers at school and returned their monitors after the seven day monitoring period to research staff visiting the school. To encourage accelerometer wear children received a $5 gift card for every reliable day (at least 600 minutes per day) of accelerometer data received, in addition to $10 for the safe return of the accelerometer. Sirard *et al*[180] did not report the study consent rate, but they obtained reliable data (at least four days of data) from a high proportion of children (95%). A total of 44 children were dropped from the sample due to insufficient battery and two monitors malfunctioned.

The authors found no gender differences between children who did and did not return reliable data (p=0.37), but did report that younger children (14 to 15 years) were more likely to return reliable data than older children (18 to 19 years), although the *p*-value for differences between the two samples was 0.05. They also found that students receiving free or reduced school meals accumulated on average, one more day of complete data compared to those receiving meal assistance (6.2 vs. 5.3 days; *p*=0.02).

Sirard *et al*[180] apply their findings to their population of alternative high school students, stating that the generalisability of their study is limited by the small sample size drawn from four urban alternative high schools within one Midwestern region.

Troiano et al (2008)

Troiano *et al's*[130] study included 1,844 children aged between 6 and 19 years participating in the NHANES. The number of reliable days of data obtained were reported (as a percentage) according to age and gender. Although differences between groups were not statistically tested, older children (12 to 19 years) were less likely to return reliable data than younger children (6 to 11 years; 61.1% vs. 70.1%), and in contrast to Mattocks *et al*[138] and Gidlow *et al*[123], girls were less likely to return reliable data than boys (69.3% vs.70.9% in 6 to 11 year olds, and 62.0% vs. 62.1% in 12 to 19 year olds). Despite finding that girls and older children were less likely to provide reliable data, the NHANES still generalise their findings to the USA population.

Van Sluijs et al (2008)

Van Sluijs *et al*[152] analysed accelerometer data collected from 2,064 children participating in the SPEEDY study. The authors investigated differences between the whole SPEEDY cohort and children participating in the activity monitoring, and found that girls were more likely to take part in the study than boys (*p*<0.05). They also used independent *t*-tests and chi-squared tests to evaluate differences between children who did and did not return reliable data, and they observed no differences in BMI, overweight status, or parental education ($p>0.05$). In contrast to the ALSPAC[138] and the CHAMPS UK[123], girls were less likely to provide reliable data than boys ($p<0.05$).

Owen et al (2009)

Owen *et al*[64] investigated ethnic differences between consenting and non-consenting children, and between children who did and did not return reliable accelerometer data in the CHASE study. In agreement with Sirard *et al*[181], they found no ethnic differences between consenting and non-consenting children ($p=0.11$), and stated that there was no evidence to suggest that there were any ethnic differences in the number of days of data achieved because an average of five days was received from each ethnic group[64].

Although Owen *et al*[64] found no ethnic differences between consenting and non-consenting children they report the potential for selection bias as a result of the low consent rate (62%), and in particular, that this may reflect lower participation rates among less active children, possibly leading to the overestimation of true levels of PA. However, they report that because the demographic, ethnic, and anthropometric characteristics of children who did and did not provide reliable data were similar, the ethnic group comparisons described were likely to be valid.

Page et al (2009)

Page *et al*[145] investigated differences between children who did and did not return reliable weekend and weekday accelerometer data in the PEACH study. The authors found no differences between children who did and did not return reliable weekday data in terms of age, level of deprivation, BMI, pubertal status, and local independent mobility ($p>0.05$). However, children with higher area independent mobility were less likely to provide reliable weekday data than those with lower area independent mobility. Reliable weekend data was also less likely to be obtained from children with higher mean scores for local independent mobility, area independent mobility, and those living in less deprived neighbourhoods.

Sirard et al (2009)

Sirard *et al*[181] quasi-experimental study of 87 children from the USA was conducted to determine the effect of hypothesized strategies on reliable accelerometer data acquisition. Children from four different schools were assigned to one of four groups: the control group ($n=20$) received their accelerometer along with brief verbal instructions, a one page summary of the instructions, and a phone call the night before they were due to return their accelerometer; the journal group ($n=20$) additionally completed a timesheet; the phone condition ($n=21$) additionally received two phone calls throughout their monitoring period; and, the contingent group ($n=26$) were additionally given $5 for each reliable day (at least 600 minutes per day) of data recorded, in addition to receiving $10 for returning their monitor.

The study consent rate was 35%. Reliable accelerometer data was obtained from 70% of consenting children in the control group, 72% of children in the phone group, 85% of children in the journal group, and 96% of children in the contingent group[181]. After adjusting for grade level, ethnicity, and school level SES, the percentage of children returning reliable data in the contingent group was greater than the percentage of children returning reliable data in all other experimental groups ($p=0.04$). In agreement with Sirard *et al*[181], the authors found that younger children were more likely to return reliable data than older children

(89.8% vs. 71.1%; $p \leq 0.008$), and in agreement with Janz *et al*[17], they found no gender or ethnic differences between children who did and did not return reliable data (p>0.05). They also found no significant differences in PA levels expressed as cpm (p=0.69) and the percentage of time spent in varying activity intensity levels (p=0.16 to 0.97).

Sirard *et al*[181] apply their findings to high school students, and recommend that a contingent compensation strategy should be used to improve the accelerometer data acquisition in high school students. Importantly, they report limitations of their study that may influence the generalisability of their findings, and in particular, that there was a high level of economic deprivation among students in the contingent school group which may have provided them with a very strong incentive to return their accelerometer. Furthermore, they point out that their findings may not be generalised to other high school students as all subjects were recruited from one Midwestern city.

3.5.2.10 Summary of findings and discussion

Few articles[64 152 160] have evaluated predictors of consent in children's accelerometer studies. Only one of these articles found gender differences between consenting and non-consenting children[152]. Other factors known to be associated with children's PA such as SES, weight status, and geographic location have not been investigated as potential predictors of consent in children's accelerometer studies[13 183-185]. It is possible that these factors may be associated with study consent which could introduce the likelihood of bias, and compromise the validity of the study findings.

A total of 11[17 64 123 130 132 138 145 149 180 181 152] articles were identified which evaluated differences between children who did and did not return reliable accelerometer data, and findings from these studies were inconsistent. Studies were most likely to determine whether the child's age was associated with the likelihood of children providing reliable accelerometer data. Four articles[130 138 180 181] found that younger children were more likely to provide reliable accelerometer data than older children, and four articles[123 132 145 149] found no age differences. Results were also contradictory for articles evaluating whether gender[138 123 130 152 149 132] or weight status[123 144 148 151 132 138] predicted accelerometer data acquisition. Four articles[64 123 132 181] found that there were no ethnic differences in reliable data acquisition.

Only studies using accelerometers were included in the review due to the limitations associated with objective methods of PA measurement. All articles discuss the benefits of using an objective method of PA measurement compared to subjective methods. However, several studies[130 138 149 160 178] also discuss the limitations associated with the use of accelerometers. Several studies[64 123 132 152 160] also report that PA measurement can be affected by the season of measurement, and these studies control for season in their statistical analyses, or restrict accelerometer measurement to one season.

Limitations across the studies included small sample sizes, non-random sampling procedures, and inconsistent accelerometer data processing protocols. The majority of studies comprised geographically clustered samples, limiting the representativeness of their findings. Few studies evaluated predictors of consent, and there was also limited and conflicting evidence regarding the association of PA with reliable data aquisition[149 179]. Both studies compared the PA levels of children who did and did not return reliable data; however, PA is not reliably estimated in children without reliable data. Only studies with an alternative measure of activity can accurately estimate PA differences in non-response and therefore no conclusions can be reached on this. Few articles[132 138 178 180 181] offered advice to encourage response in future accelerometer studies.

Future studies evaluating the predictors of non-response need to use large geographically dispersed samples and a consistent standardised approach to accelerometer data processing. Additional research is also needed to understand the predictors of consent in large scale studies so that researchers are aware of specific groups of children that are unlikely to provide consent. Additional research is also needed in different countries and in studies using different accelerometer distribution and return methods. Studies also need to reliably investigate whether PA predicts response in large scale accelerometer studies using a measure of PA that is collected for the whole study sample.

3.5.2.11 Key points

- Only three articles were identified which evaluated differences between consenting and non-consenting children in accelerometer studies.
- In only one article were differences between consenting children and non-consenting children found: girls were more likely to consent than boys.
- Therefore, more studies are required to determine the factors associated with consent in large scale accelerometer studies in children.
- 11 articles evaluated differences between children who did and did not return reliable accelerometer data.
- Findings assessing predictors of reliable accelerometer data acquisition were unclear; no single predictor variable was consistently associated with data acquisition.

- Therefore, additional studies with large geographically dispersed samples of children are required to confirm the factors associated with reliable data acquisition in children’s accelerometer studies.

3.5.3 Objective 3: Methodological approaches to processing accelerometer data

3.5.3.1 Overview of articles

The minimum number of days of accelerometer data required by each child to be included in analyses was evaluated by 14 articles[28 46 108 113 120 123 129 134 138 158 186-189] (Table 8). Date of publication ranged from 1990[189] to 2008[123 129 138 187]. The minimum number of minutes per day required to characterise children's usual daily PA was investigated in two articles[138 188]. No articles were identified that investigated non-wear time or EHCV. Seven included articles involved studies from the USA[28 46 120 129 134 186 189], six from Europe (including four from the UK[108 123 138 188])[158 187], and one from New Zealand[113]. Only three articles[113 129 187] included studies that were longitudinal and the remainder were cross-sectional. Eight articles[28 46 120 123 129 138 186 187] stated the date of data collection, which ranged from 1992[46] to 2007[123 129].

Table 8: Table summarising articles (*n*=14) investigating the minimum number of days per child and/or the minimum number of minutes per day required to reliably estimate children's habitual physical activity

Authors	Year; country	Sample [Size; gender; mean age (±SD)]	Period of data collection	Accelerometer protocol (model; days wear; epoch; reliable data; intensity cut points)	Mean daily wear time (±SD)	Main results	Summary of main findings
Gidlow *et al*[123]	2008; England	*n*=503; 250m, 253f; 10.4 (3.7)y	Nov 2006-May 2007	ActiGraph GT1M; 7d wear; 60 sec epoch; ≥ 2d, ≥ 600min/d (w/d), ≥ 1d , ≥ 480min/d (w/e); MVPA: Freedson *et al*[173]	NS	*Days needed for ICC values of 0.8:* 2 (w/d)	2d of accelerometer data needed to achieve a reliability of 0.8 for w/d PA
Janz *et al*[46]	1994; USA	*n*=31; 16m, 15f; 11.2 (2.0)y	May- Jun 1992	ActiGraph 7164; 3d wear; 60 sec epoch	733 (32)min	*Reproducibility coefficients(R) using cpm:* D1 and 2 (0.49), D1 and 3 (0.53), D2 and 3 (0.32)	>3d accelerometer data needed to obtain stable PA level
Janz *et al*[186]	1995; USA	*n*=30; 15m, 15f; 11.2 (2.0)y	Jun- Aug 1994	ActiGraph 7164; 6d (720min wear); 60 sec epoch; 6d, ≥ 600 min/d; SB:< 25cpm, MPA:25-499cpm, VPA:> 500cpm	734 (41)min	*ICC using cpm, % SB, MPA & VPA:* 1d (0.42 -0.47), 2d (0.59-0.64), 3d (0.69-.07), 4d (0.75- 0.78), 5d (0.79-0.82), 6d (0.81-0.83)	5d of accelerometer data needed to achieve a reliability of 0.8
Kristensen *et al*[187]	2008; Denmark	*1997 sample:* *n*=589; 9-10y *2003 sample:* *n*=458 8-10y	1997 & 2003	ActiGraph 7164; 4d wear; 60 sec epoch; ≥ 3 days, ≥ 600 min/d (Non-wear:≥ 10min zero counts)	NS	*Reproducibility coefficients (R) using cpm:* *1997 sample (m;f):* 1d (0.45; 0.46), 4d (0.74; 0.78) *2003 sample (m;f):* 1d (0.36; 0.36), 4d (0.65; 0.68)	Secular trend where children in 2003 exhibit less day to day variability in PA that was the case in 1997
Mattocks *et al*[138]	2008; England	*n*=5595; 2747m, 2848f; 11.77 (0.23)y	2002- 2003	ActiGraph 7164; 7d wear; 60 sec epoch; ≥ 600 min/d (Non-wear:≥ 10min zero counts) MVPA:> 3600 cpm	w/d: 13.1 (range 10.0-18.3)hr w/e: 12.3 (range 10.0-20.5)hr	*ICC using cpm & max number of d available:* 600min/d (0.45), 540 min/d (0.44), 480 min/d (0.44), 420 min/d (0.43) *Days needed for ICC values of 0.7, 0.8, 0.9:* 600min/d=2.9, 4.9, 11.0; 540min/d=3.0, 5.1, 11.5; 480 min/d=3.0, 5.1, 11.5; 420 min/d=3.1, 5.3, 11.9	5d of accelerometer data needed to achieve a reliability of 0.8, number of days more influence on reliability than number of hr per day

Authors	Year; country	Sample [Size; gender; mean age (±SD)]	Period of data collection	Accelerometer protocol (model; days wear; epoch; reliable data; intensity cut points)	Mean daily wear time (±SD)	Main results	Summary of main findings
Mattocks *et al*[108]	2007; England	*n*=315; 148m, 167f; m: 11.64 (0.18)y, f: 11.67 (0.21)y	NS	ActiGraph 7164; 7d wear; 60 sec epoch; ≥ 3d, ≥ 600 min/d (Non-wear:≥ 10min zero counts) MVPA:> 3600 cpm	13.1 (0.8)hr	*ICC using cpm (fully adjusted):* 3d (0.45), 4d (0.48), 5d (0.52), 6 or 7d (0.56) *ICC using min of MVPA (fully adjusted):* 3d (0.38), 4d (0.40), 5d (0.44), 6 or 7d (0.46)	Substantial intra-variation in children's PA throughout year (controlling for month), decreased variability as number of days included in data analysis increased
Murray *et al*[134]	2006; USA	*n*=436; 436f; 14.1 (0.45)y	NS	ActiGraph 7164; 7d wear; 30 sec epoch; ≥ 7d (imputed up to 6d)) MVPA:≥ 1500 counts/30 sec	NS	*ICC using min of MVPA:* 1d (0.42), 4d (0.75), 5d (0.79), 6d (0.82), 7d (0.84)	5 to 6d of accelerometer data needed to achieve reliability of 0.8
Nader *et al*[129]	2008; USA	*Age 9y sample:* *n*=839; 408m, 431f; 9.0 (0.3)y *Age 11y sample:* *n*=850; 416m, 434f; 10.7 (0.3)y *Age 12y sample:* *n*=699; 532m, 532f; 11.9 (0.3)y *Age 15y sample:* *n*=604; 280f, 324f; 15.0 (0.2)y	2000, 2002, 2003 & 2007	ActiGraph 7164; 7d wear; 60 sec epoch; ≥ 4d, first non-zero count after 05:00 until one of the following: ≥ 60min zero counts after 17:00, ≥ 30min zero counts after 20:00, last zero count before 00:00 MVPA: Freedson *et al*[173]	NS	*ICC (R) using min of MVPA:* 4d (0.73), 7d (0.81), 2d w/e (0.54)	Between 4 to 7d of accelerometer data needed to achieve reliability of 0.8
Penpraze *et al*[188]	2006; Scotland	*n*=76; 40m, 36f; 5.6 (0.04)y	NS	ActiGraph; 7d wear; 60 sec epoch; 7d, ≥ 360min/d	10.9 (1.9)hr	*ICC using cpm & 10hr/d:* 1d (0.36), 4d (0.69), 7d (0.80) *ICC using cpm & 7d of data:* 180 min (0.79), 420 min (0.78),	7d accelerometer data with 10hr/d produced highest reliability of 0.8, number of days more influence on reliability than number of hr per day

Authors	Year; country	Sample [Size; gender; mean age (±SD)]	Period of data collection	Accelerometer protocol (model; days wear; epoch; reliable data; intensity cut points)	Mean daily wear time (±SD)	Main results	Summary of main findings
						600 min (0.80), 780 min (0.52)	
Riddoch *et al*[158]	2004; Denmark, Portugal, Estonia, Norway	*n*=2185; m: 9.7 (0.4)y & 15.5 (0.5)y, f: 9.6 (0.4)y & 15.4 (0.6)y	NS	ActiGraph 7164; 4d wear; 60 sec epoch; ≥ 3d, ≥ 600min/d (Non-wear:≥ 10min zero counts)	NS	*Differences in PA levels using ≥ 1d & ≥ 3d reliable data (cpm):* *Age 9y sample:* m (772 vs. 784); f (635 vs. 649) *Age 15y sample:* m (597 vs. 615); f (485 vs. 491)	Inclusion of children who achieved 1-2d recording had little effect PA levels
Sallis *et al*[189]	1990; USA	*n*=30; 20m, 15f; 10.8y	NS	Caltrac; 2d wear; 60 sec epoch	10.5 (1.0)hr	*Reproducibility coefficients(R) using cpm:* D1 and 2 (0.30)	PA not very stable between measurement days
Taylor *et al*[113]	2009; New Zealand	*Age 3y sample:* *n*=244; 137m, 107f *Age 4y sample:* *n*=237; 133m, 104f *Age 5y sample:* *n*=225; 126m, 99f	NS	Actical Accelerometer; 5d wear; (worn 24 hr/d)	*Mean time awake* *Age 3y sample:* 12.9 (0.7)hr *Age 4y sample:* 12.9 (0.9)hr *Age 5y sample:* 12.8 (0.6)hr	*ICC using cpm & mean number of d available:* *Age 3y sample:* 4.9d (0.8); *Age 4y sample*: 5.1d (0.79); *Age 5y sample:* 6.1d (0.84)	5d of accelerometer data provided acceptable reliability at age 3, 4 and 5y
Treuth *et al*[28]	2003; USA	*n*=68; 68f; 9.0 (0.6)y	Spr 2000-sum 2000	ActiGraph 7164; 4d wear; 60 sec epoch; ≥ 3d, ≥ 1000min/d; (Non-wear:≥ 20min zero counts)	NS	*ICC using cpm:* 3d (0.64), 4d (0.70), 5d (0.75), 7d (0.8)	7d of accelerometer data needed to achieve a reliability of 0.8
Trost *et al*[120]	2000; USA	*n*=381; 189m, 192f; 7.2 (1.4)y, 10.4 (1.0)y, 12.9 (0.9)y, 15.8(1.1)y	Oct 1996-Apr 1997	ActiGraph 7164; 7d wear; 60 sec epoch; 7d, zero counts must be indicative of sleeping time;	*Age 7.2y sample:* 12.4 (1.1)hr *Age 10.4y sample:*	*ICC using min of MVPA:* *Age 7.2y sample:* 1d (0.46), 4d (0.77), 7d (0.86); *Age 10.4y sample:*	4 to 5d of accelerometer data needed for children, & 8 to 9d of accelerometer data needed for adolescents to achieve a reliability of 0.8

Authors	Year; country	Sample [Size; gender; mean age (±SD)]	Period of data collection	Accelerometer protocol (model; days wear; epoch; reliable data; intensity cut points)	Mean daily wear time (±SD)	Main results	Summary of main findings
				MVPA: Freedson *et al*[173]	13.3 (1.1)hr *Age 12.9y sample:* 13.4 (1.4)hr *Age 14.3y sample:* 14.3 (1.4)hr	1d (0.49), 4d (0.79), 7d (0.87); *Age 12.9y sample:* 1d (0.33), 4d (0.66), 7d (0.77); *Age 14.3y sample:* 1d (0.31), 4d (0.64), 7d (0.76) *Days needed for ICC values of 0.7, 0.8, 0.9:* *Age 7.2y sample:* 2.7d, 4.7d, 10.6d; *Age 10.4y sample:* 2.4d, 4.2d, 9.4d; *Age 12.9y sample:* 4.8d, 8.3d, 18.6d; *Age 14.3y sample:* 5.1d, 8.8d, 19.8d	

Abbreviations: *n*=sample size; m=males; f=females; y=years; spr=spring; sum=summer; NS=not specified; Apr=April; Jun=June; Aug=August; Oct=October; Nov=November; d=days; hr=hours; min=minutes; sec=seconds; cpm=counts per minute; MVPA=moderate and vigorous PA; MPA=moderate physical activity; VPA=vigorous physical activity; w/d=weekday; w/e=weekend; PA=physical activity; vs.=versus.

3.5.3.2 Analytical aim

The aim of seven articles[28 46 120 134 186 188 189] was to investigate the minimum number of accelerometer wear days required by each child to reliably estimate habitual PA, although only five of these[28 46 134 186 189] collected the data for the main use of answering this research question. In nine articles[108 113 120 123 129 138 158 187 188] data were collected for another purpose and the paper reported between day variability of PA in addition to the primary statistical analyses.

3.5.3.3 Recruitment and sampling procedures

One article did not report how participants were recruited[189]. Only seven studies[113 120 123 129 138 187] specified the sampling procedures. The majority of articles (*n*=9)[113 120 123 129 138 187 188 108 158] analysed data from subjects recruited as part of large scale studies which are detailed in section 3.5.1. Further recruitment of participants was either via university newsletters[46 186] or school recruitment[28 134].

3.5.3.4 Sample size calculations

Sample size calculations were reported in four articles[123 138 158 187]. All of these articles included subjects recruited to take part in large scale studies; details of these calculations are discussed in section 3.5.1.

3.5.3.5 Accelerometer measurement protocol

Accelerometer model

The ActiGraph accelerometer was used (ten used the 7164 model[28 46 108 129 134 138 158 186 187], one the GT1M model[123], and one model not specified[188]) in twelve articles, one used the Actical[113], and the remaining article used the Caltrac accelerometer[189].

Epoch

Nearly all (*n*=12) studies[28 46 108 123 129 138 158 186-189] used a 60 second epoch. This is likely to be because most of these studies used the older ActiGraph 7164 model which is only capable of storing data collected using sampling epochs of greater than 60 seconds for a limited number of days due to limited battery life and data storage capacity. As previously stated, Murray *et al*[134] used a 30 second epoch, and Taylor *et al*[113] did not state which sampling epoch they used.

Accelerometer wear protocol

Subjects were asked to wear their accelerometer for between two[189] to seven days[108 123 129 134 138 188]. In nearly all articles (*n*=13)[28 46 108 113 123 129 134 138 158 186-189] participants were asked to wear the accelerometers during waking hours only, and only subjects participating in the FLAME study were not asked to remove their accelerometers when sleeping[113].

Accelerometer data processing

Only five articles[28 108 138 158 187] reported the methods used to identify periods of non-wear. In these articles periods of at least 10[108 138 158 187] or 20 minutes[28] of continuous zero counts were used to define non-wear time.

Nine articles[28 108 123 129 138 158 186-188] reported the criteria they used to determine the minimum daily wear time. In these articles thresholds of at least 360[188], 600[108 123 138 158 186 187] and 1,000[28] minutes were used to determine the minimum daily wear time. Gidlow *et al*[123] used the thresholds specified by the FLAME study, Trost *et al*[120] used an alternative method specified by the AHA study, and Nader *et al*[129] determined wear time according to that specified by the NICHD study.

3.5.3.6 Outcome variables

All articles measured PA as their outcome variable(s). Eight articles investigated the reliability of accelerometer-determined PA measurement according to mean cpm[28 46 113 138 158 187-189], one article[134] investigated reliability according to the mean daily minutes of MVPA[129 134], and three articles[108 120 129] investigated reliability according to the mean cpm and daily minutes of MVPA. Gidlow *et al*[123], Nader *et al*[129] and Trost *et al*[120] used age-specific count thresholds to determine levels of MVPA that were derived from the EE prediction equation developed by Freedson *et al*[173]. Murray *et al*[134] defined MVPA as greater than 1,500 counts/30 seconds, and Mattocks *et al*[108] used a slightly higher definition of greater than 3,600 cpm. Janz *et al*[186] used thresholds of less than 25 cpm, at least 250 cpm, and at least 500 cpm to define SB, MPA, and VPA respectively. Only one article[123] did not report the outcome measure.

3.5.3.7 Sample characteristics

Study sample sizes ranged widely from 30[186] to 5,595[138]. Study sample sizes for the five articles undertaken for the primary purpose of investigating the minimum number of wear days required for analyses ranged from 30[186] to 436[134]. The majority (*n*=8[28 46 108 123 138 186 187 189]) included children (6 to 12 years); two[113 188] included preschool children (two to five years), and one[134] included only adolescents (13 to 18 years). Nader *et al*[129], Riddoch *et al*[158], and Trost *et al*[120] included children and adolescents (6 to 18 years). Nearly all included both boys and girls, and two included girls only[28 134].

Five[28 113 120 123 129] out of 14 studies reported the ethnicity of their sample: participants were predominantly white (40%[134] to 91%[123]). Studies were more likely to report a measure of weight status than ethnicity, with nine studies[28 108 113 123 129 134 138 187 189] reporting either the weight or BMI of their sample.

3.5.3.8 Bias in consent

Study consent rate was reported in eight articles[108 113 120 123 129 138 158 187], and ranged from 38%[120] to 93%[108]. Differences between consenting and non-consenting children were evaluated in only three articles[113 123 158]: findings have been previously discussed (section 3.5.2).

3.5.3.9 Bias in reliable accelerometer data acquisition

Reliable accelerometer data acquisition rate ranged from 69%[187] to 99%[134]. Differences between children who did and did not return reliable accelerometer were evaluated in only three articles[113 123 138]: findings have been previously discussed (section 3.5.2).

3.5.3.10 Representativeness of sample to external population

Only one article[123] discussed how their study sample population compared to the wider population in question. In order for researchers to make statements about a wider population from their sample population clinical inference is required whereby the researcher argues that results found in the study population will apply elsewhere.

3.5.3.11 Statistical methods

The ICC describes how strongly units in the same group resemble each other, and is defined as the ratio of between individual variance to the sum of the between- and within- individual variance in the primary outcome variable. An ICC value of 1.0 indicates that all the variation is between- rather than within-children, corresponding to good reliability or repeatability. An

ICC value of 0.8 is commonly regarded as a marker of acceptable reliability. Ten studies[28 108 113 120 123 129 134 138 186 188] calculated ICC values to determine: 1) the reliability between single days of accelerometer measurement, and/or; 2) the reliability of PA measurement using varying numbers of days of accelerometer data or varying daily wear lengths. Five articles[28 120 123 138 188] used the Spearman-Brown prophecy formula[190] to investigate reliability of measurement when changing the number of days of accelerometer data required by each child to be included in data analyses, and two studies[138 188] used this formula to investigate reliability when changing the minimum daily wear time required. The only paper that did not report ICC values or reproducibility coefficients to investigate day to day variability in PA was Riddoch *et al*[158] who compared the PA levels of all children providing at least one day (at least 600 minutes per day) of accelerometer data with children who provided at least three days of data.

3.5.3.12 Main findings

Summary of articles

Most studies (*n*=8)[28 120 123 129 134 138 186 188] determined how many days of accelerometer measurement are required to achieve an ICC of at least 0.8. The number of measurement days required to achieve an ICC of at least 0.8 would represent a value in which the between person variance is at least 80% of the total variance. The number of days needed to achieve an ICC of at least 0.8 ranged from two[123] to nine days[120], and was dependent on the age of the subjects and the year of data collection[187]. Six studies[46 134 186-189] also investigated the consistency of PA between single-measurement days. ICC values between single-measurement days ranged from 0.30[189] to 0.53[46], and were also dependent on the age of the subjects.

The main findings of all articles included in this review to address objective three will now be described individually in chronological order. The two studies[138 188] evaluating the minimum daily wear time required to characterise children's usual daily PA are reported at the end of this section.

Sallis et al (1990)

Sallis *et al*[189] analysed day to day variability of PA in 30 children aged 10 to 11 years using paired *t*-tests and Pearson's correlation coefficients. The mean daily activity counts per hour for day one and two were similar (9.0 and 9.3 counts per hour respectively) but the correlations across these days were low and non-significant. No confidence intervals (CI) for ICC values were reported which is particularly important as the small sample size may influence precision of the ICC estimates. The only conclusions that can be drawn from their findings is that researchers need to measure PA in children for more than two days to obtain stable estimates of activity in a sample of this size.

Janz et al (1994)

Janz *et al*[46] used Pearson's correlation coefficients and repeated measures analysis of variance (ANOVA) to determine significant group mean differences between three days of accelerometer measurement in 31 children aged between 7 and 15 years. Between day means were not significantly different for any of the activity variables. Pearson's correlation coefficients were moderate between day one and two, and between day one and three (0.38 to 0.48 and 0.43 to 0.53 respectively; $p < 0.05$), and weak between day two and three (0.23 to 0.32; $p \geq 0.05$). Again, no CI for ICC values were reported which is particularly important as the small sample size may influence precision of the ICC values. Their findings further those found by Sallis *et al*[189], and suggest that researchers need to measure PA in children for more than three days to provide reliable estimates of children's PA.

Janz et al (1995)

Janz *et al*[186] investigated day to day variability in PA using 30 children aged between 7 and 15 years and found similar ICC values to those found by Trost *et al*[120] in similarly aged children. They reported ICC values (95% CI) for average cpm of 0.42 (0.27, 0.60), 0.59 (0.42, 0.75), 0.69 (0.52, 0.82), 0.75 (0.59, 0.86), 0.79 (0.65, 0.88) and 0.81 (0.69, 0.90) based on one, two, three, four, five and six days of accelerometer measurement respectively. ICC and 95% CI values were reported for the average cpm and also for the percentage of the day spent in SB, MPA and VPA according to the number of days of measurement. ICC values for the percentage of the day spent in SB, MPA and VPA were similar to those found for average cpm (95% CI) and ranged from 0.44 (0.28, 0.62) to 0.47 (0.32, 0.65) using one day of monitoring and from 0.82 (0.70, 0.91) to 0.84 (0.74, 0.92) using six days of monitoring. Their calculations suggest that between five and six days of measurement would be needed to achieve an ICC of at least 0.8 for all PA and SB outcome variables.

Trost et al (2000)

Trost *et al*[120] analysed data from 381 children who provided seven days of accelerometer data and reported ICC values (95% CI) for MVPA of between 0.31(0.17, 0.45) and 0.46 (0.34, 0.57) for one day of measurement, 0.64 (0.57, 0.72) and 0.77 (0.73, 0.82) for four days of measurement, and between 0.76 (0.71, 0.81) and 0.86 (0.82, 0.89) for seven days of measurement, depending on the age of the children. ICC values were lower in older children than younger children (i.e. intra-individual variation was greater in older children than younger children) for all variations in the numbers of days of measurement included in analyses. ICC and 95% CI were calculated using repeated measures ANOVA.

Trost *et al*[120] used the Spearman-Brown prophecy formula to determine how many days of monitoring were required to achieve ICC values of 0.7, 0.8, and 0.9. They found that fewer days were required to achieve similar ICC values to those reported by Treuth *et al*[28] (using similarly aged children): children needed between two and three days to achieve an ICC value of 0.7, between four and five days to achieve an ICC value of 0.8, and between 9 and 11 days to achieve an ICC value of 0.9. A greater number of wear days were required from adolescents than children to achieve the same ICC values. Between four and five days of accelerometer data were required from adolescents to achieve an ICC value of 0.7, between eight and nine days to achieve an ICC value of 0.8, and between 18 and 20 days to achieve an ICC value of 0.9.

Treuth et al (2003)

Treuth *et al*[28] reported a single day ICC of 0.37 (p<0.0001) for average cpm in 68 girls aged eight to nine years during a four day measurement period. Differences in PA between days were assessed using repeated measures ANOVA. However, no CI for ICC values were reported which is particularly important as the small sample size may influence precision of the ICC values. Average cpm were significantly different across the four days (p=0.02), and decreased from 410 cpm (SD=174 cpm) during day one to 374 cpm (SD=113 cpm) during day four. Using the Spearman-Brown prophecy formula, the authors suggested that a minimum of seven days of data would be required to achieve an ICC of 0.8.

Riddoch et al (2004)

Riddoch *et al*[158] investigated whether PA levels would be influenced by including only children with reliable data (≥ three days) in analyses compared to including all children who provided at least one day of accelerometer data. They found that including an additional 602 children with one or two days of data had little effect on their results. Inclusion of these children lowered the estimated mean PA levels by 1 to 3% (772 vs. 784 cpm for nine year old boys; 635 vs. 649 cpm for nine year old girls; 597 vs. 615 cpm for 15 year old boys; and, 485 vs. 491 cpm for 15 year old girls).

Murray et al (2006)

Murray *et al*[134] found that between five and six days of accelerometer measurement were required to achieve an ICC value of 0.8 in 13 to 14 year old girls. In their study of 436 girls they also investigated single day variation in PA and found similar ICC values of 0.42 for minutes of MVPA for one day of PA measurement to those found by Trost *et al*[120]. The reliability increased to 0.75, 0.79, 0.82, and 0.84 when including children with at least four, five, six, and seven days of accelerometer measurement respectively.

Mattocks et al (2007)

The results of the studies discussed so far have measured PA over a single-measurement period, however, Mattocks *et al*[108] investigated the reliability of PA measurement using repeated accelerometer measurements. They investigated the variation of PA over the course of a year, and also re-analysed their data restricting the number of wear days required by each child to three, four, five, and, six and seven days combined (restricted to those who had data in all four measurement occasions). Analyses for cpm were adjusted by gender, age, BMI, and month, and analyses for MVPA were also adjusted for these variables but with two sine and two cosine harmonic functions. Mean cpm and mean minutes spent in MVPA increased as the number of wear days required increased. Sample size and intra-individual variation for both cpm and mean minutes of MVPA decreased as the number of wear days required increased. ICC values for cpm increased from 0.45 to 0.56 when including children with three days compared to six and seven days combined respectively. ICC values for the mean minutes spent in MVPA increased from 0.38 to 0.46 when including children with three days compared to six and seven days combined respectively.

Gidlow et al (2008)

Gidlow *et al*[123] evaluated the minimum number of weekday measurements required to provide reliable estimates of typical weekday PA by calculating ICC values for activity cpm in their sample of 3 to 16 year old children (*n*=503). Their calculations suggested that two week days of accelerometer measurement would be required to achieve an ICC of 0.8. This calculation formed part of the methods sections of the article and as a result, CI for ICC values, and mean and SD values for PA cpm according to the number of days of measurement were not reported.

Kristensen et al (2008)

Kristensen *et al*[187] analysed reliability coefficients of PA (mean cpm) using a single-measurement day, and using a four day measurement period in a sample of 589 children aged nine to ten years who were measured in 1997. ICC (95% CI) values were similar to those found by Murray *et al*[134] and Taylor *et al*[113] for a single day measurement period [0.46 (0.40, 0.51) in girls; 0.45 (0.39, 0.50) in boys], and were similar to those found by Janz *et al*[186] using a four day measurement period [0.78 (0.75, 0.80) in girls; 0.74 (0.71, 0.76) in boys]. They repeated their reproducibility calculations on a different sample of eight to ten year old children whose PA was measured using accelerometers in 2003. ICC (95% CI) values for a single-measurement day were 0.36 (0.30, 0.41) and for a four day measurement period were 0.68 (0.65, 0.71) in girls, and 0.36 (0.29, 0.42) and 0.65 (0.62, 0.68) for a single and four day measurement period in boys respectively. These findings indicate that a secular trend in children's PA has occurred from 1997 to 2003 - there was less variation in children's (aged eight to ten years) PA in 2003 than 1997.

Nader et al (2008)

Nader *et al*[129] calculated the reliability of PA measurement using four and seven days of data and of two weekend days of data in 2,992 children aged 9, 11, 12 and 15 years. Four day ICC values for minutes of MVPA averaged 0.73, seven day ICC values averaged 0.81, and two weekend day ICC values averaged 0.54. These findings suggest that habitual weekly PA can be estimated from four weekday wear days, but weekend PA cannot be reliably estimated from one weekend wear day.

Taylor et al (2008)

Taylor *et al*[113] investigated single day variation in PA using a sample of children measured longitudinally at three different ages (three, four and five years old). It is unclear what PA outcome variable was used to assess variation, and no descriptive statistics (mean, SD values) for PA measurements according to the number of days of measurement were reported. However, they did report similar ICC values to those found by Murray *et al*[134] and Kristensen *et al*[187] in older children: single day ICC values for PA were 0.45, 0.42 and 0.46 when the children were aged three, four, and five years respectively[113]. These results suggest that day to day variation in PA did not change dramatically in the two year follow ups. Taylor *et al*[113] also investigated ICC values using the mean number of days provided by each child at each measurement age: at age three years ICC values were 0.80 using 4.9 days of accelerometer measurement, at age four years ICC values were 0.79 using 5.1 days of accelerometer measurement, and when the children were five years old ICC values were 0.84 using 6.1 days of measurement. Taylor *et al's*[113] findings indicate that their wear time threshold (including children with at least five days of data) provided a reliable estimate of children's habitual PA.

Penpraze et al (2006)

The articles discussed so far have investigated how many days of data are needed per child to reliably measure children's habitual PA, however, Penpraze *et al*[188] also determined how many minutes per day are needed to reliably measure children's daily PA in five to six year old children (*n*=76). The Spearman-Brown prophecy formula was used to determine the reliability of PA measurement using various day lengths (180 to 720 minutes per day) and numbers of wear days (one to seven days). Reliability of measurement depended on the number of minutes per day *and* the number of wear days required by each child to be included in analyses. PA measurement remained relatively stable using 180 minutes up to, and no more than 600 minutes per day. For example, the estimated reliability of PA cpm for four days of activity measurement was 69% using both 180 and 600 minutes per day, but then dropped to 38% when using 780 minutes per day. In contrast, at all constant day lengths higher reliabilities were achieved as the number of days of accelerometer measurement increased. For example, the estimated reliability of PA using 180 minutes per day for one day of measurement was 35%, for four days of measurement was 69%, and 79% for seven days of measurement. Their calculations suggest that four days lasting at least 600 minutes per day would be required to achieve 80% reliability.

Mattocks et al (2008)

The reliability of PA using varying numbers of days of measurement with varying day lengths was also assessed in 11 year old children participating in the ALSPAC[138]. The reliabilities reported by Mattocks *et al*[138] were higher than those calculated in younger children[188]. For example, approximately five days of accelerometer data lasting between 480 to 600 minutes per day were required to achieve a reliability of 0.8, compared to Penpraze *et al*[188] who reported that at least seven days of data lasting at least 600 minutes per day were required to achieve a reliability of 0.8. They also found that ICC values for PA remained constant at varying daily wear lengths (between 420 to 600 minutes) but using constant numbers of measurement days. For example, the ICC values using the maximum number of reliable days available but daily wear lengths of 600, 540, 480 and 420 minutes were 0.45, 0.44, 0.44 and 0.43 respectively.

3.5.3.13 Summary of findings and discussion

A number of articles were identified that investigated the influence of varying the number of wear days included in analyses on the reliability of PA measurement. The findings of these studies vary greatly, and are dependent on the age of the children and the year of data collection[187]. Studies most commonly reported how many days of data were required to achieve an ICC value of at least 0.8. Table 9 summarises the articles included in this review which investigated the number of days of accelerometer data needed to achieve an ICC higher than or equal to 0.8.

Table 9: Articles evaluating the number of days of accelerometer data needed to achieve an intraclass correlation coefficient of at least 0.8

Article	Age group	Number of days of accelerometer data
Taylor *et al*[113]	Preschool children	5
Penpraze *et al*[188]	Preschool children	7
Gidlow *et al*[123]	Children	2 (weekdays)
Trost *et al*[120]	Children	4 to 5
Mattocks *et al*[138]	Children	5
Janz *et al*[186]	Children	5 to 6
Treuth *et al*[28]	Children	7
Nader *et al*[129]	Children and adolescents	4 to 7
Murray *et al*[134]	Adolescents	5 or 6
Trost *et al*[120]	Adolescents	8 to 9

Only two articles[138 188] were identified that also evaluated the influence of varying the minimum daily wear time on the reliability of PA measurement. Both studies reported that daily wear length had less influence on reliability than the number of wear days required.

Limitations across the studies included small sample sizes, non-random sampling procedures, and inconsistent accelerometer data processing protocols. The majority of studies comprised geographically clustered samples, limiting the representativeness of their findings. Furthermore, in a number of studies[46 120 186 189] data collection took place over a decade ago, which may influence study findings, especially as a secular trend in children's day to day variation of PA has been observed between 1997 to 2003[187].

Several studies acknowledge the limitations of using accelerometer-based count thresholds to define levels of MVPA. This is particularly important to consider when comparing ICC values determined using the mean daily minutes of MVPA[129 134 108 120 129], as the use of different thresholds could limit comparison between studies. For example, Trost *et al*[120] used an MVPA threshold that was approximately half (depending on the age group) the count value of the threshold used by Mattocks *et al* (3,600 cpm)[108 138]. A lower count threshold allows for a greater range of potential values from which to calculate the ICC, which can increase the magnitude of ICC values.

Future studies evaluating the minimum number of accelerometer wear days required from each child to achieve reliable estimates of PA need to use large geographically dispersed samples and a consistent standardised approach to accelerometer data processing. Additional research is also needed to understand the influence of varying the daily wear length on the reliability of PA measurement. Studies have shown that PA differs significantly between boys and girls[61 152], and although findings are less consistent, research has shown that it can also vary by ethnicity[64], SES[191 192] and BMI[193]. Despite these differences, previous studies have analysed combined data from both genders, and from children of different ethnic and SES groups. Additional research is needed to explore the influence of these potential confounders on the reliability of PA measurement in children. No studies were identified that investigated non-wear time or EHCV and therefore research is needed to explore the influence of these data processing decisions in children's accelerometer studies.

3.5.3.14 Key points

- 14 articles were identified which evaluated how many days of accelerometer data are required to reliably characterise children's habitual PA.
- Nearly all articles computed the ICC to determine the internal consistency of data and investigated how many days of accelerometer data are needed to achieve an ICC value of at least 0.8.

- Findings show that between two (just for weekdays) to seven days of accelerometer data lasting at least 480 to 600 minutes per day were required to achieve an ICC of at least 0.8 in children, and between five and nine days were required to achieve an ICC of at least 0.8 in adolescents.
- Two studies found that the number of days required by each child to be included in data analyses had a greater influence on ICC values than the number of minutes per day; however this requires further study.
- No articles were identified that formally investigated non-wear time from SB, and EHCV from VPA.
- Therefore, further research is required to investigate non-wear, EHCV, and wear time thresholds in relation to factors known to influence PA levels so that future studies have evidence to inform data processing protocols.

3.5.4 Objective 4: Seasonal differences in children's physical activity

3.5.4.1 Overview of articles

17 articles[61 64 101-115] (Table 10) were identified that investigated seasonal differences in accelerometer-determined PA in children, and three[104 105 109] of these also investigated SB. The dates of publication ranged from 2002[103] to 2010[105]. In 12 studies[61 64 102-107 109 112 113 115] between-subject seasonal differences in PA were assessed, and in the remaining five[101 108 110 111 194] within-subject seasonal differences were evaluated through repeated accelerometer measurements in the same individuals. Twelve authors reported studies from Europe (including six from the UK[61 64 104 105 108 111])[101 106 107 109 110 115], three from the USA[102 103 112], and one each from New Zealand[113] and Canada[194]. Of the remaining studies only three[107 109 113] were longitudinal and the remainder were cross-sectional. Fourteen studies[61 64 101 102 104-107 109-113 115 194] stated the date of data collection, which ranged from 1997[107 109] to 2007[64 111 113].

Table 10: Articles (n=17) investigating seasonal differences in accelerometer- determined physical activity and sedentary behaviour in children

Authors	**Year; country**	**Sample [Size; gender; mean age (±SD)]**	**Period of data collection**	**Description of study**	**Accelerometer protocol (model; no. days wear; epoch; reliable data; intensity cut points)**	**Season definition**	**Statistical methods**	**Main PA results**	**Main SB results**
Bringolf-Isler *et al*[101]	2009; Switzerland	*n*=189; 81m, 88f; 6-7y, 9-10y & 13-14y (range)	Win 2004 & spr/sum 2005	Within subject repeat measures in 2 seasons	ActiGraph 7164; 7d wear; 60 sec epoch; ≥ 1d, ≥ 480min/d	Win: NS; sum: NS	Mixed effects linear regression	No diff in PA (cpm) between win & sum (638 vs. 670 cpm; p>0.05)	NS
Burdette *et al*[102]	2004; USA	*Total n*=214; *spring sample: n*=28, *summer sample: n*=39, *autumn sample: n*=89, *winter sample: n*=58; 122m, 92f; 44 (range 29-52)mth	Jul 2000-Jun 2001	Between subject measures in 4 seasons	Tritac R3D; 3d wear (inc. 2 w/d & 1d w/e); 60 sec epoch; Reliable data: NS	Spr: Mar-May; sum: Jun - Aug; aut: Sep-Nov; win: Dec-Feb	NS	No diff in PA (cpm) across four seasons (p>0.05); win PA tend to be lower (p=0.05)	NS
Finn *et al*[103]	2002; USA	*n*=214; 106m, 108f; 3.93 (0.06)y	NS	Between subject measures in 2 seasons	Actiwatch AW16; 2d wear; 60 sec epoch; Reliable data: NS VPA: 1000cpm	Sum: NS; aut: NS	Forward-backward stepwise regression	No diff in total PA (p=0.28) or % time spent in VPA (p=0.35) between sum & aut; higher PA in aut compared sum between 09:00 and 19:00 (159.9 vs. 131.2 cpm; p<0.05)	NS
Fisher *et al*[104]	2005; Scotland	*Total n*=209; 101m, 108f; *spring sample*: *n*=70; 40m, 30f; *summer sample: n*=52; 24m, 28f; *autumn*	Feb 2001-Jul 2002	Between subject measures in 4 seasons	ActiGraph 7164; 3d wear (younger children), 7d wear (older children); Epoch: NS; Reliable day: 360min/d; SB: <1100cpm, LPA: 1100-	Spr: Feb-Apr; sum: May-Jul; aut: Aug-Oct; win: Nov-Jan	ANOVA	*Total PA:* Seasonal diff in cpm (p<0.001) Lower spr than sum (mean diff =125 cpm; p<0.001), aut (mean diff=118 cpm; p<0.01), & win (mean diff=77 cpm; p<0.05),	Seasonal diff in % time SB (p<0.001); higher (p<0.05) spr than sum (mean diff=4.8% of monitored time) or aut (mean diff=2.9% of monitored time)

Authors	Year; country	Sample [Size; gender; mean age (±SD)]	Period of data collection	Description of study	Accelerometer protocol (model; no. days wear; epoch; reliable data; intensity cut points)	Season definition	Statistical methods	Main PA results	Main SB results
		sample: *n*=41; 13m, 28f; *winter sample:* *n*=46; 25m, 21f; 4.8 (1.2)y			3200cpm, MVPA: >3200cpm			*LPA:* Seasonal differences in % time LPA (p<0.001); lower (p<0.05) spr than sum (mean diff=4.3% of monitored time) or aut (mean diff=2.8 % of monitored time) *MVPA:* Seasonal diff in % time MVPA (p<0.01); lower (p>0.05) in spr than sum (mean diff=4.3% of monitored time) & aut (mean diff=1.0% of monitored time)	
King *et al*[105]	2010; England	*n*=480; 244m; 236f; 7y	2006- 2007	Between subject measures in 4 seasons	ActiGraph 7164 & GT1M; 7d wear; 15 sec epoch; Reliable days: ≥ 2d & 1d w/e; SB: <1100 cpm, MVPA: ≥ 3200 cpm	Spr/aut: Mar- Oct; sum: May-Aug; win: Jan-Dec	Linear regression	PA (cpm) lower in win, & spr/aut than sum (β coefficient: 0.0033 to 0.058; p<0.001); MVPA lower in spr/ aut than sum (β coefficient: 0.087 to 0.208; p<0.001)	SB lower in spr/aut & win than summer (-2.907 to -1.684; p<0.001).
Kolle *et al*[106]	2009; Norway	*Total n* =1824; 940m, 884f *Age 9y sample*: *n*=1127; 602m, 525f *Age 15y sample:* *n* =697; 338m, 359f	Mar 2005- Oct 2006	Between subject measures in 3 seasons	ActiGraph 7164; 4d wear (inc. 1d w/e); 10 sec epoch; ≥ 2d, ≥ 480min/d	Spr: 1 Mar-15 June; Aut: 1 Sep-30 Nov; Win: 1 Dec- 28 Feb	Linear and logistic regression	*Age 9y:* Higher spr than win (diff girls: 188 cpm; CI: 112 to 265; p<0.001; diff boys: 121 cpm; 41 to 201; p=0.001) & aut (girls diff: 112 cpm; CI: 57 to 167; p<0.001; boys diff: 113 cpm; CI: 53 to 172; p<0.001)	NS

Authors	Year; country	Sample [Size; gender; mean age (±SD)]	Period of data collection	Description of study	Accelerometer protocol (model; no. days wear; epoch; reliable data; intensity cut points)	Season definition	Statistical methods	Main PA results	Main SB results
								Age 15y: No diff in cpm across seasons (*p*>0.05)	
Kristensen *et al*[107]	2008; Denmark	*1997 sample:* *n* =377; 177m, 200f; 9.7 (0.4)y *2003 sample:* *n*=416; 179m, 237f; 9.8 (0.4)y	1997 & 2003	Between subject measures in 4 seasons in 2 groups of children (1997 & 2003)	ActiGraph 7164; 5d wear; Epoch: NS; ≥ 3d, ≥ 600 min/d	Spr: Mar-May; sum: Jun-Aug; aut: Sep-Nov; win: Dec-Feb	Wald tests	*Age 8-10y:* Highest PA (cpm) in spr than win & aut months in 1997 & 2003 ($p<0.0001$) *Age 14-16y:* No diff in PA (cpm) between months in 1997 & 2003 ($p=0.06$)	NS
Mattocks *et al*[108]	2007; England	*n*=315; 148m, 167f; 11.65 (0.19)y	NS	Within subject repeat measures in 4 seasons	ActiGraph 7164; 7d wear; 60 sec epoch; ≥ 3d, ≥ 600 min/d; SB: 0-199 cpm, MPA: ≥ 3600 cpm, VPA: ≥ 6200 cpm	Spr: Feb-Apr; sum: May-Jul; aut: Aug-Oct; win: Nov-Jan	ICC values	PA (cpm) highest sum & lowest win (diff: 93 cpm; *p*: NS)	NS
Nilsson *et al*[109]	2009; Denmark, Portugal, Estonia & Norway	*n*=1954; 918m, 1037f; 9.7 (0.4)y & 15.5 (0.5)y	1997 & 2003	Between subject measures in 3 seasons in 2 groups of children (1997 & 2003)	ActiGraph 7164; 4d wear (inc. 2 w/e); 60 sec epoch; ≥ 3d (inc. 1 w/d), ≥ 600 min/d; SB: <100 cpm, MVPA ≥ 2000 cpm	Spr: NS; aut: NS; win: NS	Repeat measures ANOVA (adjusted for season)	Adjusting for the season of measurement did not change PA (cpm & MVPA)	Adjusting for season of measurement did not change SB
Nyberg *et al*[110]	2009; Denmark	*n*=97; 41m, 56f; *Baseline age:* 7.5 (0.92)y *Follow-up age:* 9 (0.92)y	2002- 2005	Within subject repeat measures in 2 periods between	Actiwatch-4; 7d wear; 60 sec epoch; ≥4d , ≥ 600 min/d	Dark: Oct-Mar; Light: Apr-Sept	Linear regression	Diff in PA (cpm) higher in dark followed by light measurements & light followed by light measurements than light followed by dark	NS

Authors	Year; country	Sample [Size; gender; mean age (±SD)]	Period of data collection	Description of study	Accelerometer protocol (model; no. days wear; epoch; reliable data; intensity cut points)	Season definition	Statistical methods	Main PA results	Main SB results
				2002 - 2005				measurements (p=0.001 and p=0.024)	
Owen *et al*[64]	2009; England	n=2144; 1029m, 1115f; 9.9 (range 9.2-10.7)y	Jan 2006-Feb 2007	Between subject measures across 4 seasons	ActiGraph GT1M; 7d wear; 5 sec epoch; ≥1d, ≥ 600 min/d	Monthly	Multilevel linear regression	PA (mean activity counts & cpm) higher in sum than win	NS
Riddoch *et al*[61]	2007; England	n=5595; 2262m; 2933f 11.79 (SD 0.24)y	Jan 2003-Jan 2005	Between subject measures across 4 seasons	ActiGraph 7164; 7d wear; 60 sec epoch; ≥ 3d, ≥ 600 min/d; MVPA: ≥ 3600 cpm	Spr: 1 Mar-31 May; sum: 1 Jun-31 Aug; aut: 1 Sep–30 Nov; win: 1 Dec-28 Feb	ANOVA	PA (cpm & MVPA) highest in sum & lowest in win (p<0.001)	NS
Rowlands *et al*[111]	2009; England	n=64; 32m, 32f; 9.9 (0.3)y	Jan/Feb 2007 & Jun/Jul 2007	Within subject repeat measures in 2 seasons	ActiGraph GT1M; 6d wear; 2 sec epoch; ≥ 3d (w/d), ≥ 600 min & ≥1d (w/d); ≥ 480 min; MPA & VPA: Trost *et al*[121]	Sum: Jun-Jul; win: Jan-Feb	Repeated measure ANOVA; ICC values	*Total PA:* PA (cpm & MPA) higher in sum than win for boys on w/e & w/d & higher for girls on w/e (p<0.05); VPA higher in sum than win for boys on w/d (p<0.05) *PA bouts:* PA bout duration (LPA, MPA &VPA) higher in sum than win (p<0.05) in boys; PA bout frequency & intensity (VPA) higher in sum than win (p<0.05) in girls *Consistency of PA:* PA less seasonal	NS

Authors	Year; country	Sample [Size; gender; mean age (±SD)]	Period of data collection	Description of study	Accelerometer protocol (model; no. days wear; epoch; reliable data; intensity cut points)	Season definition	Statistical methods	Main PA results	Main SB results
								variation in girls than boys when including w/d & w/e (girls ICC: 0.72- 0.90; boys ICC: 0.63- 0.68; all $p<0.01$)	
Rundle *et al*[112]	2009; USA	*n*=437; 213m, 224f; 50.7 (8.0)m	Jun 2003- Jan 2006	Between subject measures in 2 seasons	Actiwatch; 6d wear; 60 sec epoch; Reliable data: NS	Sum: May-Sep; win: Oct-Apr	Linear regression	PA (cpm) higher in sum than win (β coefficient: 87.04; $p<0.001$)	NS
Taylor *et al*[113]	2008; New Zealand	*Total n*=574; 319m, 255f *Age 3y sample:* *n*=208; 113m, 95f *Age 4y sample:* *n*=180; 101m, 79f *Age 5y sample:* *n*=186; 105m, 81f;	2004 - 2007	Longitudinal between subject measures between 3 seasons at 3 different ages	Mini Mitter Actical; 5d wear; Epoch: NS ≥ 3d, length of day calculated from parental report; MVPA: 715 counts/15sec	Spr: Sep-Oct; sum: Nov-Feb; aut: Mar-May; win: Jun-Aug	Linear regression	*Age 3y:* PA (cpm) lower in spr than sum or win ($p<0.001$) *Age 4 & 5y:* No diff in PA (cpm) across 3 seasons at 4 & 5y ($p=0.974$ & $p=0.383$ respectively)	NS
Tremblay *et al*[194]	2005; Canada	*n* =219; 8 – 12y (range)	Aut 2002 & sum 2003	Within subject repeat measures in 2 seasons	ActiGraph; 7d wear; 60 sec epoch; Reliable data: NS; MVPA: NS	Sum: NS; aut: NS	ANCOVA	*Total sample:* No diff MVPA across 3 seasons ($p=0.076$) *Lifestyle group:* Lifestyle group & season interaction: MVPA 4% higher in OOM & 20% higher in RSK groups in sum compared with aut ($p<0.001$)	NS
Wennlöf *et al*[115]	2005; Sweden	*Total n*=969; 471m, 498f	Spr 1999	Between subject	ActiGraph 7164; 3-4d wear;	Spr: Mar-May;	Three way ANOVA (age,	PA (cpm) highest during Apr & May;	NS

Authors	Year; country	Sample [Size; gender; mean age (±SD)]	Period of data collection	Description of study	Accelerometer protocol (model; no. days wear; epoch; reliable data; intensity cut points)	Season definition	Statistical methods	Main PA results	Main SB results
		Age 9y sample: 9.5 (range 8.5-10.3)y *Age 15y sample:* 15.6 (range 14.7- 16.4)y		measures in 3 seasons	Epoch: NS; ≥ 1d; ≥ 600min/d;	aut: Sep-Nov; win: Dec-Feb	gender, season)	significant effect from month of measurement in cpm (p<0.001)	

Abbreviations: *n*=sample size; m=males; f=females; y=years; mth=months; spr=spring; sum=summer; aut=autumn; win=winter; NS=not specified; Jan=January; Feb=February; Mar=March; Apr=April; Jun=June; Jul=July; Aug=August; Sep=September; Oct=October; Nov=November; Dec=December; d=days; min=minutes; sec=seconds; cpm=counts per minute; SB=sedentary behaviour; LPA=light physical activity; MPA= moderate physical activity; MVPA=moderate and vigorous physical activity; VPA=vigorous physical activity; w/d=weekday; w/e=weekend; PA=physical activity; ICC=intraclass correlation coefficient; ANOVA=analysis of variance; ANCOVA=analysis of covariance; diff=differences; RSK=rural Saskatchewan; OOM=Old Order Mennonite.

3.5.4.2 Analytical aim

In seven articles[104 106-108 111 115 194] the aim was to investigate seasonal differences in PA levels in children, and one of these also investigated seasonal differences in SB in children[104]. In ten articles[64 101-103 105 109 110 112 61 113] data were collected for another purpose and the authors investigated associations between PA and season in addition to the primary statistical analysis. Only two[105 109] of these articles investigated seasonal differences in SB in addition to the primary statistical analysis.

3.5.4.3 Recruitment and sampling procedures

One article did not report how their study samples were recruited: this was an abstract by Tremblay *et al*[194] published in the North American Society for Paediatric Exercise Medicine. Nine studies[61 64 101 104 106 107 109 110 115] specified their study sampling procedures. The majority of articles (*n*=11[61 64 101 104 105 107-109 112 113 115]) analysed data collected from subjects recruited as part of large scale studies, three studies recruited children via schools[106 110 111], one study recruited preschool children at childcare centres[103], and one study recruited children through advertising in brochures and community news articles[102].

3.5.4.4 Sample size calculations

One article[61] reported sample size calculations; Riddoch *et al*[61] included subjects recruited to take part in the EYHS (section 3.5.1).

3.5.4.5 Accelerometer measurement protocol

Accelerometer model

In twelve articles the ActiGraph accelerometer was used (nine used the 7164 model[61 101 104-109 115], two used the GT1M model[64 111], and one model not specified[194]), three used the Actiwatch[103 110 112], one used the Tritac R3D accelerometer[102], and the remaining article the mini Mitter Actical accelerometer[113]. The validity and feasibility of the ActiGraph, the Tritac R3D, and the Actical accelerometer has been previously discussed in section 3.5.1.1.2. Despite being a wrist worn accelerometer the Actiwatch has shown high reproducibility and high validity in children, and has also compared favourably with HR monitoring and the ActiGraph accelerometer[90].

Epoch

In 14 (82%) articles authors reported the epoch selected; this was usually 60 seconds[61 101-103 108-110 112] with individual studies using shorter epochs, namely 2[111], 5[64], 10[106], and 15[105] seconds.

Accelerometer wear protocol

Subjects were asked to wear their accelerometer for between two[103] to seven days, with most (*n*=8[61 64 101 104 105 108 110 194]) requesting seven days wear. All articles requested subjects to wear their accelerometers during waking hours only.

Accelerometer data processing

The criteria used to determine the number of days of accelerometer data required per child to characterise habitual activity were specified in 13 articles: these ranged from one[64 101 115] to four[110 111] days. In five, at least one weekend day was stipulated[102 105 106]

[109 111]. In 12 (71%) articles duration of wear required in any single day was specified: these ranged from at least 360[104] to at least 600[61 64 107-110 115] minutes.

3.5.4.6 Outcome variables

All articles had a PA measure as their outcome variable(s). Sixteen articles measured total PA using mean cpm[61 64 101-113 115], seven articles reported levels of PA according to the number of minutes spent in MVPA[61 104 105 108 109 113 194], one article the number of minutes spent in LPA[104], one article the number of minutes spent in MPA[111], and three articles reported the number of minutes spent in VPA[103 109 111]. Three studies also reported seasonal differences in the time spent in SB[104 105 109]. MVPA was defined using a range of count thresholds varying from 2,000[109] to 3600[61 108] cpm. VPA was defined using Trost *et al*[121] and a threshold of 1,000 cpm[103].

3.5.4.7 Seasonal definition

In seven articles[61 64 102 104 105 107 108] PA levels across all four seasons were compared, four articles[106 109 113 115] compared PA levels across three seasons, and six articles[101 103 110-112 194] compared PA levels across two seasons. Nyberg *et al*[110] investigated differences between dark and light months, which they defined as October to March, and April to September, respectively. Five studies[64 101 103 109 194] (28%) did not report the dates used to define the seasons. This is important as there are no definitive dates to define the seasons, particularly as seasons vary depending on the geographic location of subjects. For example, Taylor *et al's*[113] article included children living in New Zealand and they defined spring as September to October, summer as November to February, autumn as March to May, and winter as June to August. In comparison, Fisher *et al's*[104] article included children living in the UK and they defined spring as

March to May, summer as May to July, autumn as August to October and winter as November to January.

3.5.4.8 *Sample characteristics*

The sample sizes for studies that used a repeated measures design ranged from 64[111] to 315[108], and from 209[104] to 5,595[61] for studies investigating seasonal differences between subjects. Children aged 2 to 5 years, 6 to 12 years, or 13 to 18 years were included in five[102-104 112 113], eight [61 64 105 107 108 110 111 194], and four[101 106 109 115] studies respectively. All studies included both boys and girls. In 13 articles a measure of weight status was reported, while in only four was ethnicity[64 102 103 112] or SES[101 103 105 107] of the sample reported.

3.5.4.9 *Bias in consent*

Study consent rate was reported in nine articles[61 64 101 105 107 108 113 115 195], which ranged from 50%[115] to 93%[61]. Understanding the predictors of non-response in repeated measurements studies is particularly important because the increased number of measurements enhances the potential for further drop out and potential bias. Four articles[105 110 115 64] investigated predictors of non-consent and all of these investigated seasonal differences in PA between different subjects.

Mattocks *et al*[108] compared the characteristics of children who consented to their seasonal study (*n*=315) with those who consented to the ALSPAC main stage activity monitoring study (*n*=6,844). They found little differences in BMI, weight, and SES. However, children consenting to the seasonal study tended to be slightly younger

(11.65 years vs. 11.79 years; $p<0.001$) and slightly shorter (150.0cm vs. 150.8cm; $p<0.05$) than those in the main study.

3.5.4.10 Bias in reliable accelerometer data acquisition

Fourteen articles[61 64 101 103-108 110-113 115] reported the reliable data acquisition rate, and this ranged from 60%[64] to 97%[104]. Of the five studies[101 108 110 111 194] that investigated seasonal differences in PA using repeated accelerometer measurements, only two[111 138] reported the proportion of children who returned reliable data in each season, and none investigated if there were any differences between children who did and did not provide reliable data in each season.

3.5.4.11 Statistical methods and main findings

Summary of articles

Thirteen articles[61 64 102 104-108 110-113 115] found seasonal differences in children's PA, and two[104 105] found differences in children's SB. Four articles[101 102 109 194] found no seasonal differences in children's PA. Kolle *et al*[106] and Kristensen *et al*[107] found no seasonal differences in PA in their 15 year old sub samples, and Taylor *et al*[113] found no differences in their four and five year old sub samples.

The statistical methods and main findings of all articles included in this review to address objective four will now be described individually in chronological order.

Finn et al (2002)

Finn *et al*[103] measured PA using accelerometers in 214 children aged three to five years to identify factors associated with PA in young children. They found no differences between summer and autumn total PA (cpm) and VPA. However, slightly higher activity counts were observed between 05:00 and 19:00 in autumn compared to summer (159.9 vs. 131.2 cpm, respectively; $p<0.05$).

Burdette et al (2004)

Burdette *et al*[102] found no variation according to the season of measurement in their study of 214 children from the USA (aged 29 to 52 months; $p=0.05$). However, although statistical significance was not achieved, PA in winter tended to be slightly lower than in autumn. Mean PA levels were 619, 681, 659, and 698 cpm during winter, spring, summer, and autumn, respectively. Differences in between subject measurements of PA levels collected in all four seasons between July 2000 and June 2001 were assessed using ANOVAs.

Fisher et al (2005)

Fisher *et al*[104] compared total PA (cpm) and the percentage time spent in SB, LPA, and MVPA across all four seasons in 209 Scottish children (mean age 4.8 years). PA outcome variables were tested for normality and one way ANOVAs and two sample *t*-tests were used to determine seasonal differences. Adjustments were made for age, gender and BMI. They found seasonal differences in mean cpm ($p<0.001$) and the percentage of time spent in SB ($p<0.001$), LPA ($p<0.001$) and MVPA ($p<0.01$). Total PA was lower in spring (701 cpm) than summer (826 cpm; $p<0.001$), autumn (819 cpm; $p<0.01$), and winter (778 cpm; $p<0.05$). Children were more sedentary in spring than summer or autumn, and children spent less time in LPA during spring than summer or autumn.

Tremblay et al (2005)

Tremblay *et al*[194] compared the time spent in MVPA during autumn 2002 and summer 2002 in 219 Canadian children. Using ANCOVA, and adjusting for age, they found no seasonal differences in MVPA between summer and autumn for the total sample (p=0.076). However, they did find a significant group by season interaction: the weekly time spent in MVPA was 4% higher in the old order Mennonite children and 20% higher in the rural Saskatchewan children during summer compared to autumn (p<0.001). In contrast, urban Saskatchewan children were more active during autumn than summer.

Wennlöf et al (2005)

Wennlöf *et al*[115] compared the PA levels (cpm) of 969 Swedish children aged between nine and 15 years who were measured once only in spring, autumn, or winter . Three way ANOVAs including gender, age group, and month of measurement were undertaken to assess the association between gender, age, season of measurement and total PA (cpm). They found that children were most active during April and May with a significant effect of month of measurement on total PA being observed (p<0.001).

Mattocks et al (2007)

Mattocks *et al*[108] evaluated the seasonal and intra-individual variation of PA in 315 UK children aged 11 years by obtaining four repeat accelerometer measurements over a full calendar year. ICCs were calculated to determine the extent to which activities in different seasons vary. The authors tested the PA outcome variables for normality, and because they were skewed, log transformations were used. ICC values for variation in activity (cpm) over the course of the year increased from 0.49 to 0.53 after adjusting for month of measurement, indicating an effect of month. PA levels were higher in summer than winter (615 vs. 522 cpm respectively).

Riddoch et al (2007)

Riddoch *et al*[61] compared the PA levels (cpm) of 969 Swedish children between the ages of 9 and 15 years who were measured once only in spring, autumn, or winter. ANOVA tests revealed that children were most active during April and May with a significant effect for month of measurement on total PA being observed.

Kristensen et al (2008)

Kristensen *et al*[107] compared PA levels (cpm) across all four seasons in 8 to 10 and 14 to 16 year old children during two separate sweeps in 1997 and 2003. Wald tests were used to test whether PA differed by season of measurement according to the age of the children and the year of measurement. They found that season had less influence on 14 to 16 year olds than in eight to ten year olds: younger children were more active during spring than winter and autumn in 1997 and 2003 ($p<0.0001$), but PA did not differ by season in 14 to 16 year olds during 1997 or 2003.

Nyberg et al (2009)

Nyberg *et al*[110] investigated the stability of PA in 97 children aged six to ten years by investigating baseline and follow-up. PA measurements were collected during two seasons between 2002 and 2005. Multiple linear regression models were fitted to determine predictors of PA at follow-up, adjusting for baseline PA, gender, age, BMI, follow up time, and the season of measurement (defined as dark: October to March and light: April to September). They found that the season of accelerometer measurement contributed significantly to reducing the variance of the modelled PA (cpm) at follow-up. The mean difference in PA between each season was significantly higher for measurements taken during the dark season followed by the light season, and light to light season measurements than baseline measurements made in the light season with follow-up during the dark season (p=0.001 and p=0.024 respectively).

Bringolf-Isler et al (2009)

Bringolf-Isler *et al*[101] investigated the association between PA (cpm) and socio-demographic and environmental characteristics, including season in a longitudinal study of 189 Swiss children aged between 6 and 14 years old who were measured once in either winter 2004 or summer 2005. Mixed linear regression analyses reported no differences in PA cpm between winter and summer (638 cpm vs. 670 cpm; p>0.05).

Kolle et al (2009)

Kolle *et al*[106] compared PA levels (cpm) across spring, autumn, and winter in 2,299 Norwegian children aged between 9 and 15 years. Using linear regression models they assessed the association between gender, age, season of measurement, and total PA (cpm). They found that season had less influence on PA in Norwegian 15 year olds than in Norwegian nine year olds: younger children were more active during spring than during winter (mean difference for girls: 188 cpm; p<0.001; mean difference for boys: 121 cpm; p=0.001) and autumn (mean difference for girls: 112 cpm; p<0.001; mean difference for boys: 113 cpm; p<0.001), but the PA levels of 15 year olds did not vary by season (p>0.05). Using logistic regression analysis they also investigated the odds of children meeting the recommended levels of daily PA according to the season of measurement, and found that children had a higher chance of meeting the guidelines during spring than winter at both 9 ($p<0.001$) and 15 years ($p<0.05$).

Nilsson et al (2009)

Nilsson *et al*[109] determined between- and within- day differences in total PA (cpm), and the daily time spent in MVPA in 1,954 European children aged between nine and 15 years. Repeat measures ANOVA were used to investigate differences in mean cpm, and the time spent in MVPA and SB during weekdays and weekend days. After the main analyses were performed they reanalysed their data and found that adjustment for season of PA measurement (autumn, winter and spring) did not alter their main findings.

Owen et al (2009)

Owen *et al*[64] investigated ethnic differences in mean daily PA (cpm) in a cross-sectional study of 144 eleven year old UK children. Children were measured in one of four seasons between January 2006 and February 2007. Tests for normality were undertaken and multilevel linear regression models were used to provide ethnic and gender differences in PA, which were adjusted by age, gender, day of the week and the month of measurement. They found that mean activity counts and total cpm were higher in summer than winter and did not vary by gender.

Rowlands et al (2009)

Rowlands *et al*[111] are the only authors to have considered the influence of gender on seasonal variation of PA in a longitudinal study of only 64 UK children aged between 9 and 11 years who were measured in only one of two seasons (summer and winter). Tests for normality revealed that some of the PA outcome variables were skewed so log transformations were undertaken and repeated measures ANOVAs were used to determine differences in mean activity counts, and the time spent in MPA and VPA according to the season of measurement and day of measurement (weekday and weekend). Total PA (cpm) and MPA were higher during summer than winter for boys on weekend and weekdays, and higher for girls on weekend days ($p<0.05$). For boys, VPA was higher during summer than winter on weekdays, while weekday VPA was higher in summer than winter; for girls, weekend VPA was higher in summer than winter ($p<0.05$).

Rowlands *et al*[111] are also the only authors to have assessed seasonal variation in PA patterns according to the frequency, intensity and duration of PA bouts (lasting greater than four seconds) of LPA, MPA, and VPA. They found that the mean duration of all intensity PA bouts were greater during summer than winter in boys, and the frequency and intensity of VPA bouts were greater during summer than winter in girls ($p<0.05$).

Rowlands *et al*[111] also investigated the individual consistency of total PA levels and activity bouts according to the season of measurement and day of measurement for boys and girls separately. PA tracked most highly between weekdays and weekends during winter in girls (ICC: 0.71 for total PA, 0.66 for MPA, and 0.69 for VPA), and total PA and VPA tracked most highly during summer in boys (ICC: 0.48 and 0.58

respectively). No specific dimension of activity bouts (frequency, intensity or duration) showed greater seasonal variation than another. Less variation in total PA and activity bouts were observed across seasons than between weekday and weekend days within a season.

Rundle et al (2009)

Rundle *et al*[112] compared the activity levels of 437 four year olds living in the USA measured either during summer or winter. Linear regression models were fitted to determine seasonal differences in children's PA and to also identify a range of other variables associated with children's PA including child's gender, age, and ethnicity, mother's age, the number of rooms in the home, whether the mother spent a substantial time away from home, whether the child played video games, and the amount of time the child spent watching TV. A multivariable regression model containing all the variables was first constructed and then each variable removed one at a time to determine the effects on other variables. They found that season of measurement was the strongest predictor of mean activity counts with children more active during summer than winter (p<0.001).

Taylor et al (2009)

Taylor *et al*[113] compared total PA (cpm) across all four seasons in New Zealand children at age three, four and five years. Linear regression models were fitted to determine seasonal variation in mean PA (cpm). Seasonal differences in PA varied by age group: children were less active during spring than summer or winter at age three years (p=0.001), but these differences were not observed at four or five years

(p=0.974 and p=0.383, respectively). At the aged three year measurement, season explained 8.7% of the total variance in activity cpm (p<0.001).

King et al (2010)

King *et al*[105] explored 22 potential correlates (including season) of PA and SB in 480 seven year old UK children. PA outcome variables were tested for normality and univariate linear regression analyses were used to determine the relationship between season of PA measurement (and other correlates), total PA (cpm), and the percentage of time spent in MVPA and SB. Season of measurement was significantly associated with PA in the univariate models and was therefore included in a stepwise multiple linear regression model. Season remained significant in the final model. The authors found that total PA and MVPA were lower in winter, spring, and autumn than in summer (p<0.001), and SB was higher in spring, autumn and winter than in summer (p<0.001).

3.5.4.12 Summary of findings and discussion

There are a lack of studies that have investigated seasonal differences in objectively measured PA in children using a repeated measures study design [120 127 129 130 206]. Even fewer studies have used this method to assess seasonal differences in objectively measured SB[123 124 128] and PA patterns[111]. In those that are available, differences in accelerometer protocols, data processing procedures, sample characteristics, study designs, seasonal definitions, and geographic regions all restrict the ability for researchers to compare findings between studies. However, seasonal differences in PA were reported in the majority of studies[52 73 121 123-127 129-132 134], and in younger rather than older children. These seasonal differences were reported in all UK studies, and children's PA was highest during summer[61 64 108 111 112] and lowest during winter[61 64 106 108 111 112]. Findings from non-UK studies were inconsistent: seasonal variation in PA was reported in seven studies, but not in four [98 99 106 192].

Few studies evaluated seasonal differences in SB[101 102 106] independently of total PA. Two studies[104 105] were from the UK, and both compared the seasonal levels of SB using different children. Findings were inconclusive for SB. For example, two studies[104 105] found that SB was lower during summer than spring, autumn and winter, but one[109] found no seasonal differences in SB. In addition, only one study[111] considered the influence of gender on seasonal variation in PA, and found that season influenced gender differentially. Gender differences in PA across season may relate to the type of playground activities typically undertaken by boys and girls at school. Boys undertake more VPA during play time at school than girls and therefore warm summer weather may have an increased impact on the amount of PA that they undertake[196]. However, Ridgers *et al*[197] found that children's play time activity does not vary across season, so PA undertaken out of school may be influenced to a greater extent than PA undertaken during school time.

Limitations across the studies included small sample sizes, inconsistent study designs and accelerometer protocols, and the use of varied seasonal definitions and statistical methods. Several studies[108 109 110 113] also discussed the limitations associated with the use of accelerometers that have been previously discussed. There were also few studies that employed a repeated measures study design, the most appropriate design allowing differentiation between seasons and between subjects. The studies included in the current review also comprised geographically clustered samples, limiting the representativeness of their findings. There was also limited and conflicting evidence regarding gender and age effects on seasonal variation in PA therefore no conclusions can be reached on this.

Future studies of seasonal PA in children need to use large samples, employ a repeated measures study design, use comparable definitions of season, and use a consistent standardised approach to accelerometer measurements. This should include the use of a short epoch, presenting count data as well as minutes of MVPA, and also consider activities that cannot be measured accurately by accelerometers. Further research is also needed to understand seasonal variation in children's SB and VPA independently of total PA so that public health interventions aimed at reducing SB and increasing VPA can be targeted at specific times of the year.

Seasonal variation in PA appears to be location specific; therefore additional research is needed in different countries and within different regions of larger countries. Characteristics that define seasons including the weather, ecology, and hours of daylight vary according to country, and even within different regions of large individual countries. Regional differences in seasonal variation may reflect variations in climate. As the meteorological factors associated with seasons in a specific region cannot be altered, there may be a role for future research to study other factors associated with variation of PA and SB throughout the seasons. This will enable us to understand what encourages a child to be more or less physically active in specific seasons. For example, previous research evaluating regional differences in pedometer-determined PA between urban and rural primary children living in Cyprus found an interaction between season and rural/urban regions: rural children were more active in summer, and urban children were more active in winter[198]. To my knowledge, only one study has evaluated seasonal differences in accelerometer-determined PA in rural and urban children[194].

Additional research is needed that examines possible interactions of season with other factors known to influence PA and SB such as gender, age, ethnic group, weight status and geographic location[13 183-185]. We found some evidence suggesting that season influenced children but not adolescents[106]. This may be because adolescents have less free time to play outdoors than children; therefore, their PA may be less influenced by fluctuations in daylight and weather. Adolescents are also more likely to participate in organised PA that tends to take place all year around[199]. In the majority of studies identified for this review, authors reported a measurement of weight and several reported the ethnic composition of their sample; however, none determined whether seasonal variation in activity were associated with weight status', or ethnic group. It is possible that the influence of season on PA and SB may be enhanced in specific ethnic groups, or in overweight children compared to underweight children.

3.5.4.13 Key points

- 17 articles were identified that investigated seasonal differences in accelerometer-determined PA, and three also investigated seasonal differences in SB.
- Five articles investigated seasonal differences in PA using a repeated measures study design and 12 investigated differences across seasons using different subjects.

- Seasonal differences in PA were reported in the majority of UK studies: levels of PA were normally highest during summer and lowest during winter.
- Seasonal differences were less likely in older children than younger children.
- Two articles investigated seasonal differences in children's SB, but findings are inconclusive.
- Only one article investigating seasonal variation and differences in PA patterns was found.
- Additional studies are needed to understand seasonal variation in children's SB and VPA independently of total PA.
- Further research is also required to examine the possible interactions of season with other factors such as gender, age, ethnic group, weight status and geographic location.

4 Chapter 4: Methods

4.1 Chapter overview

This chapter describes the MCS, and the MCS4 main stage and seasonal accelerometer studies. The accelerometer protocol used to measure PA and SB is described, and the MCS interview variables used to explore the research objectives are also defined.

4.2 Millennium Cohort Study

4.2.1 Background

The MCS is a UK wide prospective study of approximately 19,000 British children born at the start of the new century[200]. The MCS is the fourth of the UK's world-renowned national birth cohort studies and was established to study the influence of contemporary society on children's development across the life course. The director of the study is Professor Lucinda Platt at the CLS, Institute of Education, University of London.

Four sweeps of the MCS have been completed so far, when the children were nine months, and three, five and seven years. The fifth sweep of the MCS is currently being carried out (2012/3) while the children are aged 11 years. Detailed information has been obtained on demographic, social, and health factors relating to the children, and the children's siblings and parents through interviews of the main respondents and their partners in the home. The MCS interview questions cover diverse topics including parenting, childcare, school choice, child behaviour and cognitive development, child and parental health, parents' employment and education, income and poverty, housing, neighbourhood and residential mobility, social capital and ethnicity.

4.2.2 Aim

The aims of the MCS are widespread and cover a variety of topics. Some of the overarching aims are[201]:

- To provide a multi-purpose long-term resource for the research and policy community.
- To chart the initial conditions of the social, economic, and health advantages and disadvantages facing children in the new century and their consequences
- To observe intergenerational transmission of advantage and disadvantage, and the processes involved.
- To compare patterns of development with other British and international cohorts.
- To collect information on previously neglected topics, such as father's involvement.
- To investigate the wider social ecology of the family, including community and services using geo-coded data.

4.2.3 Sampling

The cohort was taken from a random sample of electoral wards that were disproportionately stratified to ensure an adequate representation of all four UK countries, disadvantaged areas, and ethnic minority groups. Sample weights were created so that the analyses correspond to a cohort which is nationally representative.

In England, electoral wards (as established in 1998) were categorised as 'ethnic' (based on the 1991 Census, if at least 30% of residents were from an ethnic minority group) and the remainder as 'disadvantaged' (above the upper quartile of the Child Poverty Index[202]) or advantaged (all remaining wards). In Wales, Scotland, and Northern Ireland there was no 'ethnic' stratum[203]. Families were invited to participate in the MCS if they received Child Benefit and were a resident in England, Wales, Scotland, or Northern Ireland when their child was approximately nine months old[204].

4.2.3.1 Sample response

MCS1 (age 9 months)

MCS1 comprised 18,819 children (18,553 families; 68% response rate) born between September 2000 and January 2001 in England and Wales, and between November 2000 and January 2002 in Scotland and Northern Ireland[205]. Among the 18,819 children, 18,296 were singletons, 492 were twins, and 30 were triplets. Data collection for the MCS1 took place between June 2001 and September 2002 when the children were approximately nine months old.

MCS2 (age 3 years)

MCS2 occurred when the children were approximately three years old, and comprised 15,590 families[205]. Children who participated in the MCS1 who did not die or permanently emigrate were eligible to participate in the MCS2. The second sweep included an additional 692 families in England who appeared to have been living in sample wards at the MCS1, and were therefore eligible for the survey but were not originally included[154]. The second sweep of the MCS comprised 15,808 children (78% response rate), of which 15,286 were singletons, 492 were twins, and 30 were triplets. The MCS2 interviews took place between September 2003 and December 2004 in England and Wales, and between December 2003 and February 2005 in Scotland and Northern Ireland.

MCS3 (age 5 years)

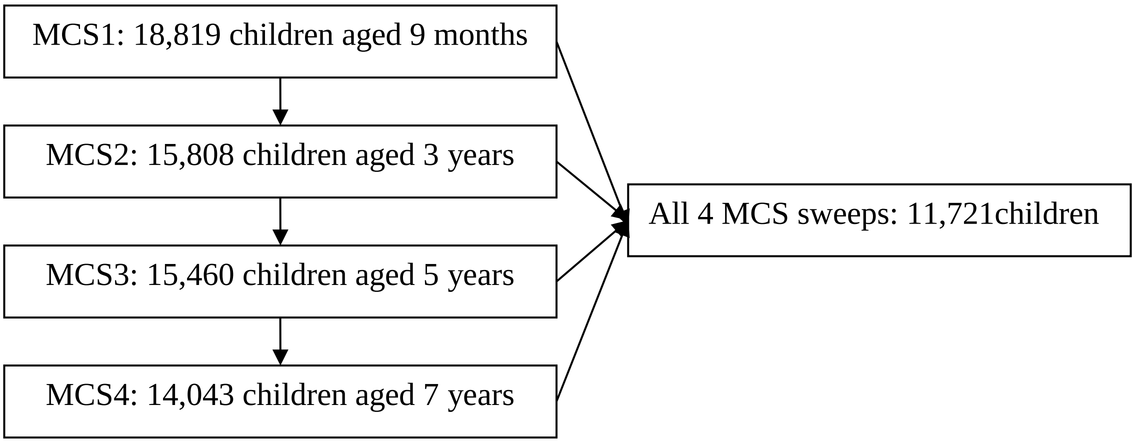
MCS3 occurred when the children were approximately five years old, and comprised 15,246 families (79% response rate)[206]. All children that did not die, did not permanently emigrate, or had not permanently refused to take part in previous sweeps were eligible to participate in the MCS3. There were a total of 15,460 children in the third sweep of the MCS, of which 15,042 were singletons, 388 were twins, and 30 were triplets. The MCS3 interviews took place between January 2006 and July 2006 in England and Wales, and between April 2006 and December 2006 in Scotland and Northern Ireland.

MCS4 (age 7 years)

MCS4 interviews took place between January 2008 and August 2008 in England and Wales, and between April 2008 and December 2008 in Scotland and Northern Ireland, when the children were approximately seven years old. The total sample comprised 13,857 families (72% response rate[207]) including 30 triplets, 332 twins, and 13,681 singletons. Families with white cohort children had the highest response rate (74%) while those in the other, while those in the ‘other’ (including Chinese and other Asian) ethnic-group had the lowest (61%). The majority of singletons in the MCS4 (86%) were white (Chapter 7), 51% were boys, 87% were living in households including at least one other child and 64% lived in England. The mothers of 38% of children were non-employed, and 23% were lone mothers.

Overall, a total of 11,721 (61%) families have participated in all four MCS sweeps (Figure 15). The percentage of families who have participated in all MCS sweeps ranges from 59% in Scotland to 64% in Wales.

Figure 15: Flow chart showing the number and age of children participating at each sweep of the Millennium Cohort Study



4.2.4 Ethics

Research ethics approval for the first three sweeps of the MCS was granted by the London Multi-Centre Research Ethics Committee, and for the MCS4, by the Northern and Yorkshire Research Ethics Committee (REC number: 07/MRE03/32).

4.2.5 Funding

The MCS is funded by grants to the CLS from the Economic and Social Research Council and a consortium of government departments.

4.3 Millennium Cohort Accelerometer Study

4.3.1 Millennium Cohort main stage accelerometer study

4.3.1.1 Aim

Accelerometers were introduced into the MCS4 to measure PA and SB. The initial objective of collecting accelerometer measurements was to use this data to investigate determinants of PA in a contemporary cohort of pre-pubertal primary school aged children. There are currently no equivalent longitudinal studies of accelerometer-determined PA on this scale using pre-pubertal children in the UK.

Information regarding the factors in early life that promote children's PA is scarce. The current recommendations for the minimum amount of daily time children should spend in PA are largely based on limited cross-sectional studies that have used self-reported PA. There has also been increasing government interest in the evidence linking SB with negative health outcomes, and whether there is sufficient evidence to make recommendations for limiting SB[80]. As a result, the MCS accelerometer data is also being used to explore determinants of SB in UK children. Furthermore, the primary data collection of accelerometer measurements in the MCS raised awareness of a number of methodological considerations in large scale accelerometer-based studies and, as a result, the data were used to address some of these issues within this thesis.

4.3.1.2 MCS4 accelerometer fieldwork protocol

MCS4 home interview

The MCS4 home interviews in England, Scotland and Wales were conducted by the NatCen, and in Northern Ireland by the Northern Ireland Statistics and Research

Agency. All children taking part in the MCS4 interviews were invited to participate in the MCS4 accelerometer study. Parents were given information leaflets and those willing for their child to participate in wearing an accelerometer were asked to provide written consent. Interviewers then explained how the child should wear the accelerometer using a 'dummy' activity monitor. They also explained how to fill in the timesheet, how and when they should expect to receive their child's activity monitor, and how and when they should return the monitor. Parents were shown copies of the timesheet, information leaflet and teacher letter (documents explained later in this section).

Obtaining subject information

Contact details (postal address, and at least a home telephone number, mobile telephone number, or e-mail address) of families who gave consent were posted in fortnightly batches on a secure exchange portal by the MCS management team at the CLS. Waist circumference data were also given to guide selection of belt size. This information was imported into a secure password protected Access database (created by Dataphiles Limited, West Yorkshire) by researchers at the UCL Institute of Child Health (ICH) to enable efficient fieldwork procedures.

The Access database was used for the following functions:

- To securely store the accelerometer project child identification numbers, names, waist circumference measurements and contact details of all consenting children.
- To automatically generate names and addresses on all cover letters for outgoing activity monitor packs.

- To automatically log (as a result of the cover letters being generated) all sent accelerometers.
- To manually log the identification of the accelerometer sent to each child.
- To automatically generate the identification labels for the timesheets.
- To manually log all returned accelerometers and timesheets.
- To automatically generate address labels for feedback certificates.
- To automatically log (as a result of the feedback certificate labels being generated) all feedback certificates sent.
- To automatically generate address labels for the reminder letters (these were generated automatically based on the accelerometer send date and a maximum lapsed time for non-return of the accelerometer).
- To automatically generate contact lists for reminder texts, e-mails or phone calls (based on the time lapsed from the accelerometer send date).
- To manually log any reminder texts, e-mails or phone calls.
- To manually log any lost or damaged accelerometers.
- To manually log any activity monitor packs, feedback certificates or reminder letters that were returned to the ICH by the postal service without reaching the family.
- To log any children that required their accelerometer to be resent.
- To securely record any phone or letter correspondence between the ICH and parents.

Accelerometer

Levels and patterns of PA and SB were measured using the ActiGraph GT1M bi-axial accelerometer (ActiGraph, Pensacola, Florida); a small (38 x 37 x 18 mm) and lightweight (27g) device. The ActiGraph GT1M measures acceleration in the vertical and anterio-posterior planes in the range of 0.05 to 2 *G* within a frequency range of 0.25-2.5 Hz, a range consistent with normal human movement and allows the rejection of high intensity vibrations. The Actigraph GT1M contains a solid state monolithic accelerometer and uses microprocessor digital filtering. Acceleration is summed over a user defined time period (epoch) and reported in the form of an activity count. The validity and feasibility of the ActiGraph in large scale studies in children has been previously discussed (section 3.5.1.1.2).

The MCS4 interviews took place over a 13 month period which meant that each accelerometer could be worn by more than one child. A total of 4,070 accelerometers were purchased based on the speed with which the monitors could be charged, distributed, worn, returned and prepared for subsequent use, taking into account accelerometer non- returns, loss and repair. Each accelerometer was identified by an irremovable label that stated a unique identification number and an ‘if found’ return telephone number. The accelerometer number provided an easier identification method than the unique serial number stored on the hardware of each accelerometer. A list of all accelerometer identification numbers and the corresponding serial numbers were stored on the fieldwork database in case any labels were removed.

Accelerometer charging and initializing

Accelerometers were fully charged by the fieldwork team before being sent out to families using multi-hub charging units that were each capable of charging six accelerometers at a time. Accelerometers were initialized using ActiLife Lifestyle Monitoring System software version 3.8.3 (ActiGraph, Pensacola, Florida). Initialization is the process of preparing the accelerometer to collect activity data[208]. The following parameters were selected to initialize all accelerometers:

- Activity (default mode): enabled
- Sampling epoch: 15 seconds
- Step count: enabled
- Flash light: disabled
- Start date: two days after posting to the families
- Start time: 05:00
- Subject information name: Unique child identification number

The shortest possible epoch (based on the number of wear days needed) was selected in order to capture the sporadic nature of children's PA[25 93 95]. Step count mode was selected because the memory and battery size of the ActiGraph GT1M enabled the MCS to collect step and count data, and created additional research opportunities. The flashing light mode was disabled for two reasons: 1) to conserve the battery life for collection of movement data, and; 2) to reduce the likelihood of children playing with their monitor.

Accelerometers were programmed to start collecting data two days after posting to the families because children were asked to start wearing them the morning after they received their activity monitor pack (allowing for one day of postage). The start time was selected for 05:00 as it was considered that this would be the earliest possible time that children would start wearing their accelerometer. A unique child identification number (corresponding to the identification stored in the Access database) was programmed into the accelerometer until download to ensure that all accelerometer data could be linked to the correct child.

Accelerometer distribution protocol

Due to the geographical disbursement of the MCS children accelerometers and corresponding documents were posted to families via Royal Mail first class delivery. Accelerometers were sent out in order of interview date unless parents/guardians had specifically stated at the interview that a date (within six weeks after interview) was not convenient. Distribution occurred between May 2008 and August 2009.

Consenting MCS families were sent a PA monitor pack that contained the following:

1. Parent cover letter (Appendix G)
2. Programmed accelerometer (attached to a belt)
3. Information leaflet (Appendix H)
4. Time sheet (Appendix I)
5. Letter for the child’s class teacher (Appendix J)
6. Pre-paid envelope

The cover letter explained the contents of the activity monitor pack, and briefly explained the wear and return protocol, in addition to providing a free-phone telephone number for the study. The letter also explained that if the accelerometer was lost or damaged families would not be charged for its replacement or repair, but should let the researchers at the ICH know.

The information leaflet contained detailed information regarding what the activity monitor was, how and when it should be worn, an explanation of the timesheet, what to do if they receive the monitor when their child was at school, how they should return the monitor and timesheet, information regarding feedback they would receive upon return of the accelerometer, and a free-phone telephone number to call if they had any further questions.

Families were asked to complete a timesheet, recording the time the accelerometer was first put on in the morning and taken off at night, and any periods during the day when the accelerometer was not worn (including time spent swimming). Additionally, parents were asked to record the amount of time their child spent cycling because the ActiGraph GT1M measures vertical accelerations, and cannot accurately assess the movement associated with non-ambulatory activities[29]. The timesheet contained the unique child identification number and the activity monitor number so that timesheets could be linked to a child even when they were returned separately from the corresponding accelerometer.

The letter for the child's class teacher contained details of the child's involvement in the study and explained when the child should wear the accelerometer. Parents could also record their child's monitor identification number to prevent device loss whilst at school - particularly important because several schools have more than one MCS child. Families were asked at the home interview whether they would like to receive one of 11 translated versions (Welsh, Turkish, Hindu, Punjabi, Tamil, Arabic, Kurdish, Bengali, Gujarati, Somali, and Urdu) of the parent cover letter, information leaflet and timesheet.

Accelerometer wear protocol

The MCS children were instructed to wear their accelerometer (attached to an elasticated belt) on the right hip. Children received either a 26" or 32" sized belt based on their waist size. Parents were informed that the monitor should be tightly, but comfortably, fitted to their child's body so that the accelerometer only moved when their child's body moved. They were also instructed to place the activity monitor on top of indoor clothing (not outdoor clothing such as coats). Children were instructed to wear their accelerometer for seven consecutive days during all waking hours, but were asked to remove it during aquatic activities as the accelerometers are not waterproof.

Families who informed the ICH that their child had been unable to wear their accelerometer as requested, and over a week had passed since they received it were asked to return the monitor so that it could be recharged and initialized for a more convenient date. Parents/guardians were asked to inform us if their monitor was lost or damaged. They were then issued with a new activity monitor pack.

Accelerometer return protocol

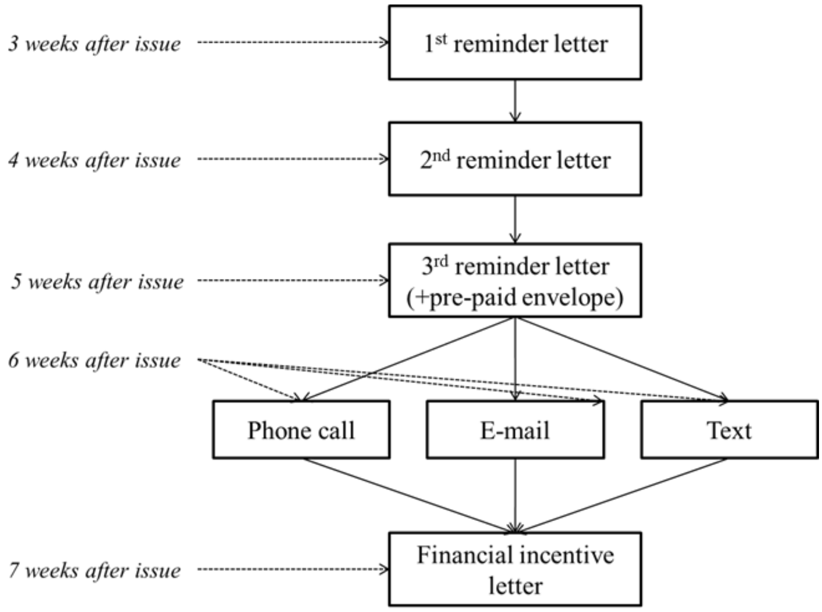
Families were asked to return their accelerometer (attached to the belt) and completed timesheet to the ICH as soon as possible after the monitoring period in a pre-paid envelope.

Reminder methods

Three postal reminder letters (Appendix K) were sent at weekly intervals to the MCS families who had not returned their accelerometer by three weeks after issue. An additional pre-paid envelope was provided with the third reminder letter. The reminder letters asked families to return their accelerometer and timesheet as soon as possible, and explained that if their child no longer wished to take part in the activity monitoring they should still return the activity monitor.

Further weekly reminders were issued by text, e-mail or phone call depending on the contact details held. A final reminder letter (Appendix L) was sent to all MCS families that had received three reminder letters and either a text, e-mail or phone call and had still not returned their accelerometer. The final reminder letter offered the family a £10 gift voucher for the return of their accelerometer. If families had lost their monitor they were asked to inform researchers by completing and returning an enclosed freepost postcard (Appendix M). Figure 16 shows the order and timing of the reminders issued to families not returning their accelerometer within the specified time period.

Figure 16: Order and timing of reminders issued



Feedback certificates

All parents that returned their child's accelerometer were sent a feedback certificate pack unless they had explicitly stated that the accelerometer had not been worn. The feedback certificate pack contained the following:

1. Certificate (Appendix N)
2. Set of PA graphs for their child (Appendix O)
3. Explanation letter (Appendix P)

The certificate was professionally designed and printed in colour, and thanked the children for participating in the PA monitoring study. Families were sent a set of graphs summarising their child's PA for every day that the child wore their monitor which were generated by an Access macro created by Philip Lindner (Somerset, UK). Each graph showed a red line that represented the count value at which MVPA was reached so that parents could see the daily amount of time their child met the current national PA guidelines.

The explanation letter thanked the family for taking part in the PA monitoring study, explained their child's PA graphs, and also gave a simple explanation of the graphs for their children. If the Access macro was unable to create any graphs for the child (likely to be because the accelerometer had not been worn but parents had not explicitly stated this) the family were sent a certificate and an alternative letter (Appendix Q).

4.3.2 Pilot study and dress rehearsal

A pilot and dress rehearsal study of the accelerometer protocol were completed during April 2007 and August 2007 that comprised 38 and 102 children respectively. Two reports were written detailing the findings of the pilot study (Appendix A) and dress rehearsal (Appendix B).

4.3.3 MCS4 seasonal accelerometer study

4.3.3.1 Background

The MCS4 accelerometer study also included a sub-study that investigated seasonal variation in levels and patterns of children's PA and SB. Repeated accelerometer measurements were obtained in each of the four seasons during a single calendar year from children who had already participated in the MCS4 accelerometer study. The MCS4 seasonal accelerometer study took place between November 2008 and October 2009.

4.3.3.2 Seasonal accelerometer fieldwork protocol

This study adopted the same fieldwork protocol as the main stage study.

Seasonal consent

All children who wore an accelerometer for the minimum wear period (Section 6.3) in the MCS accelerometer study during winter 2008/09 (November 2008 to January 2009) were invited to participate in the MCS4 seasonal accelerometer study. Parents were sent an invitation letter (Appendix R) explaining the purpose of the seasonal study and what it would involve for their child. Families were offered a £5 gift voucher for each season (£15 total) that their child wore and returned the accelerometer. Parents of those willing for their child to participate in the seasonal study were asked to sign and return a consent form (Appendix S).

Seasonal accelerometer distribution

Consenting families were posted an accelerometer at approximately three month intervals so that a measurement was made in each season throughout a single calendar year. Families were sent a text approximately a week before they were due to receive their accelerometer to confirm the suitability of the time period. If this was unsuitable, families contacted the researchers at ICH to reschedule a more suitable time. Seasonal accelerometer distribution periods were defined as: winter (November 2008 to January 2009); spring (February to April 2009); summer (May to July 2009), and; autumn (August to October 2009). These definitions are the same as those used by the ALSPAC seasonal study[108], and were chosen to increase our ability to make reliable comparison between study findings.

4.3.4 Accelerometer data management

4.3.4.1 Accelerometer data download

Data were downloaded from all returned accelerometers unless parents had explicitly stated that the accelerometer was not worn. Data were downloaded using the ActiLife Lifestyle Monitoring System software version 3.8.3.

4.3.4.2 Accelerometer data processing software

Data processing software was needed to clean and process the accelerometer files in order to produce the activity outcome variables that were used in analyses. A variety of accelerometer data processing software were tested for suitability, including KineSoft (KineSoft, Saskatchewan, Canada; www.kinesoft.org) MAHUffe (Medical Research Council Epidemiology Unit, University of Cambridge; http://www.mrc-epid.cam.ac.uk/Research/PA/Downloads.html) and a Microsoft™ Access 2000 programme developed specifically for the ALSPAC. After consideration of the available data processing software, researchers at the ICH (lead by Dr Marco Geraci) decided to develop their own processing software using algorithms developed in the R software environment for statistical computing (version 2.15.1)[209]. This processing software was favoured over others due to the following reasons:

- *Speed* - the ability to quickly clean, process and derive outcome variables for large volumes of accelerometer data files.
- *Expertise* – the statistical and accelerometer expertise at the ICH meant that the programme could be personalised to suit the needs of the MCS accelerometer study and modified when necessary.

- *Modifiable* - the ability to stipulate a 'true' starting wear date and to change all data processing decisions including: the EHCV threshold, non-wear and minimum wear time, and activity intensity thresholds.
- *Output* - the ease of importing batch reports of outcome variables into statistical packages for analyses, and the ability to modify which outcome variables are produced throughout the analyses phases.

4.3.4.3 Accelerometer data processing standard operating procedure

A series of cleaning and processing procedures were applied to the raw accelerometer data so that it could be used in subsequent analyses. The ICH researchers developed a standard operating procedure specifying a set of processing criteria[210]. Three processing stages of increasing level of data refining were identified.

Stage one

Stage one involved basic data cleaning and checked that the accelerometer metadata corresponded to the pre-defined accelerometer initialization parameters (including date range, date format, activity mode and epoch). The data were checked for the following: files containing all five digit values, files containing all one value, count values equal to 32,767, files containing counts that do not return to baseline, and negative values[211 212].

Stage two

Stage two included time stamping each count and step value using the start time and date together with the epoch, non-wear time classification, and the exclusion of low and high end days based on the definition of observational period. Non-wear was defined as any time period of consecutive zero counts for a minimum of 20 minutes[64].

The postal distribution and return of accelerometers resulted in a substantial amount of monitors being worn later than the programmed start date, and also many that continued to record data after the child had finished wearing the monitor (during posting). As a result, low and high end days needed to be excluded from analyses. Researchers at the ICH (Francesco Sera and Dr Mario Cortina-Borja) created a function using algorithms developed in the R software environment for statistical computing (version 2.15.1)[209] that detected the observational period for each accelerometer file. The start and end dates were detected based on a specified amount of daily waking time (defined as between 07:00 and 21:59) required to be different from zero counts.

A gold standard experiment on a random sample of 582 files was undertaken to test the validity of the R function. Using another customised R function, a graph was generated for each child showing the recorded count values according to the time and date of wear, and the start date for each child was manually selected. The manually selected start dates were then compared to the automatically generated start dates. Table 11 shows the sensitivity and specificity of the R function to determine the start date according to the minimum daily wear time. As the minimal daily wear time increased the sensitivity of the results automatically obtained by the R function decreased and the specificity increased, that is, the function's ability to correctly identify wear days as wear decreased, but the function's ability to correctly identify non-wear days as non-wear increased as the minimum daily wear time required increased.

Table 11: Sensitivity and specificity of the R function to automatically generate start date for accelerometer files

Minimum daily wear time (min)	Sensitivity (%)	Specificity (%)
60	99.4	92.0
90	98.6	96.9
120	98.1	98.6
150	97.6	99.2
180	96.5	99.6

Based on the results of this experiment the threshold for the observational period was set to at least 150 minutes per day. To determine the first and last days of the observational period, total wear time for each day was assessed. The first and last days with a total wear time exceeding the threshold were set as the start and end date respectively.

Stage three

Stage three included the removal of EHCV, defining reliable accelerometer data (according to the minimum daily wear time and the minimum number and distribution of wear days), defining SB, LPA, MPA, and VPA, and the creation of the summary outcome variables.

EHCV need to be removed prior to data analyses. Section 6.2 will define the threshold used to remove EHCV. Section 6.3 defines the minimum wear time criterion used by the MCS to determine whether children wore their accelerometer for a sufficient amount of time to be included in analyses.

We conducted our own calibration study in seven year old children (n=53)[213]. All children aged seven to eight years attending a North London primary school were invited to participate; written consent was obtained from parents prior to participation in the study.

The ActiGraph GT1M was calibrated against EE measures (kcal/kg/hour) over a range of activity intensities using a COSMED K4b^2 (COSMED, Rome, Italy) portable metabolic unit. This is small (70mm x 50mm x 100mm), lightweight (475g) indirect calorimetry system that is worn in a chest harness (Figure 17). Children wore the accelerometer on their right hip whilst taking part in seven activities of increasing intensity. These activities were selected because they provide a range of activity intensities, from sedentary to vigorous, and also reflect typical free-living activities of seven year olds. The activities were as follows:

1. Lying down watching a DVD (30 minutes)
2. Sitting playing a computer game (five minutes)
3. Slow walking (five minutes)
4. Brisk walking (five minutes)
5. Jogging (five minutes)
6. Hopscotch (five minutes)
7. Basketball including dribbling, running, and shooting (five minutes)

Figure 17: The COSMED K4b^2 and Actigraph GT1M accelerometer

Threshold values for the accelerometer cpm were defined as less than 100 for SB, and 100 to 2,240, 2,241 to 3,840, and greater than 3,840 for LPA, MPA, and VPA respectively. These thresholds were therefore used when deriving the PA summary variables.

Comparison of the MCS activity thresholds with those generated by other studies are complicated due to the variation in sample age, criterion measure, accelerometer protocol, and the activities undertaken as part of the study. Table 12 compares the MCS activity intensity thresholds with those defined by a number of previous studies using children of similar ages[50 98 170 177].

Table 12: Thresholds generated by the Millennium Cohort Study and other calibration studies in children

	Puyau *et al*, 2002[98] (*n*=26)	Treuth *et al*, 2004[177] (*n*=74)	Mattocks *et al*, 2007[170] (*n*=163)	Evenson *et al*, 2008[50] (*n*=33)	Pulsford *et al*, 2011[213] (*n*=53)
Sample age (years)	6-12	13-14	12	5-8	7-8
SB (cpm)	≤ 800	≤ 100	-	≤ 100	≤ 100
LPA (cpm)	8001-3200	101-2999	-	101-2292	101-2240
MPA (cpm)	3201-8200	3000-4999	3581-6129	2293-4008	2241-3840
VPA (cpm)	≥ 8201	≥ 5000	≥ 6130	≥ 4009	≥ 3841

4.3.4.4 Derived physical activity variables

Table 13 reports the main PA and SB variables that were generated by our data processing software.

Table 13: Variables created by accelerometer data processing software

Variable name	**Variable label**
MCSID	MCS Research ID
DCNUM00	Cohort member number
MBSTATUS	Multiple birth status
N_DAYS_V	Total number of reliable* days
N_WEDAYS_V	Total number of reliable weekend days
N_WKDAYS_V	Total number of reliable week days
TREGTIME_V	Total time worn (minutes) across all reliable days
TOT_NW_V	Total non-wear time across all reliable days (minutes)
TOTCOUNT_V	Total sum of counts across all reliable days
MNCOUNT_V	Daily mean counts across all reliable days
TOTPATY99_V	Total time (minutes) recorded as extreme high count values across all reliable days
TOTPATY0_V	Total time (minutes) spent in sedentary behaviour across all reliable days
MNPATY0_V	Mean time (minutes) spent in sedentary behaviour across all reliable days
TOTPATY1_V	Total time (minutes) spent in light activity across all reliable days
MNPATY1_V	Mean time (minutes) spent in light activity across all reliable days
TOTPATY2_V	Total time (minutes) spent in moderate activity across all reliable days
MNPATY2_V	Mean time (minutes) spent in moderate activity across all reliable days
TOTPATY3_V	Total time (minutes) spent in vigorous activity across all reliable days
MNPATY3_V	Mean time (minutes) spent in vigorous activity across all reliable days
TOTSTEPS_V	Total sum of steps across all reliable days
MNSTEPS_V	Daily mean steps across all reliable days
CPMR_V	Mean counts per minute (reliable days)

Taken from Geraci et al, 2012[210]

4.3.5 Ethics

Research ethics approval for the MCS4 main stage and seasonal accelerometer studies was granted by the Northern and Yorkshire Research Ethics Committee (REC number: 07/MRE03/32) and the UCL Research Ethics Committee (REC number: 1325/ 002) respectively.

4.3.6 Funding

The MCS4 main stage and seasonal accelerometer studies were funded by the Wellcome Trust (grant 084686/Z/08/A). CR was funded by this grant. The MCS accelerometer calibration study was funded by the International Centre for Child Studies. The Medical Research Council Centre of Epidemiology for Child Health is supported by funds from the UK Medical Research Council (grant G0400546). Research at the ICH & Great Ormond Street Hospital for Children receives a proportion of funding from the Department of Health's National Institute for Health Research Biomedical Research Centres funding scheme.

4.4 Data linkage

Data obtained from the MCS4 accelerometer fieldwork database had to be linked with the derived PA and SB summary variables, which also had to be linked to the MCS1-4 interview data. Once the MCS4 accelerometer fieldwork was completed, all related fieldwork databases, accelerometer files and timesheets were handed over to the data management team at the CLS, and all identifying information held by the ICH was destroyed.

The UK Data Archive makes use of a unique `MCSID`, which is a unique identifiable variable for each family involved in the MCS. A second identifiable variable, `CHILDNO`, is used in combination with the `MCSID` to identify individual cohort children. The link between the personal data and the `MCSID` is only held by the CLS. The CLS data management team used mapping files to replace the ICH accelerometer fieldwork identifiers with the `MCSID` (`CHILDNO` was retained in the database) to enable linkage. The MCS1 to 4 interview data were obtained from the UK Data Archive, University of Essex, and linked to the accelerometer fieldwork data and derived accelerometer variables using STATA 12.1 (Stata Corporation, Texas, USA).

4.5 Interview variables

The interview variables used in analyses for this thesis are reported in Table 14. The majority of these have been previously described[214-216]. The variables selected for data analyses were chosen based on prior evidence of factors associated with PA and SB in children[13 183 184].

Table 14: Millennium Cohort Study variables, sweep of data collection and factor levels of analysis

Factor	Age of child at data collection	Level for Analysis
Biological		
Child's gender	7 years	Male; female
Child's ethnicity[a]	7 years	White; mixed; Indian; Pakistani/Bangladeshi; black or black British; other
Child's BMI[b]	7 years	Underweight/normal weight; overweight/obese
Social		
Mother's age at birth (years)	9 months	14-19; 20-29; 30-39; ≥ 40
Maternal current occupation[c]	7 years	Managerial & professional; intermediate; small employers & own account workers; lower supervisory & technical; semi- routine & routine; non-employed
Maternal highest academic qualification	7 years	Degree(s)/ post graduate diplomas; higher education/ teaching qualifications/ diplomas; A/AS/S-levels; O-levels/GCSE grades A-C; GCSE grades D-G; other academic qualifications; none of these
Lone parent status	7 years	Non-lone parent; lone parent
Number of children in the household (including the cohort child)	7 years	1; 2-3; ≥ 4
Main household language	7 years	English only; English and other language; non-English speaking
Whether anyone smokes near the child	7 years	Yes; no
Whether the mother is in work or not	7 years	In work or on leave; not in work or leave

Main housing tenure	7 years	Own outright, own mortgage/loan, part own/mortgage; rent from local authority or housing association; rent privately; other
Type of accommodation	7 years	House or bungalow; flat or maisonette; studio, room, bedsit, other
Household income (per year)	7 years	<£10400; £10400-20800; £20800-31200; £31200-52000; >£52000
Behavioural		
Whether the child has any illnesses or disabilities that limits activity	7 years	Yes; no
Number of days a week the child participates in sport or exercise: parent report	7 years	≥ 3 days/week; 2 days/week; 1 day/week; less often/not at all
Number of hours the child watches TV on weekdays	7 years	less than an hour/not at all; 1-3 hours; 3-5 hours; > 5 hours
Whether the child was ever breastfed	9 months	Yes; no
Environmental		
Access to garden	7 years	Yes; no
Ward type	9 months	Advantaged; disadvantaged; ethnic
Government office region	7 years	North East; North West; Yorkshire and the Humberside; East Midlands; West Midlands; East of England; London; South East; South West; Wales; Scotland; Northern Ireland; Isle of Man/Channel Islands
UK country	7 years	England; Wales; Scotland; Northern Ireland

[a] Categorised according to guidelines from the Office for National Statistics[217]
[b] BMI calculated from weight (measured to the nearest 0.1kg) divided by height (measured to the nearest 0.1cm) squared. BMI categories defined using the International Obesity Task Force cut-off for BMI[218]
[c] Classified according to the National Statistics Socio-economic Classification[219]

5 Chapter 5: Accelerometer fieldwork report

5.1 Chapter overview

This chapter provides a comprehensive report of the MCS4 main stage accelerometer fieldwork including the consent rate, accelerometers sent and returned, reminders issued and reliable data acquisition. The success of using a postal methodology to distribute and return accelerometers in the MCS4 is compared to other large scale accelerometer studies using face-to-face distribution and return methods.

5.2 Introduction

The majority of previous large scale accelerometer studies have involved a demonstration of the activity monitor to participants and distributed them in the context of a face-to-face meeting within a clinic[61 113 130] or school setting[64 120 123 131 143 145 149 152 153 158 162 163 166 167]. Although effective, the cost and time constraints of this method of data collection can be substantial, particularly in large studies where subjects are geographically dispersed. The use of postal methods to distribute and return accelerometers has the potential to achieve higher population coverage than face-to-face administering and return, whilst also potentially reducing time and financial costs. Despite this, there is a lack of studies that have demonstrated the use of postal methods to distribute and return accelerometers. Only one large scale study has used postal methods to distribute and return accelerometers[17], and another two have shown that accelerometers can be successfully returned by post[61 130]. There are no large scale studies in UK children that have reported the use of this method.

Research involving children requires parents to give consent for their child to participate in the study. Gaining consent is vital in studies that require personal data to be obtained, for example, in postal studies where contact and address details are required. The consent rate obtained in previous large scale accelerometer studies in children using face-to-face distribution methods ranges from 27%[165] to 100%[164]. It is not known if using a postal methodology to distribute and return accelerometers influences consent rate.

PA studies usually ask participants to wear their accelerometer for a fixed period of time; normally during all waking hours for seven consecutive days[61 130]. Studies have used a variety of reminder methods and incentives to increase the likelihood of children wearing and returning their accelerometer as requested. Reminder methods that previous accelerometer studies have used include the completion of accelerometer wear timesheets, reminder letters and phone calls, and staff visits throughout the monitoring period to the contact site (e.g. the school). Incentives that previous accelerometer studies have offered include certificates, toy prizes, money, vouchers and graphs showing the child's activity throughout the monitoring week. Despite the use of various reminder methods and incentives, children do not always wear their accelerometer for the whole requested time period.

Reliable data acquisition is important for researchers to consider when calculating study sample size. Researchers need to account for loss of data from non-consenting children, consenting children not returning accelerometers, and from returned accelerometers not containing reliable data. In nearly all large scale accelerometer studies using face-to-face distribution methods the proportion of consenting children returning reliable data has been reported: ranging from 50%[132] to 100%[164].

There is a greater risk to the acquisition of reliable data using postal distribution and return methods, compared to face-to-face methods because of the increased reliance on external factors such as an efficient postal service and reliance on subjects to return their monitors. It is likely that some children will not return their accelerometer, and even if children return their accelerometer they may not wear them for a long enough time period.

5.3 Aim

The main aim of this chapter is to provide a report of the MCS4 main stage accelerometer fieldwork and to also discuss the success of using postal methods to distribute and return accelerometers in the MCS4 compared to alternative distribution and return methods.

5.4 Methods

5.4.1 Subjects

All children (*n*=14,043) that took part in the MCS4 main stage interviews.

5.4.2 Statistical analyses

Summary statistics were calculated using STATA 12.1. Frequencies and percentages are reported for all categorical variables.

5.5 Results

5.5.1 MCS4 interview

A total of 19,244 families were eligible for inclusion in the MCS4 interviews, of which 13,857 families (14,043 children; 72% response rate) were productive in the MCS4 interviews (i.e. some data was obtained regarding the child and/or their parents; Table 15)[207].

Table 15: Millennium Cohort Study fourth sweep overall interview response

Outcome		**Number of families (*n*)**	**Proportion of potentially eligible families (%)**
Productive		13857	72.0
Ineligible (emigrant families, deaths)		488	2.5
Uncertain eligibility (away temporarily, untraced movers)		848	4.4
Unproductive	Refusals	3516	18.3
	Non-contact	149	0.8
	Other (language problems, ill/ incapacitated, deleted/ lost data)	386	2.0
Total		*19244*	*100.0*

Taken from Gray et al, 2010[207]

5.5.2 MCS4 main stage accelerometer study

5.5.2.1 Consent

Protocol breaches

The fieldwork team at the ICH received the personal details of 12,816 'apparent' consenting children. However, during the course of the MCS4 main stage accelerometer fieldwork two protocol breaches occurred relating to a small number of families (*n*=144) who had not given written consent for their child to participate in wearing an accelerometer, and as such, their contact details should not have been sent to the ICH fieldwork team. The protocol breaches were reported to the research ethics committee and are detailed in Appendix T.

Delay in receiving funding

The MCS4 interviews started in January 2008. Funding for the MCS4 accelerometer study was received on 22nd May 2008. The delay in receiving funding resulted in a backlog of consenting children awaiting an accelerometer. As a result, the ICH wrote to approximately 9,000 families to inform them that there would be a delay in the delivery of accelerometers. The apology letter (Appendix U) asked families to contact the ICH if they, or their child, no longer wanted to take part in the study. In response to this letter, a total of 15 families withdrew consent for their child to participate in the study.

Verifying consent variable

Once the accelerometer fieldwork had been completed, the ICH verified those children who were considered to have consented (as their details were given to them during the fieldwork) with the accelerometer study consent variable generated by the data management team at the CLS. As a result of this, 114 children were identified by the CLS as non-consenters, but their details were sent to the ICH during fieldwork. All of these children were sent an accelerometer: 81 were returned and 41 of these contained reliable data (section 6.3). The accelerometer data from these children has been included in analyses unless otherwise stated. Details of 565 consenting children were also not transmitted to the ICH fieldwork team, and therefore, these children were not sent an accelerometer.

Sample

A total of 13,219 out of 14,043 (94.1%) interviewed parents gave consent for their child to participate in the MCS4 main stage accelerometer study (Table 16).

Table 16: Millennium Cohort Study main stage accelerometer study consent rate

Consent obtained	**Reason**	**Number of children (*n*)**	**Proportion of children interviewed (%)**
YES	Details given to the ICH	12654	90.1
	Details not given to the ICH	565	4.0
NO	Non-consent at interview	665	4.7
	Non-consent but details given to ICH in error – identified after fieldwork	114	0.8
	Non-consent but details given to the ICH in error-identified during fieldwork	30	0.2
	Withdrew consent following delay	15	0.1
Total		14043	100.0

5.5.2.2 Children

Children sent an accelerometer

A total of 12,773 children were sent at least one accelerometer (Figure 18). This included 148 children that did not consent but the ICH received their details as a result of one of the protocol breaches (*n*=144), or they withdrew consent following the delay in fieldwork (*n*=4). Accelerometers were sent to 12,625 (95.5%) consenting children; 29 (0.2%) consenting children were not sent a monitor because the fieldwork team were unable to send it during the requested time period (i.e. the date had passed or was beyond the study end date), and 565 (4.3%) children were not sent an accelerometer because their details were not transmitted to the ICH fieldwork team.

Children returned an accelerometer

A total of 10,136 out of 12,773 (79.4%) children who were sent an accelerometer returned it (this included 10,034 consenting children and 102 children who had not consented due to the protocol breach explained earlier in section 5.5.2.1).

Children with a saved accelerometer files

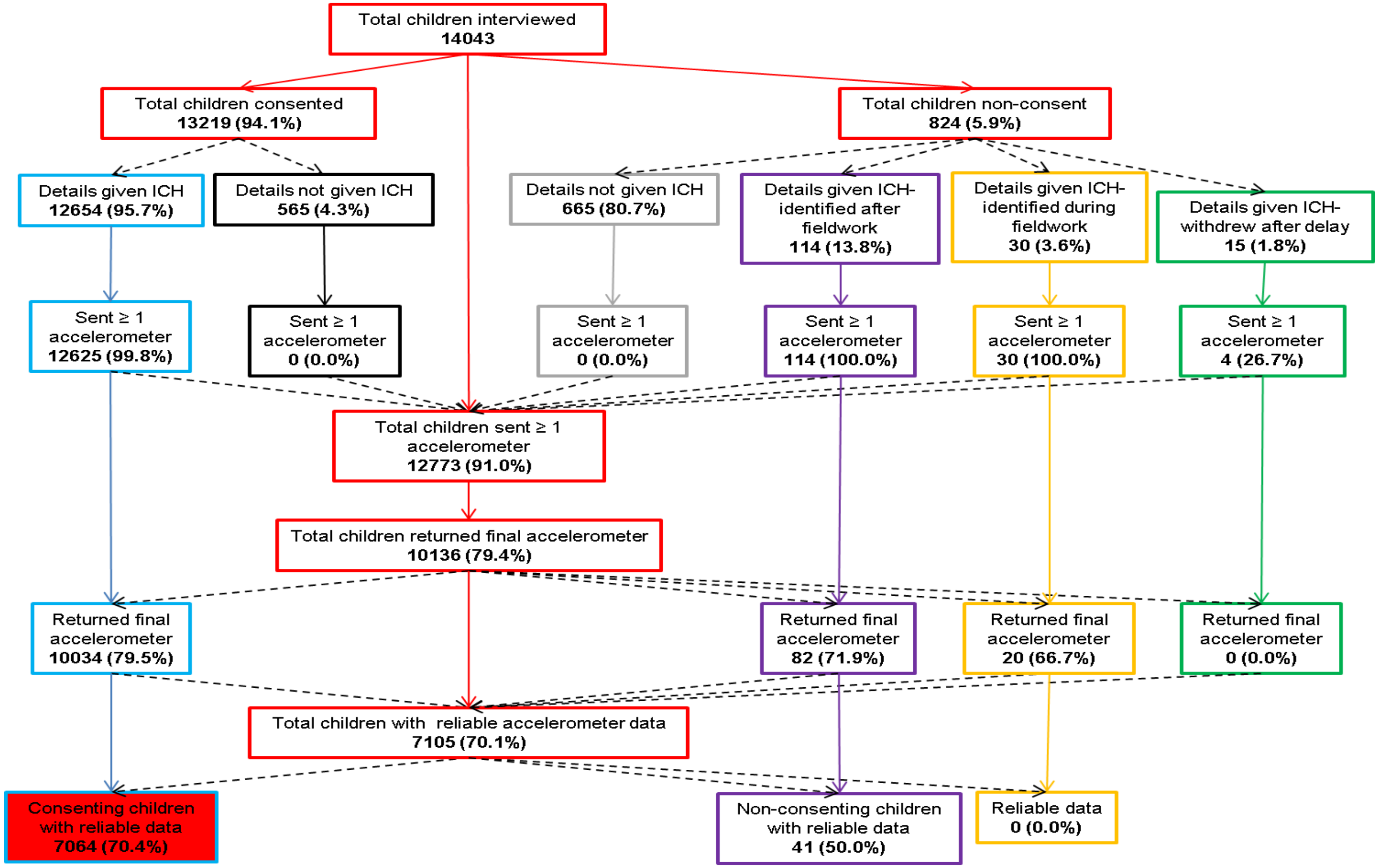
An accelerometer file was saved and processed (i.e. all families that returned their child's final accelerometer unless they had explicitly stated that the accelerometer had not been worn) for 9,005 MCS children, of which 8,939 were consenting MCS children.

Children with reliable data

We obtained reliable accelerometer data (≥ two days, ≥ 360 minutes per day; section 6.3) from 7,105 children. Reliable data was obtained from 7,064 (53.4%) consenting children.

Figure 18 provides an overall summary of children in the MCS4 main stage accelerometer study according to reasons for consent or non-consent.

Figure 18: Summary of children in the main stage accelerometer study according to reasons for (non-) consent



Please note: percentages are calculated using the *n* of the previous text box as the denominator

5.5.2.3 Accelerometers

Accelerometers sent

Overall, a total of 13,489 accelerometers were distributed to the MCS4 children (Table 17): 716 extra monitors were distributed because the child's initial accelerometer was either lost (*n*=150), damaged (*n*=6), or needed recharging once (*n*=550) or twice (*n*=10). When considering only consenting children, a total of 13,336 accelerometers were distributed, including 12,625 initial accelerometer sends.

Table 17: Accelerometers sent to the children by sending reason and (non-) consent

		Number of accelerometer sends according to the following sending reason					
Consent obtained	**Reason**	**Initial send**	**1st recharge resend**	**2nd recharge resend**	**Lost resend**	**Damaged resend**	***Total***
YES	Details given to the ICH	12625	547	10	148	6	*13336*
NO	Non-consent but details given to ICH in error– identified after fieldwork	114	3	0	2	0	*119*
	Non-consent but details given to the ICH in error- identified during fieldwork	30	0	0	0	0	*30*
	Withdrew consent following delay in receiving monitor	4	0	0	0	0	*4*
Total		12773	550	10	150	6	*13489*

Accelerometers returned

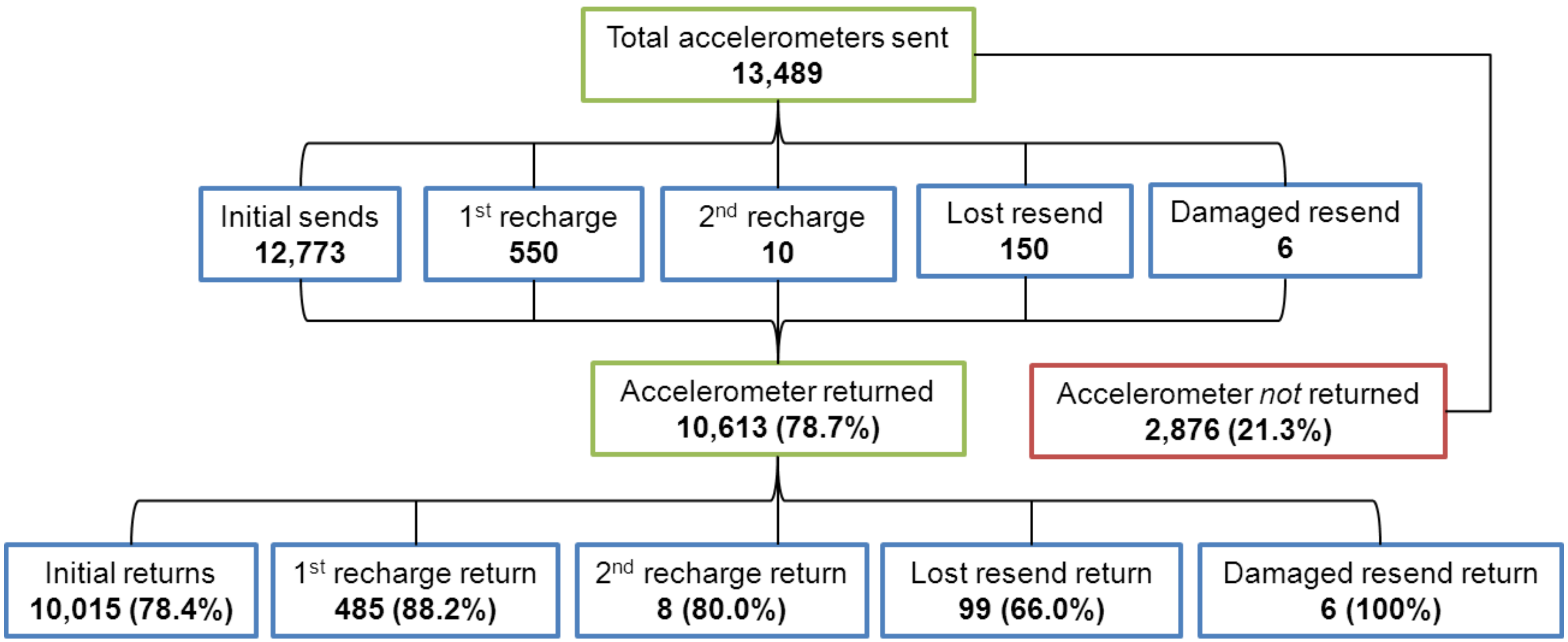
A total of 10,613 out of 13,489 (78.7%) sent accelerometers were returned (Table 18).

Table 18: Accelerometers returned by the families according to (non-) consent

Consent obtained	**Reason**	**Number of sent accelerometers returned (%)**	**Number of sent accelerometers *not* returned (%)**	***Total***
YES	Details given to the ICH	10509 (78.8)	2827 (21.2)	*13336*
NO	Non-consent but details given to ICH in error– identified after fieldwork	84 (70.6)	35 (29.4)	*119*
	Non-consent but details given to the ICH in error- identified during fieldwork	0 (0.0)	4 (100.0)	*4*
	Withdrew consent following delay in receiving monitor	20 (66.7)	10 (33.3)	*30*
Total		10613 (78.7)	2876 (21.3)	*13489*

Figure 19 summarises the accelerometers returned by the MCS families according to the sending reason. Families were least likely return their accelerometer if it had been sent after their previous accelerometer had been lost (66.0% of those sent following a lost monitor).

Figure 19: Accelerometers sent to, and returned by the children



Reasons for accelerometer (non-) return

A total of 568 families reported that they or their child had lost the monitor, largely reporting that they had not received it in the post, however, 53 (9.3%) of these families subsequently returned their lost accelerometer (Table 19). Overall, a total of 515 out of 13,489 (3.8%) sent accelerometers were reported lost and not found. There were 12 accelerometers that were reported to be damaged, of which five were returned. A total of 961 (7.1%) returned accelerometers were reported to be not worn, largely because the child or family had subsequently changed their mind about taking part in the study. Overall, 585 families contacted the ICH to inform the fieldwork team that they needed to return their accelerometer for a recharge as their child had not worn the accelerometer as soon as they had received it: 498 (85.1%) of these families subsequently returned their monitor for a recharge. There were 26 accelerometers returned in the post undelivered, either because the addressee was unknown at the address or because the address could not be accessed.

Table 19: Accelerometers returned and not returned by the children by type of return and sending reason

	Initial sends	**1st recharge resends**	**2nd recharge resends**	**Lost resends**	**Damaged resends**	**Total**
Total returned (% of accelerometers sent)	10015 (78.4)	485 (88.2)	8 (80.0)	99 (66.0)	6 (100.0)	10613 (78.7)
Returned (no other)	8,524	449	5	86	6	9070
Lost returned	52	1	0	0	0	53
Returned damaged	5	0	0	0	0	5
Returned for recharge	488	8	0	2	0	498
Returned undelivered	25	1	0	0	0	26
Returned unworn	921	26	3	11	0	961
Total not returned (% of accelerometers sent)	2758 (21.6)	65 (11.8)	2 (20.0)	51 (34.0)	0 (0.0)	2876 (21.3)
Not returned (no other)	2,163	55	2	47	0	2,267
Lost	502	9	0	4	0	515
Damaged not returned	6	1	0	0	0	7
Returning for recharge not returned	87	0	0	0	0	87

5.5.2.4 Reminder methods

Reminder letters

A total of 15,643 reminders letters were sent to the MCS families to encourage return of the accelerometers. Table 20 reports the numbers of reminder letters that were sent to families and the number of accelerometers that were returned after receiving a letter.

Table 20: Reminder letters sent and subsequent accelerometers returned by sending reason

Sending reason	**1st reminder letters sent (*n*)**	**Monitors returned after 1st letter**	**2nd reminder letters sent (*n*)**	**Monitors returned after 2nd letter**	**3rd reminder letters sent (*n*)**	**Monitors returned after 3rd letter**
Initial send	5972	797	5116	665	4407	1356
1st recharge resend	64	24	35	10	21	9
Damaged Resend	0	0	0	0	0	0
Lost resend	19	5	5	0	4	2
2nd recharge resend	0	0	0	0	0	0
Total sends (%)	*6055*	*826 (13.6)*	*5156*	*675 (13.1)*	*4432*	*1367 (30.8)*

Text, phone, e-mail and incentive reminders

Table 21 summarises the additional reminders issued and the MCS families returning an accelerometer after reminder issue. A total of 5,025 phone calls, texts, e-mails, or final incentive letters were sent which resulted in 635 accelerometers being returned.

Table 21: Additional reminders issued and subsequent families returning an accelerometer

Reminder issued	**Families received reminder**	**Families returning an accelerometer after reminder (%)**
Phone call	225	30 (13.3)
Text	1690	193 (11.4)
E-mail	385	48 (12.5)
Final incentive letter	2725	364 (13.4)
Total	*5025*	*635 (12.6)*

5.5.2.5 Timesheets

Overall, a total of 6,970 (54.6%) timesheets were returned by the MCS families (Table 22).

Table 22: Timesheets returned by children according to the sending reason

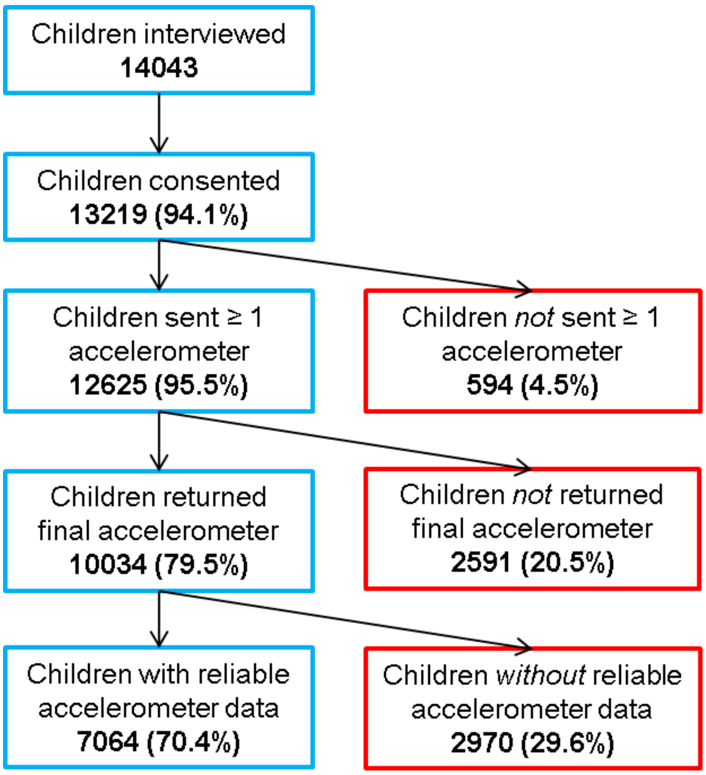
Sending reason	**Children returning final timesheet (%)**	**Children *not* returning final timesheet (%)**
Initial send	6482 (53.7)	5590 (46.3)
1st recharge resend	410 (76.6)	125 (23.4)
2nd recharge resend	4 (40.0)	6 (60.0)
Lost resend	69 (46.0)	81 (54.0)
Damaged Resend	5 (83.3)	1 (16.7)
Total	*6970 (54.6)*	*5803 (45.4)*

5.6 Discussion

5.6.1 Summary of fieldwork

In this nationally representative cohort of UK children, a high proportion of families (94.1% of children interviewed; *n*=13,219) agreed to take part in a study that used postal methods to distribute and return accelerometers in order to measure children's SB and PA. A total of 13,489 accelerometers were sent to 12,625 consenting children across the UK: 10,613 (78.7%) of these accelerometers were returned. The use of a postal methodology enabled the MCS to acquire a large volume of reliable accelerometer data (*n*=7,064; 53.4% of consenting children). This was achieved with the help of an effective reminder system. The MCS4 main stage accelerometer study fieldwork for consenting children is summarised in Figure 20.

Figure 20: Overall summary of children in Millennium Cohort Study main stage accelerometer study (consenting children only)



Please note: percentages are calculated using the *n* of the previous text box as the denominator

5.6.2 Comparison with existing research

Our ability to compare our findings with other studies is limited as few studies have used postal methods to return accelerometers[61 108 130], and only one study has reported using postal methods to distribute and return accelerometers[17].

The MCS achieved a higher consent rate (91%) than nearly all large scale studies (*n*=21; 3.5.1): only the ALSPAC[138], and rural Saskatchewan children participating in Esliger *et al's*[164] study achieved a higher consent rate (93% and 100% respectively). The method of accelerometer distribution and return did not seem to influence study consent rate.

Matthews *et al*[208] reported that 5% of accelerometers were lost when they distributed them by post to participants. Despite the use of various reminders, 4% of accelerometers sent to the MCS children were reported lost (*n*=515), and a further 21% (*n*=2,876) of accelerometers were not returned. The National Health and Nutrition Examination Survey (NHANES)[130] and the ALSPAC[61] also required subjects to return their accelerometer by post, however, published articles using accelerometer data from these studies have not reported accelerometer return or loss. Page *et al*[145] distributed and collected accelerometers via school visits to 1,300 eleven year old UK children: only 23 (1.8%) children failed to return their accelerometer or returned it broken.

We were unable to download data from 27 accelerometers (0.3% of accelerometers returned), which was considerably less than the number reported by the ALSPAC who used the older ActiGraph 7164 model. Van Coevering *et al*[132] also used the ActiGraph 7164 and were unable to download data from 9.6% (*n*=27) of children issued with accelerometers. Few other large scale accelerometer studies report the reasons for data loss. However, several smaller studies have reported the following reasons: battery malfunction[178 180], monitor malfunction[160 179 180 225], monitor software failure[178], broken accelerometers[145], accelerometer loss[132 160 225], and the child forgetting to wear the monitor[160 178 179]. Studies that have distributed and collected accelerometers via school visits have reported data loss due to child absence or because participants had moved school during the monitoring period[123 132 145].

The MCS obtained a lower proportion (56%; *n*=7,064) of reliable data from consenting children than other large scale accelerometer studies in children using face-to-face distribution methods: rates of reliable data acquisition range from 50%[132] to 100%[164]. The use of a postal methodology to return accelerometers may reduce reliable data acquisition due to the increased reliance on external factors such as an efficient postal service and relying on subjects to return their accelerometers. However, the ALSPAC[138] obtained reliable data from 78% (*n*=5,595) of consenting children that returned their accelerometers via post. The IOWA Bone Development study used postal distribution and return methods and also obtained a higher proportion (87%) of reliable data from consenting children (*n*=368) than the MCS. However, the IOWA Bone Development Study was conducted using a smaller and more geographically clustered sample than the MCS.

The proportion of children returning reliable accelerometer data is highly dependent on the study definition of the minimum wear time threshold (section 6.3). For example, the CHASE defined the minimum wear time period as at least one wear day lasting at least 600 minutes per day, and obtained reliable data from 97% (*n*=2,071) of consenting children[64]. The NHANES defined the minimum wear time period as at least four days lasting at least 600 minutes per day, and obtained reliable data from 71% of boys and 69% of girls aged 6 to 11 years, and from 62% of boys and girls aged 12 to 19 years[130]. However, if the NHANES used the same minimum wear time threshold as used by the CHASE then the proportion of reliable data obtained by these two studies would be comparable: reliable accelerometer data would have been acquired from 95% of 6 to 11 year old boys and girls, and from 91% and 90% of 12 to 19 year old boys and girls respectively.

The MCS distributed various incentives and reminders to encourage compliance with the accelerometer wear protocol and timely return of accelerometers. A total of 6,055 (45%) accelerometers sent to the MCS children were issued at least one reminder for its return. Other large scale studies have not reported the success of issuing reminders. In addition, relatively little systematic research has been conducted to evaluate the best reminder and incentive methods to encourage wear and return of accelerometers[208]. To my knowledge, only one study[181] has evaluated the effectiveness of various reminder and incentive strategies on reliable data acquisition, and this was done in a small sample of children (*n*=87).

5.6.3 Future practice

Considerable effort before, during and after accelerometer posting is needed to maximise return rate, and reduce data and accelerometer loss in studies adopting this method of data collection. Prior to starting the study, researchers must determine the number of accelerometers required for data collection. Several factors need to be taken into account when calculating the number of accelerometers needed, including: the number of children receiving accelerometers; the length of the accelerometer wear protocol; the speed that accelerometers can be distributed, worn, returned, and prepared for subsequent use (taking into account staff availability, reliability of the postal system, available charging units), and; the anticipated loss of accelerometers. Researchers are also advised to determine how many charging units are needed to charge the required amount of accelerometers that need to be distributed each day. In addition, they need to decide the most suitable method of accelerometer attachment to the children. There were no problems encountered with the use of elastic belts in the MCS, with all children given a belt that corresponded to their waist size. The accelerometers should also be labelled with an identification sticker for quick reference for both researchers and subjects. This is particularly useful if more than one child at the same school is wearing an accelerometer at the same time.

In accelerometer studies involving home interviews, it is also advisable to supply the interviewers with accelerometers (real or dummy) to demonstrate the correct placement of the monitor. Interviewers are also advised to ask the parents if there are any upcoming dates that are not suitable for them to receive the accelerometer. Families should be given a free-phone number to call if they have any questions or problems before, during, or after the monitoring period.

The information documents that accompany the accelerometers must clearly explain the wear protocol. To reduce accelerometer loss during posting, ‘return to sender’ information was pre-printed on the activity monitor pack envelopes in the MCS. A review by Edwards *et al*[37] evaluated the methods to increase response rates to postal questionnaires and highlighted the need to send outgoing mail by first class or recorded delivery post, and to also supply subjects with a stamp returned envelope. The present study, as well as several other large studies[2;7] supplied subjects with pre-paid envelopes that provided sufficient strength and padding for safe accelerometer return. The outgoing accelerometer packs should also be posted to families using secure envelopes to prevent accelerometer loss or damage.

Subjects should be given a timesheet to record the time they put on and took off the accelerometer, the length of time they spent swimming and cycling, and the length of time that they forgot to wear the monitor. The timesheet can be used to verify compliance with accelerometer wear protocols and to troubleshoot any reasons for problem data (e.g. distinguishing periods of non-wear from SB)[208]. It also encourages and reminds subjects to wear their monitor as requested. The information documents sent to families should remind them to enclose their completed timesheet when returning their accelerometer.

It is important in large scale studies that an efficient database is used to enable the timely sending of accelerometers and reminders, to track outstanding accelerometers, store subject details, and report any correspondence with study families. Staff must be trained in using the database and be able to quickly charge, program, and distribute the accelerometers.

Reminder letters, texts, e-mails, and phone calls are all effective methods to increase the likelihood of accelerometer return. Due to the widespread use of mobile phones and the internet, text messages and e-mails are a fast and cost effective way to contact subjects. Phone calls are more time consuming and within this study often led to answer phone messages rather than personal contact. However, when a researcher was able to speak to a parent many of them did subsequently return their child's accelerometer. Providing an extra pre-paid envelope with a reminder letter proved valuable as accelerometer return rate was highest after families received their third reminder letter. The financial incentive offered in the last resort reminder letter also proved to be an effective method of encouraging families to return their accelerometer.

Future studies should report the success of their fieldwork so that other researchers can compare and learn from previous experience. Further research is also needed to evaluate the most effective reminder methods and incentives to encourage the correct wear and timely return of accelerometers. Additional research could also investigate whether the distribution of all reminders was cost-effective (taking into account, staff, incentive, and postal costs) in relation to the number of accelerometer returned as a result of the reminder system.

5.7 Conclusion

The findings from the MCS accelerometer fieldwork show a good degree of acceptability from parents and children in relation to the consent and wear of an accelerometer that was distributed and returned by postal methods for the purposes of measuring SB and PA. Although large scale accelerometer studies in children using face-to-face distribution methods obtained a higher proportion of reliable accelerometer data than the MCS, our study demonstrates that a large volume of data can be obtained by using a postal distribution methodology. Considerable efforts are required before, during, and after accelerometer posting to maximise return rate and reduce the likelihood of data and accelerometer loss.

5.8 Key points

MCS children

- 13,219 out of 14,043 (94.1%) interviewed parents gave consent for their child to participate.
- Accelerometers were sent to 12,625 (95.5%) consenting children: 10,034 (79.5%) of these were returned.
- An accelerometer file was saved for 8,939 (67.6%) consenting children.

- Reliable data (≥ two days, ≥ 360 minutes per day) was obtained from 7,064 (53.4%) consenting children.

Accelerometers

- 13,489 accelerometers were distributed to 12,773 MCS4 children (includes 148 non-consenting children).
- 716 extra monitors were distributed to consenting children because the first accelerometer was either lost (*n*=150), damaged (*n*=6), or needed recharging once (*n*=550) or twice (*n*=11).
- 10,613 (78.7%) sent accelerometers were returned.
- 4,558 (42.9%) returned accelerometers were returned without the use of a reminder; 6,055 (44.9%) sent accelerometers were issued at least one reminder.

6 Chapter 6: Quality control procedures in accelerometer data processing

6.1 Chapter overview

This chapter describes a piece of work that uses the MCS4 main stage accelerometer data to explore two quality control procedures that researchers need to consider when processing accelerometer data. The chapter has two separate studies:

- Section 6.2 explores EHCV by firstly, proposing an EHCV threshold, and secondly, determining: (i) typical error values recorded by the ActiGraph GT1M and the consistency of pre-defined accelerometer initializing parameters (e.g. start time and date, epoch mode); (ii) frequency of EHCV, and; (iii) the influence of varying the approach to determine EHCV on daily estimates of VPA.
- Section 6.3 proposes a threshold for minimum wear time based on the minimum number of hours per day and the minimum number of days of data required from each child to achieve reliable estimates of PA in population-based accelerometer studies. The influence of gender and the purposeful inclusion of children with and without weekend day data are also explored.

The EHCV and minimum wear time thresholds will be used to process the MCS4 accelerometer data that are used in all subsequent analyses in this thesis.

6.2 Study 1: Identifying extreme high count values

6.2.1 Introduction

Technological advances have made accelerometers smaller, lighter, and cheaper. These developments, combined with increases in battery life and memory storage, have made accelerometer data collection feasible in population-based studies in children. However, uncertainties still remain regarding the implementation of accelerometer data processing protocols.

Not all studies report whether quality control procedures are undertaken prior to processing accelerometer data; when they are undertaken, different protocols are used to exclude entire subjects, days, or data within a day. This may threaten the validity of activity estimates, potentially introducing biases and increasing measurement errors. In the absence of standardised data processing protocols it is difficult to compare activity levels across studies and countries. Even small differences in data cleaning may have a substantial impact on derived outcome variables[226-229].

Accelerometers are designed to record accelerations within a defined range of movement for humans. Signal frequency filtering techniques are employed within devices to exclude accelerations unlikely to be generated by human movement, such as those caused by electrical noise and mechanical vibrations. Despite this, EHCV can occur, possibly as a result of accelerometer malfunction, or participant misuse of the accelerometer such as vigorous shaking[230].

The ActiGraph 7164[61 130 158] and GT1M[130 145 152] accelerometers have been widely used in large scale studies in children. The firmware digital filter in the GT1M is favoured over the more error prone hardware digital filter in the ActiGraph 7164[231]. The GT1M may also be less prone to recording EHCV because, unlike the 7164, it does not require calibration after it leaves the factory. The 7164 model has been reported to record EHCV, including repeated values equal to 32,767 which indicate voltage signal saturation within the monitor, at which value the accelerometer malfunctions[211 212 232].

Previous authors have emphasised the need for quality control procedures to identify typical EHCV that may result from monitor malfunctions, participant tampering or human error (e.g. errors caused at the time of initializing accelerometers)[208 212]. In order to identify EHCV, a threshold is needed that is low enough to exclude EHCV, but high enough to include genuine records of VPA. To my knowledge, only a few studies have used[64 114 138 156 212], and even less have proposed[64 138 212] a threshold value to remove EHCV. Given the impact that very high count values are likely to have on estimates of VPA, further clarification on the use of an EHCV count threshold is needed. There is also a need to determine typical error count values recorded by the ActiGraph GT1M so that they can be identified and removed prior to data analyses.

6.2.2 Aim

The aim of this study is twofold:

1. To propose an EHCV threshold based on population-based accelerometer data in UK children.
2. To use the MCS main stage accelerometer data to:
    a) Determine typical error count values recorded by the ActiGraph GT1M;
    b) Determine the consistency of pre-defined accelerometer initializing parameters (e.g. start time and date and epoch mode);
    c) Determine the frequency of EHCV (as defined by the study threshold);
    d) Undertake a sensitivity analysis to investigate the influence of varying the approach to determine EHCV on daily estimates of VPA.

6.2.3 Methods

6.2.3.1 Subjects

Accelerometer data obtained as part of the MCS main stage accelerometer study were used in all analyses for this study. Accelerometer data were processed using functions developed by Dr Mario Cortina-Borja and Dr Marco Geraci in the R software environment for statistical computing (version 2.15.1)[209]. Accelerometer counts were converted from 15 to 60 second epochs for ease of comparison with previous studies. Data from all MCS children who returned an accelerometer were included in the analyses unless parents/guardians had explicitly stated that the accelerometer had not been worn (*n*=9,005; section 5.5.2.2).

6.2.3.2 Statistical analysis

To define the EHCV threshold we developed a procedure based on the sample quantiles of the accelerometer counts distribution restricted to positive values only. Firstly, we estimated the empirical quantile function for a fine sequence of probabilities τ, namely from τ=0.8 to τ=0.999 with 0.001 increments. Secondly, we calculated the first and second derivatives of the quantile function. The first derivative is also called the sparsity function and corresponds to the reciprocal of the density function. Therefore, the second derivatives of the quantile function, which measures its curvature, provides an indication of the rate at which data become more sparse (less dense) as the extreme end of the distribution is approached. Thirdly, we identified the take-off point of the curvature, which signals the beginning of the extreme tail of the distribution where the density of the data starts decreasing rapidly. Finally, we defined the EHCV threshold as the upper limit of the one-sided 95% CI for the quantile identified in the previous step. Numerical approximation of the quantile function derivatives was carried out using Hall and Sheather's[233] bandwidth rule. The large sample size allowed us to use standard errors obtained with a Powell's[234] sandwich estimator. The analysis was performed using the R package `quantreg`[235].

Accelerometer data were screened for EHCV and possible error count values including: files containing all five digit values; files containing all one value; count values equal to 32,767 which is the maximum value that the ActiGraph 7164 can record regardless of the specified epoch[211 212]; files containing counts that do not return to baseline[211 212]; and, negative values[211 212]. The accelerometer data were also screened to determine whether the metadata corresponded to the pre-defined accelerometer initialization parameters (including date range, date format, activity mode and epoch).

We undertook a sensitivity analysis to compare three different methods of handling EHCV on derived measures of VPA using all MCS children with reliable data. We summarised VPA, first, including all observations. We then excluded EHCV based on our proposed threshold. Finally, for each child, we excluded EHCV using a threshold proposed by Owen et *al*[64], calculated as the median plus 3.5 times the SD of all cpm. The estimated SD is considered robust against large deviations as it was obtained by regressing cpm between the 10th and the 90th percentile on their corresponding *z*-scores. Differences between the median daily minutes spent in VPA according to these different methods of excluding EHCV were assessed using the Jonckheere-Terpstra nonparametric test for homogeneity of medians in a repeated measures setting[236]. We used a Bonferroni-type adjustment for pairwise comparisons, thus the *p*-values should be less than 0.0166 to be considered significant at 5%.

6.2.4 Results

6.2.4.1 Error count values

Table 23 summarises the number of files identified that recorded error count values. A total of 11 (0.12%) MCS children returned accelerometers that contained 237 negative counts comprising 211 counts equal to -32,768 in one child. Overall, negative counts were equal to - -32,768 (234 counts), -32,161 (one count), -21,582 (one count), and -9,049 (one count). Files with negative values for counts also had negative values for steps. There were an additional 31 children with files that contained all zero counts and who had presumably not worn the accelerometer. Files with zero count values also had zero step values. No files were identified that contained all five digit values, all one value (except those with zero counts) or count values that did not return to baseline.

Table 23: Number of files with error count values

	Number of files (total *n* processed=9005)
All zero counts	31 (2,962,154 counts)
Negative values	11 (237 counts)
All five digit values	0
All one value	0
Counts that do not return to baseline	0

6.2.4.2 Accelerometer programming parameters

Table 24 summarises the number of files identified that contained incorrectly programmed accelerometer parameters. An incorrect date format of mm/dd/yyyy was identified in files relating to 22 children, and a further two dates were outside the anticipated range. There were

23 files that were set to mode 0, and therefore only recorded count values. No files were found to have an odd number of values.

Table 24: Number of files containing incorrectly programmed accelerometer parameters

	Number of files (total *n* processed=9005)
Incorrect Epoch	0
Date in mm/dd/yyyy format	22
Outside date range	2
Mode set to 0 (count only)	23
Odd total number of values	0

6.2.4.3 Extreme high count threshold

A total of 860,932,791 count values were measured by the MCS children, of which 777,929,003 (90.4%) were zero. The minimum, maximum and quantile distribution of the remaining 83,003,788 non-zero count values are summarised in Table 25.

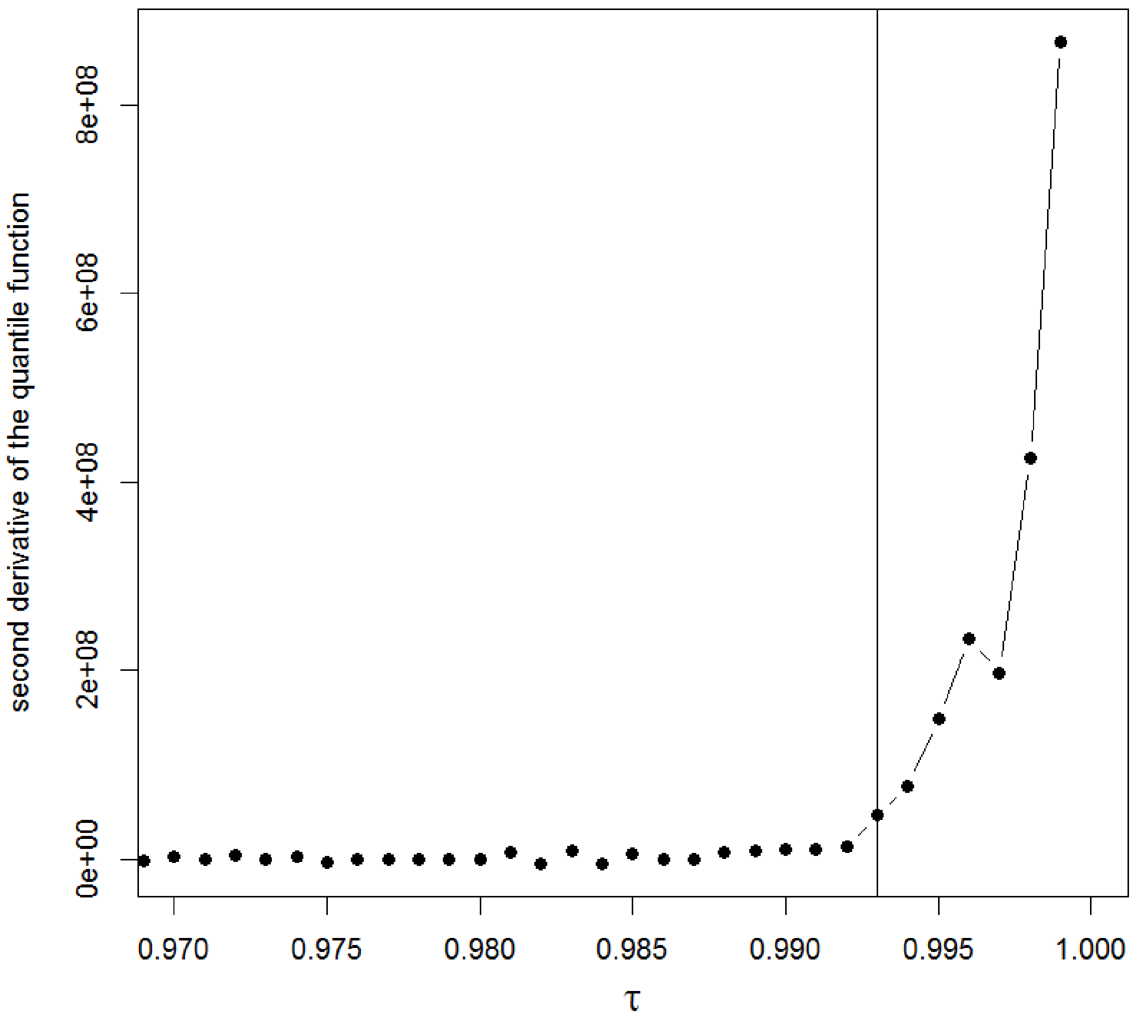
Table 25: Minimum, maximum and quantile distribution of non-zero count values

Counts per minute									
Minimum	Q1	Q2	Q3	Q90	Q95	Q99	Q995	Q999	Maximum
1	112	452	1378	2753	3765	6530	9036	22271	31695

Abbreviation: Q=quantile

Changes in curvature of the quantile function defined the optimal probability threshold as 0.993 (Figure 21); this corresponded to a quantile estimate of 1,891 counts per 15 second epoch with a standard error of 631 counts per 15 second epoch. To account for estimation uncertainty, we defined the EHCV threshold as the upper bound of the one-sided 95% CI for the quantile 0.993. This was converted to cpm using the formula 4 x (1,891 + $z_{0.95}$ × 631), where $z_{0.95}$ is the 95% critical value of a standard normal distribution. Based on this calculation, we propose a minimum count threshold of 11,715 cpm to define EHCV in large scale studies in children.

Figure 21: Plot showing the second derivative of the quantile function of non-zero count values



6.2.4.4 *Extreme high count values*

Only 0.7% (581,402 out of 83,003,788) of all non-zero accelerometer counts obtained in the MCS children were considered to be EHCV (≥ 11,715 cpm). At least one EHCV was observed in 6,459 (71.7%) MCS children: in 8,978 (99.7%) and in 2,550 (28.3%) less than 1% and 0% of total non-zero counts respectively were classified as EHCV.

6.2.4.5 *Sensitivity analysis*

The EHCV threshold value obtained following Owen *et al's*[64] method was 19,442 cpm (4,122 + 3.5 × 4,377). The three estimates of median daily minutes spent in VPA differed significantly according to the method used to exclude EHCV (Table 26; Jonckheere-Terpstra; p<0.0001). Pairwise, median daily minutes spent in VPA were not significantly higher when including all count values compared to using Owen *et al's*[64] threshold to exclude EHCV (p=0.08). In contrast, median daily minutes spent in VPA obtained using our proposed threshold were significantly lower than those estimated without excluding EHCV (p=0.0001; 6.9 vs. 6.5 minutes per day) and than those estimated when excluding EHCV using Owen *et al's*[64] threshold (p=0.0104; 6.8 vs. 6.5 minutes per day). After adjustment for multiple comparisons, conclusions on significance at the 5% level remained unchanged for all pairwise tests.

Table 26: Summary statistics and Jonckheere-Terpstra test *p*-values for daily minutes spent in vigorous physical activity using different methods of excluding extreme high count values

Definition of extreme high count value threshold	Median daily vigorous physical activity (minutes)	Interquartile range daily vigorous physical activity (minutes)
(1) None	6.9	2.1, 12.0
(2) ≥ 19,442 counts per minute[64]	6.8	2.0, 12.0
(3) ≥ 11,715 counts per minute	6.5	2.0, 11.0

Jonckheere-Terpstra test	*p*-value[a]	
Global test: (1) > (2) > (3)	<0.0001	
(1) > (2)	0.0814	
(1) > (3)	0.0001	
(2) > (3)	0.0104	

[a]A Bonferroni-type adjustment for multiple comparisons meant that pair-wise *p*-values needed to be <0.0166 to be considered significant at 5%.

6.2.5 Discussion

6.2.5.1 Summary of findings

Based on population-based data, this study proposes a minimum accelerometer count threshold of 11,715 cpm be used to define EHCV in accelerometer-based studies of primary school aged children's activity levels using the ActiGraph GT1M. EHCV have been investigated in order to determine the influence and occurrences of these values in a large scale study of accelerometer-determined PA in children. EHCV of 11,715 cpm or higher were observed in a high proportion of children (72%), however, they represented a very small proportion of the total non-zero count values (0.7%). Although unusual, malfunction of the ActiGraph GT1M can result in both negative and positive error count values. Error counts were more likely to be recorded as negative values, with -32,768 being the most common. In addition, some manual errors in initialization were identified.

Accelerometer data processing software enables data produced from large scale studies to be quickly and reliably processed and summarised as, for example, the time spent each day in SB or MVPA. Accelerometer processing software relies on a set of predefined processing criteria that are applied to all data files. This study agrees with Matthews *et al*[208] that there is a need to develop standardised quality control procedures prior to data processing in large scale studies: these should include the identification and removal of EHCV and incorrectly initialized accelerometers.

This study has also shown that the method used to define and exclude EHCV can significantly affect estimates of the daily duration of VPA: the median daily minutes spent in VPA was on average 6.2% greater when EHCV were not excluded from analyses compared to estimates obtained using our proposed threshold (≥ 11,715 cpm). Similarly, significantly higher (4.6%) estimates were obtained by using a higher threshold (≥ 19,442 cpm) as proposed by Owen *et al*[64]. However, there were no differences in VPA levels when not excluding EHCV compared to using Owen *et al's*[64] threshold to exclude EHCV.

6.2.5.2 Comparisons with existing research

A lack of previous studies have proposed a count threshold for EHCV based on population-based accelerometer data. Furthermore, few population-based studies have reported the use of a threshold to remove EHCV, and in those that have, the study sample, accelerometer protocols, and thresholds used have varied, with EHCV most commonly removed using a threshold based on basic analytical methods, such as the SD and the median cpm.

Masse *et al*[227] reviewed the methodology of accelerometer-based studies in children published in 2003 and 2004, and reported only one large scale study that used a threshold to remove EHCV[157]. As a result, the methodology of all (*n*=23) large scale (≥ 250 participants) accelerometer-based studies of children's (2 to 18 years) PA published by June 2011 have been reviewed: four (13%) were identified that reported removing EHCV[64 114 138 157]. In the EYHS, count values greater than 9 SDs away from the median were removed as these were regarded as representing a 'distinct unphysiological pattern' (threshold count value not specified)[157]. In the ALSPAC, whole days were considered implausible and removed from data analyses if the average daily count values were greater than 3 SDs (1,665 cpm) above the mean[138]. In the CHASE, count values 3.5 SD greater than the median were identified as 'outliers' and removed from data analyses[64]. Neither of these studies provided fuller justification for the approach taken to identify EHCV. Tremblay *et al*[114] used a similar method to remove EHCV by removing values that were greater than 3 SD from the mean in their study of 399 Canadian children aged between 8 and 13 years. By using SD, these studies implicitly assume a normal distribution for accelerometer counts; this may not be true, and non-parametric quantile-based methods provide a more robust approach.

The threshold defined in this study is lower than that proposed by Esliger *et al* (15,000 cpm) using the ActiGraph 7164[212]. This threshold was obtained by calculating the mean of the maxima of count values (11,555 cpm) in 94 children aged 8 to 13 years. Using this threshold they concluded that values equal to or greater than 15,000 cpm would therefore be very rare in children. In contrast, the EHCV threshold proposed by our study was similar to that used by Oliver *et al*[237] in their study of 200 six year old children using the Actical accelerometer. However, Oliver *et al*[237] did not justify the reason for using a threshold of 12,000 cpm to define EHCV.

Only one study has used observational data to propose an EHCV threshold, but this used the Actical accelerometer and used a sample with a very wide age range[230]. Colley *et al*[230] conducted an extrapolation procedure to propose the threshold, using treadmill speed and corresponding Actical accelerometer counts in 38 Canadians aged between 9 and 59 years[230]. The study proposed a minimum threshold of 20,000 cpm for the Actical, which is substantially higher than that proposed by this study using the ActiGraph GT1M. This difference may be due to differences in sample age and size, the different accelerometer model used, and/or the alternative analytical methods used in the current study to determine the threshold.

Few studies measuring PA in children report the EHCV recorded by accelerometers. However, fewer EHCV were recorded by the MCS children (0.12%) than by children included in the International Children's Accelerometry Database[211]. In the database, 44,454 'viable' accelerometer files obtained from 20 studies worldwide were processed. A total of 556 (1.2%) files were considered to be 'spurious' as they contained at least three consecutive counts of the same value that were greater than nine (with plateaus occurring most often at 32,767); negative values were not reported[211].

Colley *et al*[230] inspected seven days of accelerometer data from 987 Canadians aged between six and 79 years. In agreement with our study, the authors found that EHCV were very unusual with almost none exceeding 20,000 cpm. On the rare occasions when excessively high count data (≥ 28,404 cpm) were identified, the entire recording was found to be completely unusable because of accelerometer malfunction.

The maximum count value recorded in a study using the ActiGraph 7164 was similar (31,346 cpm) to that recorded in this study (31,695 cpm)[212]. Count values did not plateau at 32,767[211, 212] in our data, or at any other high count value in the ActiGraph GT1M, in contrast to reports based on the ActiGraph 7164.   However, the ActiGraph GT1M did occasionally malfunction by recording negative values, in particular, a count value of -32,768. The ActiGraph GT1M is a 16-bit machine with the potential to store and record signed values from -32,768 to 32,767 ($\pm 2^{15}$-1): count values as high 32,767 may not be recorded because of an enhanced digital filter that was not incorporated in the 7164. The GT1M also has an improved capacity to measure at higher frequencies than the 7164 because it filters acquired data within a frequency range of 0.25 to 2.5 hertz, compared to 0.21 to 2.28 hertz in the ActiGraph 7164[238].

No other published study has compared different approaches to excluding EHCV on estimates of VPA. An evidence-based recommendation for the duration of time children should spend in VPA has not yet been made but is likely to rely on evidence from accelerometer-based studies[60]. It is therefore important that such studies adopt a consistent approach to identifying and excluding EHCV as this study has shown that this may introduce significant and systematic biases in estimates of VPA. This study has also shown that levels of VPA can be overestimated by not using a threshold to define and exclude EHCV, or by using one that is too high. Conversely, a threshold that is too low will underestimate levels of VPA. This is a well-known trade-off in statistics; if the threshold is set too high the bias in approximating EHCV decreases, but the variance of estimates of the proportion of values exceeding this threshold increases due to smaller number of observations[239]. If the threshold is too low, the variance decreases as we would have more observations, but the bias increases as we would have a poorer representation of truly implausible values.

6.2.5.3 Strengths and limitations

This is the first study to report an EHCV threshold in the ActiGraph GT1M using population-based accelerometer data in pre-pubertal children. The study design, accelerometer protocol, and analytical methodologies employed in our study have enabled us to define a robust threshold to identify EHCV. Uniquely, our threshold has been applied in a large population-based accelerometer study to determine frequencies of EHCV, and determine the influence of varying this threshold in order to exclude implausible count values on estimates of VPA.

Furthermore, our method uses the higher values of the quantile function to define EHCV ($\geq$ 11,715 cpm) as opposed to that used by Owen *et al*[64], which is based on average count values and thus yields a conservative threshold ($\geq$ 19,442 cpm). We used non-parametric quantile-based methods as opposed to parametric methods as they allowed us to investigate the distribution of the counts without making untenable assumptions (e.g. normality).

Studies have shown that counts measured by the ActiGraph 7164 and GT1M reach a peak at very high running frequencies in adults[231 240]. Fudge *et al*[240] recommended that the frequency range of filtering in an accelerometer must include the maximum frequency elicited during running, and the sampling frequency must be twice this frequency; the ActiGraph 7164 and GT1M may fall short of this recommendation[231]. However, physiological differences in children mean that they do not reach the high running frequencies elicited in adults; this study did not identify clustering around EHCV. It is therefore unlikely that without further research the findings of this study can be reliably extended to adult populations.

As this study investigated EHCV which result from accelerometer malfunction or misuse rather than plausible human activity, our methodology should be applicable for use in all childhood populations. However, our proposed threshold is specific to the ActiGraph GT1M and may not be applicable in different accelerometer models. Accelerometers vary in cost, feasibility, validity and reliability; thus each model may require a different threshold value to define EHCV.

6.2.5.4 Recommendations for study practice and further research

This study has shown that EHCV and error count values can be recorded by accelerometers. They can also be programmed incorrectly in large scale studies. It is therefore important that researchers undertake quality control processes prior to processing accelerometer data in large scale studies. Error count values should be evaluated during fieldwork so that failing monitors are not re-issued. Researchers should check that issued accelerometers were correctly initialized. Incorrectly initialized accelerometers need to be dealt with appropriately prior to analyses, for example, by transforming data from one epoch to another. This is particularly important for studies using software to process large volumes of accelerometer data because pre-defined parameters are usually inputted into the software to enable data processing. Using the proposed EHCV threshold will enhance quality control checks by removing implausible count data and improving the validity of VPA estimates. If researchers do not remove EHCV this may lead to an overestimate of the amount of time children spend in VPA with implications for evidence used to set and assess adherence to guidelines[60]. These differences may be even more marked if bouts of activity are accumulated to meet such guidelines.

Future research should determine if the EHCV threshold proposed by the current study is applicable in adults and in different accelerometer models. Furthermore, the current threshold may not be applicable in high performance athletes, particularly as they are likely to achieve more extreme count values, so further research would be required for studies involving these populations. Although beyond the scope of this study the removal of identified EHCV may be dealt with through imputation methods[133]; future research is needed to explore the applications of imputation methods for EHCV.

6.2.6 Conclusion

Accelerometer data collection is normally completed before any data quality control checks can be undertaken. Accelerometer malfunction can occur; studies therefore need to check for error count values throughout fieldwork so that faulty monitors are not re-issued. During fieldwork, researchers also need to ensure that the accelerometers are correctly initialized. It is also crucial for population-based studies to integrate a core set of quality control procedures prior to data processing, including the identification of EHCV, typical error count values, and incorrectly initialized accelerometers. Using a minimum count threshold of 11,715 cpm will enhance data cleaning in studies collecting ActiGraph GT1M determined measurements of PA in children by ensuring only plausible data are analysed, thus improving the validity of VPA estimates.

6.2.7 Key points

- Accelerometer malfunctions can occur; error count values and EHCV can be recorded in large scale studies, in addition to incorrectly programmed accelerometers.
- Researchers should check for error count values throughout fieldwork so that faulty monitors are not re-issued.
- Studies also need to ensure that accelerometers are initialized correctly before distribution.
- EHCV need to be identified prior to analyses: using a minimum count threshold of 11,715 cpm will enhance data cleaning in studies using the ActiGraph GT1M.
- If researchers do not remove EHCV this may lead to an overestimation in the amount of time children spend in VPA each day.
- The proposed EHCV threshold is specific to the ActiGraph GT1M and may not be applicable in other accelerometer models.
- Further research is therefore required using other accelerometers and in studies with adult samples.

6.3 Study 2: Defining minimum wear time

6.3.1 Introduction

In population-based studies children are asked to wear their accelerometer for a fixed period of time, typically during all waking hours for seven consecutive days[61 130 158]. Despite various incentives and reminders, children rarely wear their accelerometer for this entire period. As a result, researchers need to determine whether each child wore their accelerometer for long enough to provide a reliable estimate of PA and be included in analyses. This can be achieved by defining the minimum number of minutes per day and the minimum number of days that the accelerometer needs to be worn by each child.

Researchers need to produce the most reliable estimate of PA using the maximum amount of data. The duration of daily wear time must be long enough to remove days when the accelerometer was not worn but short enough to prevent unnecessary days being removed from analyses, and the number of days the accelerometer needs to worn by each child must provide a reliable estimate of children's habitual PA.

Daily wear time normally includes all waking periods in which non-wear is not identified, and is usually determined by specifying a threshold that defines the minimum length of time that the accelerometer must be worn each day. No single value has been used by large scale studies in children to define the minimum daily wear time and the minimum number of wear days required by each child to be included in analyses (section 3.5.3).

There are few studies that have explored the influence of varying the thresholds used to define the minimum daily wear time and the minimum number of wear days on derived estimates of PA. However, Edwardson *et al*[226] found that changing the minimum daily wear time had a significant influence on the time that 311 children aged between 7 and 11 years spent in MVPA, MPA, LPA and SB (p<0.05): greater levels of all intensities of PA were associated with longer daily wear times. However, no statistically significant differences by daily wear time threshold were observed for any intensity of PA in 12 to 16 year olds (p>0.05; n=234).

Masse *et al*[227] explored the influence of varying the minimum number of wear days (between three and seven days) and the minimum daily wear time (between 10 and 12 hours per day) on estimates of PA and SB in 242 women aged between 40 and 70 years. The most stringent thresholds used to define the minimum wear period reduced the sample size: varying the minimum daily wear time had the greatest effect on sample size. Levels of SB, LPA, and MVPA increased slightly as the number of accelerometer wear days required by each child to be included in analyses increased. Tucker *et al*[228] also explored the influence of varying the thresholds used to define minimum daily wear time (8, 10, and 12 hours per day) and the minimum number of wear days (three, five, and seven days) on the acquisition of reliable data and estimates of MVPA in 7,086 adults participating in the NHANES. The proportion of participants returning reliable data ranged from 12.5% (n=884) to 85.9% (n=6,090) and the mean (SD) time spent in MVPA ranged from 33.6 (±52.7) to 38.4 (±66.0) minutes per day when using varying wear time thresholds. Mean daily levels of MVPA increased when the minimum number of wear days, and the minimum daily wear time used to define the wear period increased.

Reliability determines the consistency of a set of measurements or of a measuring instrument[241]. When evaluating the reliability of accelerometer measurement the variability of PA over time is assessed, and reflects measurement error and real change[186]. Few studies have explored the influence of varying the minimum daily wear time threshold on the reliability of accelerometer-determined PA measurement[138 188]. Researchers have investigated the influence of varying the minimum number of days required by each child to be included in analyses on the reliability of PA measurement but their findings are inconsistent, and study populations tend to be geographically clustered[28 120 134].

There are substantial gender differences in children’s PA[61 64 152], however, previous research investigating the influence of varying the thresholds used to define minimum wear time have combined data from boys and girls. Previous research has also found that children’s PA varies between weekdays and weekend days[109]. Week and weekend days are likely to provide different opportunities for children to be active. Despite this, few studies[64 109 242] have considered the distribution of wear days when exploring the reliability of PA measurement.

Given the impact that these data processing procedures can have on derived activity variables, further clarification on data cleaning methods is needed for researchers using these devices[227-229]. Esliger *et al*[212] emphasised the need for studies to evaluate within- and between- day variations in PA and in particular how these vary by gender.

6.3.2 Aim

The aim of this study was to propose a threshold for the minimum number of hours per day and the minimum number of days of data required from each child to achieve reliable estimates of PA in population-based accelerometer studies. The influence of gender and the purposeful inclusion of children with and without weekend day data were also explored.

6.3.3 Methods

6.3.3.1 Subjects

Accelerometer data obtained as part of the MCS main stage accelerometer study were used in all analyses for this study. Data from all singletons who returned an accelerometer with at least one hour of wear time data (periods in which non-wear was not identified) were eligible for inclusion in our analyses (*n*=7,704; Table 27).

6.3.3.2 Statistical analysis

Accelerometer data were processed using algorithms developed in R software environment (version 2.15.1)[209]. All analyses were repeated using different samples depending on whether children met the varying threshold used to define wear time based on the minimum daily wear time (one to ten hours) and the minimum number of wear days (one to seven days). Analyses were conducted for boys and girls combined, and separately. Analyses were also repeated separately for children that did, and did not, have at least one weekend wear day (of at least ten hours wear). This wear time period was chosen because it is most often used by large scale studies in children to define the minimum daily wear period[61 64 130 158 164].

The reliability of accelerometer-determined mean daily cpm was calculated using the Spearman-Brown prophecy formula[243 244] based on the ICC as a measure of reliability. The distribution of mean daily cpm was skewed so the Box-Cox family of transformations were used to account for non-normality[245]. The asymmetry parameter in this family was chosen by maximising the profile log-likelihood using the R function `boxcox`[246]. A linear mixed-effects model was fitted to the transformed cpm using the MCS survey and non-response weights to account for the clustered sampling and attrition between contacts[247]. Single day

ICC were calculated from the fitted linear mixed-effects models using the R function `ICC1.lme`[248].

Single-day ICC values were then used to calculate the influence of shortening or lengthening the monitoring period on the reliability of PA-measurement using the Spearman-Brown prophecy formula defined as:

$$Reliability = \frac{N \times \ ICC_s}{1 + (N-1)\ \times \ ICC_s}$$

where: *N*=the number of days required, ICC_s=single-day reliability[249].

We used heatmaps to produce graphical representations of reliability trends by minimum daily wear time and minimum number of wear days.

6.3.4 Results

6.3.4.1 Total sample

A total of 7,704 MCS children returned an accelerometer containing at least one hour of wear time data (Table 27).

Table 27: Number of children included in analyses according to minimum daily wear time and minimum number of wear days for the total sample and by gender (boys, girls)

	≥ 1 hour	≥ 2 hours	≥ 3 hours	≥ 4 hours	≥ 5 hours	≥ 6 hours	≥ 7 hours
≥ 1 day	7704 3815, 3889	7579 3738, 3841	7499 3694, 3805	7431 3667, 3764	7323 3601, 3722	7184 3520, 3664	7110 3472, 3638
≥ 2 days	7454 3675, 3779	7370 3631, 3739	7258 3583, 3675	7120 3503, 3617	6985 3417, 3568	6916 3376, 3540	6865 3356, 3509
≥ 3 days	7153 3493, 3660	7000 3419, 3581	6894 3364, 3530	6820 3321, 3499	6755 3292, 3463	6708 3269, 3439	6657 3237, 3420
≥ 4 days	6898 3364, 3534	6775 3309, 3466	6703 3270, 3433	6635 3240, 3395	6569 3208, 3361	6504 3171, 3333	6442 3141, 3301
≥ 5 days	6704 3268, 3436	6590 3210, 3380	6527 3181, 3346	6452 3148, 3304	6358 3104, 3254	6269 3058, 3211	6171 3016, 3155
≥ 6 days	6510 3172, 3338	6399 3125, 3274	6316 3088, 3228	6205 3040, 3165	6080 2984, 3096	5898 2899, 2999	5677 2794, 2883
≥ 7 days	6282 3061, 3221	6146 2996, 3150	6020 2953, 3067	5781 2841, 2940	5411 2667, 2744	4951 2453, 2498	4504 2246, 2258
≥ 8 days	5878 2878, 3000	5650 2781, 2869	5323 2633, 2690	4596 2278, 2318	3252 1632, 1620	1902 958, 944	1062 523, 539
≥ 9 days	5309 2612, 2697	4728 2327, 2401	3620 1789, 1831	2090 1048, 1042	857 427, 430	335 178, 157	177 95, 82
≥ 10 days	2891 1422, 1469	1706 845, 861	868 442, 426	412 208, 204	176 97, 79	91 53, 38	67 40, 27

(Table 27 continued)

	≥ 8 hours	≥ 9 hours	≥ 10 hours	≥ 11 hours	≥ 12 hours	≥ 13 hours	≥ 14 hours
≥ 1 day	7031 3442, 3589	6964 3409, 3555	6853 3351, 3502	6647 3250, 3397	5955 2942, 3013	4136 2087, 2049	1003 1140, 1003
≥ 2 days	6784 3315, 3469	6677 3262, 3415	6528 3188, 3340	6142 3023, 3119	4841 2443, 2398	2449 1294, 1155	872 493, 379
≥ 3 days	6567 3203, 3364	6408 3132, 3276	6181 3021, 3160	5513 2749, 2764	3716 1919, 1797	1421 794, 627	392 218, 174
≥ 4 days	6327 3083, 3244	6120 2989, 3131	5776 2845, 2931	4768 2428, 2340	2722 1451, 1271	802 437, 365	216 122, 94
≥ 5 days	5993 2932, 3061	5689 2801, 2888	5033 2528, 2505	3738 1932, 1806	1750 940, 810	438 240, 198	129 67, 62
≥ 6 days	5337 2634, 2703	4807 2402, 2405	3903 1993, 1910	2456 1283, 1173	883 473, 410	232 134, 98	86 44, 42
≥ 7 days	3972 2000, 1972	3202 1657, 1545	2177 1156, 1021	1077 594, 483	327 187, 140	100 56, 44	37 19, 18
≥ 8 days	625 319, 306	381 205, 176	214 119, 95	111 64, 47	49 28, 21	27 15, 12	13 6, 7
≥ 9 days	111 61, 50	76 44, 32	45 27, 18	32 19, 13	20 11, 9	13 7, 6	8 3, 5
≥ 10 days	46 26, 20	33 19, 14	28 16, 12	19 11, 8	15 8, 7	8 4, 4	6 2, 4

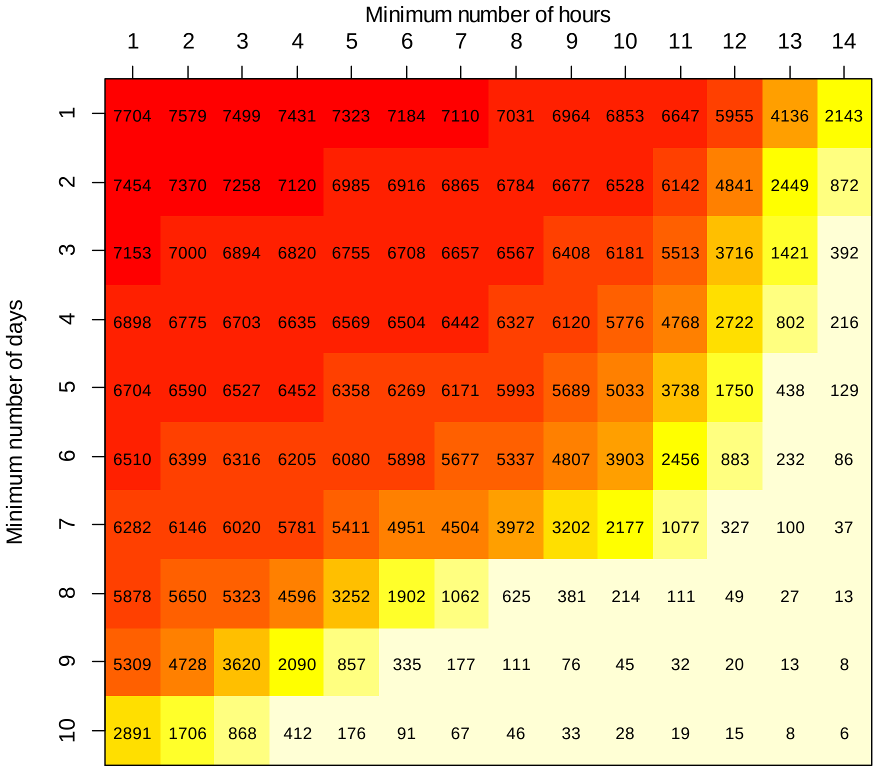
The reliability of PA measurement was influenced by the minimum daily wear time and the minimum number of days of data required by each child for inclusion in analyses (Table 28). Reliability coefficients increased as the minimum number of days required by each child for inclusion in analyses increased (between one and ten days) and also increased as the minimum daily wear time increased from at least one hour per day up to, but no more than, at least eight hours per day.

Reliability was low when children with at least one day lasting between one to three hours were included in analyses (36% to 40%). Reliability coefficients varied depending on the minimum daily wear time required when children with at least one wear day were included in analyses: reliabilities peaked at 76% when including children with at least one wear day lasting at least eight to at least ten hours per day. PA measurement was more reliable when children with at least two days or greater were included in analyses. Measurement reliability values of at least 90% were achieved when the following thresholds were used to define which children were included in analyses: at least three days lasting at least eight hours per day, at least four or five days lasting at least six hours per day, and at least six days lasting at least five hours per day (90%, 90%, 92%, and 90% respectively). As defined by the Spearman-Brown prophecy formula, the most reliable measure of PA (97%) was achieved when children with at least nine or ten days lasting from at least eight to at least ten hours per day were included in analyses. For a minimum reliability coefficient fixed at 80%, the sample size was maximised when children with at least two days lasting at least six hours per day were included in analyses (*n*=6,916; reliability 82%; Figure 22).

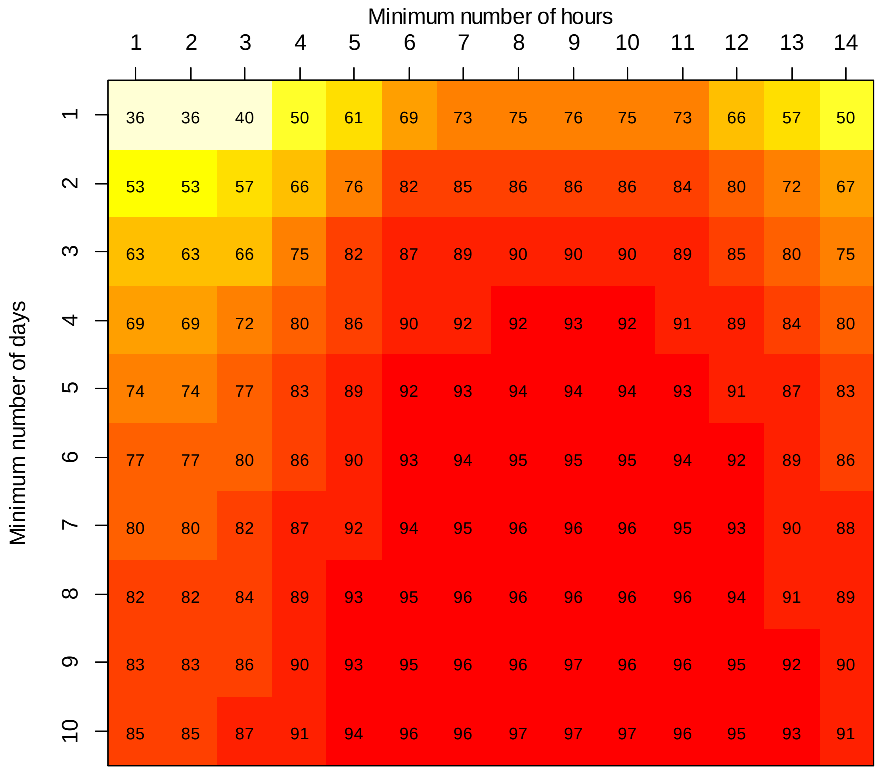
Table 28: Reliability coefficients derived according to minimum daily wear time and minimum number of wear days (total sample)

	≥ 1 hour	≥ 2 hours	≥ 3 hours	≥ 4 hours	≥ 5 hours	≥ 6 hours	≥ 7 hours	≥ 8 hours	≥ 9 hours	≥ 10 hours	≥ 11 hours	≥ 12 hours	≥ 13 hours	≥ 14 hours
≥ 1 day	0.36	0.36	0.40	0.50	0.61	0.69	0.74	0.76	0.76	0.76	0.73	0.66	0.57	0.51
≥ 2 days	0.53	0.53	0.57	0.67	0.76	0.82	0.85	0.86	0.86	0.86	0.84	0.80	0.73	0.67
≥ 3 days	0.63	0.63	0.67	0.75	0.83	0.87	0.89	0.90	0.90	0.90	0.89	0.86	0.80	0.75
≥ 4 days	0.69	0.69	0.73	0.80	0.86	0.90	0.92	0.93	0.93	0.93	0.92	0.89	0.84	0.80
≥ 5 days	0.74	0.74	0.77	0.83	0.89	0.92	0.93	0.94	0.94	0.94	0.93	0.91	0.87	0.84
≥ 6 days	0.77	0.77	0.80	0.86	0.90	0.93	0.94	0.95	0.95	0.95	0.94	0.92	0.89	0.86
≥ 7 days	0.80	0.80	0.82	0.87	0.92	0.94	0.95	0.96	0.96	0.96	0.95	0.93	0.90	0.88
≥ 8 days	0.82	0.82	0.84	0.89	0.93	0.95	0.96	0.96	0.96	0.96	0.96	0.94	0.91	0.89
≥ 9 days	0.84	0.84	0.86	0.90	0.93	0.95	0.96	0.97	0.97	0.97	0.96	0.95	0.92	0.90
≥ 10 days	0.85	0.85	0.87	0.91	0.94	0.96	0.97	0.97	0.97	0.97	0.96	0.95	0.93	0.91

Figure 22: Heatmaps illustrating sample sizes and reliabilities (%) according to minimum daily wear time and minimum number of wear days for total sample



Sample size

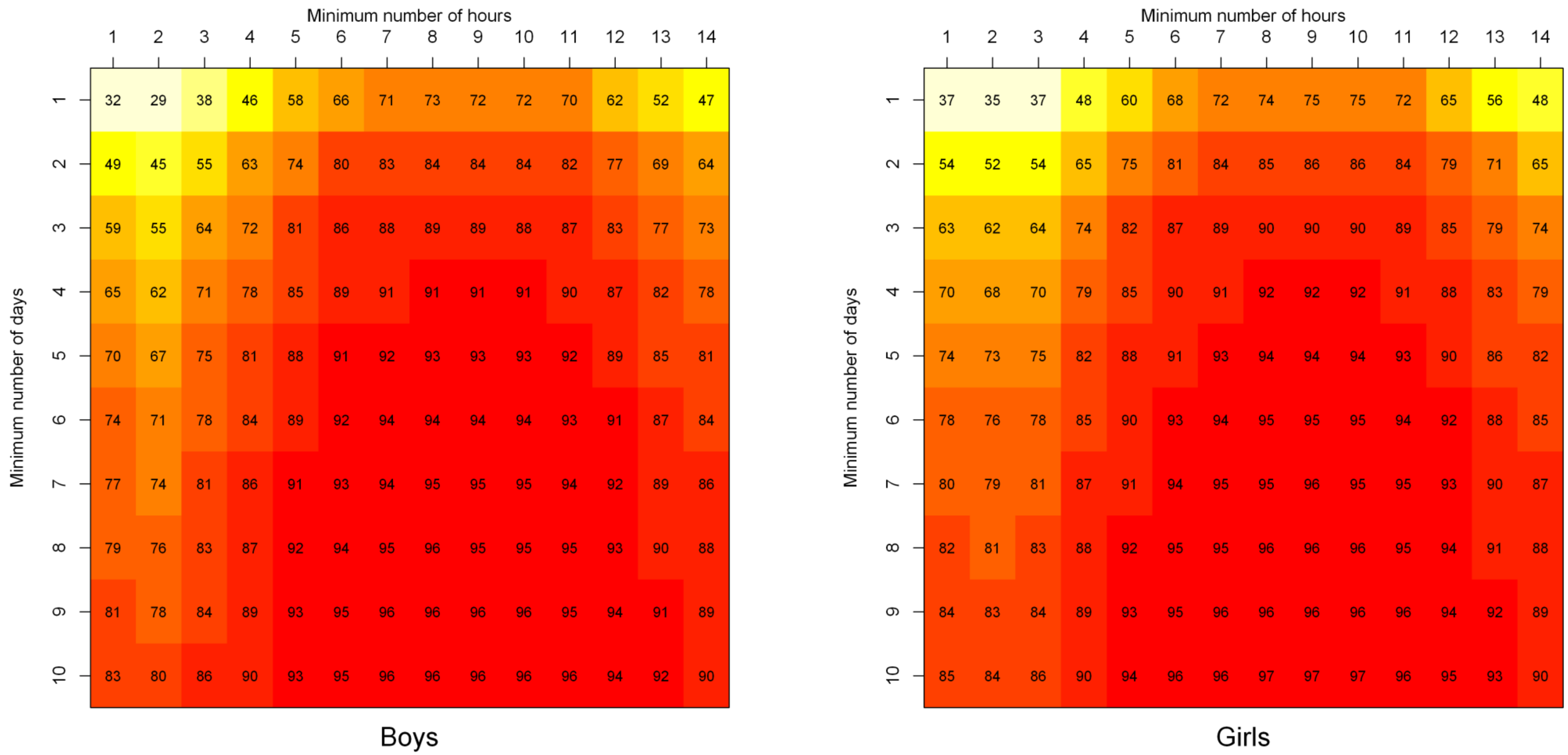


Reliabilities (%)

6.3.4.2 Gender

When reliability coefficients were calculated separately for boys and girls the results followed a similar trend in both genders to that found for the total sample (Figure 23). Reliabilities were again influenced by the minimum daily wear time and the minimum number of wear days. The reliability of PA measurement exhibited a minimal gender-related trend: measurement was slightly more reliable in girls than boys for nearly all combinations of minimum daily wear time and minimum number of wear days. For example, the reliability of measurement using data from children with at least two days lasting at least six hours per day was high in both genders, but reached 80% in boys compared to 81% in girls. The most reliable measure was achieved in boys when children with at least nine or ten days lasting from at least seven to at least 11 hours per day (96%) were included in analyses, and in girls with at least ten days lasting from at least eight to at least ten hours per day (97%).

Figure 23: Heatmaps illustrating reliabilities (%) for boys and girls according to minimum daily wear time and minimum number of wear days



6.3.4.3 Inclusion of weekend day

Total sample

Table 29 and Table 30 reports the number of children that were included in analyses with and without at least one day of weekend data (≥ ten hours) according to the minimum daily wear time and the minimum number of wear days for the total sample and by gender. A total of 2,414 singleton children (31.3% of all singletons returning data) returned an accelerometer that contained at least one day of data (≥ one hour) but no weekend day data. At least one weekend days' worth of data (≥ ten hours) was obtained from 5,290 singleton children (68.7 % of all singletons returning data).

Table 29: Number of children without at least one day of weekend data derived according to minimum daily wear time and minimum number of wear days for the total sample and by gender (boys, girls)

	≥ 1 hour	≥ 2 hours	≥ 3 hours	≥ 4 hours	≥ 5 hours	≥ 6 hours	≥ 7 hours
≥ 1 day	2414 1180, 1234	2289 1103, 1186	2209 1059, 1150	2141 1032, 1109	2033 966, 1067	1894 885, 1009	1820 837, 983
≥ 2 days	2167 1042, 1125	2086 999, 1087	1975 951, 1024	1839 872, 967	1706 787, 919	1641 748, 893	1596 732, 864
≥ 3 days	1883 870, 1013	1733 799, 934	1631 746, 885	1560 705, 855	1504 681, 823	1466 664, 802	1425 638, 787
≥ 4 days	1650 751, 899	1534 700, 834	1468 663, 805	1413 640, 773	1364 617, 747	1314 587, 727	1263 561, 702
≥ 5 days	1484 666, 818	1389 619, 770	1338 598, 740	1280 572, 708	1216 540, 676	1156 508, 648	1089 484, 605
≥ 6 days	1347 599, 748	1259 566, 693	1198 541, 657	1131 511, 620	1056 477, 579	955 432, 523	830 378, 452
≥ 7 days	1225 548, 677	1140 507, 633	1061 480, 581	942 428, 514	790 358, 432	622 282, 340	465 208, 257
≥ 8 days	1071 474, 597	947 422, 525	851 383, 468	653 297, 356	414 199, 215	218 105, 113	95 43, 52
≥ 9 days	873 389, 484	712 317, 395	511 234, 277	284 134, 150	116 54, 62	40 21, 19	14 6, 8
≥ 10 days	447 200, 247	258 117, 141	131 58, 73	60 26, 34	22 11, 11	10 4, 6	6 2, 4

(Table 29 continued)

	≥ 8 hours	≥ 9 hours	≥ 10 hours	≥ 11 hours	≥ 12 hours	≥ 13 hours	≥ 14 hours
≥ 1 day	1741 807, 934	1674 774, 900	1563 716, 847	1421 644, 777	1097 502, 595	569 254, 315	115 103, 115
≥ 2 days	1521 693, 828	1421 644, 777	1302 586, 716	1090 495, 595	634 294, 340	201 103, 98	55 28, 27
≥ 3 days	1344 605, 739	1223 552, 671	1060 470, 590	769 358, 411	336 161, 175	89 48, 41	18 10, 8
≥ 4 days	1180 516, 664	1039 458, 581	822 372, 450	491 238, 253	173 88, 85	31 17, 14	6 1, 5
≥ 5 days	973 431, 542	790 357, 433	454 212, 242	230 116, 114	56 29, 27	9 1, 8	2 NA, 2
≥ 6 days	650 290, 360	412 183, 229	61 28, 33	25 9, 16	9 4, 5	1 NA, 1	NA NA, NA
≥ 7 days	293 136, 157	127 64, 63	17 10, 7	9 5, 4	4 2, 2	NA NA, NA	NA NA, NA
≥ 8 days	44 20, 24	11 4, 7	4 2, 2	2 1, 1	1 NA, 1	NA NA, NA	NA NA, NA
≥ 9 days	9 4, 5	3 2, 1	1 1, NA	NA NA, NA	NA NA, NA	NA NA, NA	NA NA, NA
≥ 10 days	4 2, 2	1 1, NA	NA NA, NA	NA NA, NA	NA NA, NA	NA NA, NA	NA NA, NA

Table 30: Number of children with at least one day of weekend data derived according to minimum daily wear time and minimum number of wear days for the total sample and by gender (boys, girls)

	≥ 1 hour	≥ 2 hours	≥ 3 hours	≥ 4 hours	≥ 5 hours	≥ 6 hours	≥ 7 hours
≥ 1 day	5290 2635, 2655	5290 2635, 2655	5290 2635, 2655	5290 2635, 2655	5290 2635, 2655	5290 2635, 2655	5290 2635, 2655
≥ 2 days	5287 2633, 2654	5284 2632, 2652	5283 2632, 2651	5281 2631, 2650	5279 2630, 2649	5275 2628, 2647	5269 2624, 2645
≥ 3 days	5270 2623, 2647	5267 2620, 2647	5263 2618, 2645	5260 2616, 2644	5251 2611, 2640	5242 2605, 2637	5232 2599, 2633
≥ 4 days	5248 2613, 2635	5241 2609, 2632	5235 2607, 2628	5222 2600, 2622	5205 2591, 2614	5190 2584, 2606	5179 2580, 2599
≥ 5 days	5220 2602, 2618	5201 2591, 2610	5189 2583, 2606	5172 2576, 2596	5142 2564, 2578	5113 2550, 2563	5082 2532, 2550
≥ 6 days	5163 2573, 2590	5140 2559, 2581	5118 2547, 2571	5074 2529, 2545	5024 2507, 2517	4943 2467, 2476	4847 2416, 2431
≥ 7 days	5057 2513, 2544	5006 2489, 2517	4959 2473, 2486	4839 2413, 2426	4621 2309, 2312	4329 2171, 2158	4039 2038, 2001
≥ 8 days	4807 2404, 2403	4703 2359, 2344	4472 2250, 2222	3943 1981, 1962	2838 1433, 1405	1684 853, 831	967 480, 487
≥ 9 days	4436 2223, 2213	4016 2010, 2006	3109 1555, 1554	1806 914, 892	741 373, 368	295 157, 138	163 89, 74
≥ 10 days	2444 1222, 1222	1448 728, 720	737 384, 353	352 182, 170	154 86, 68	81 49, 32	61 38, 23

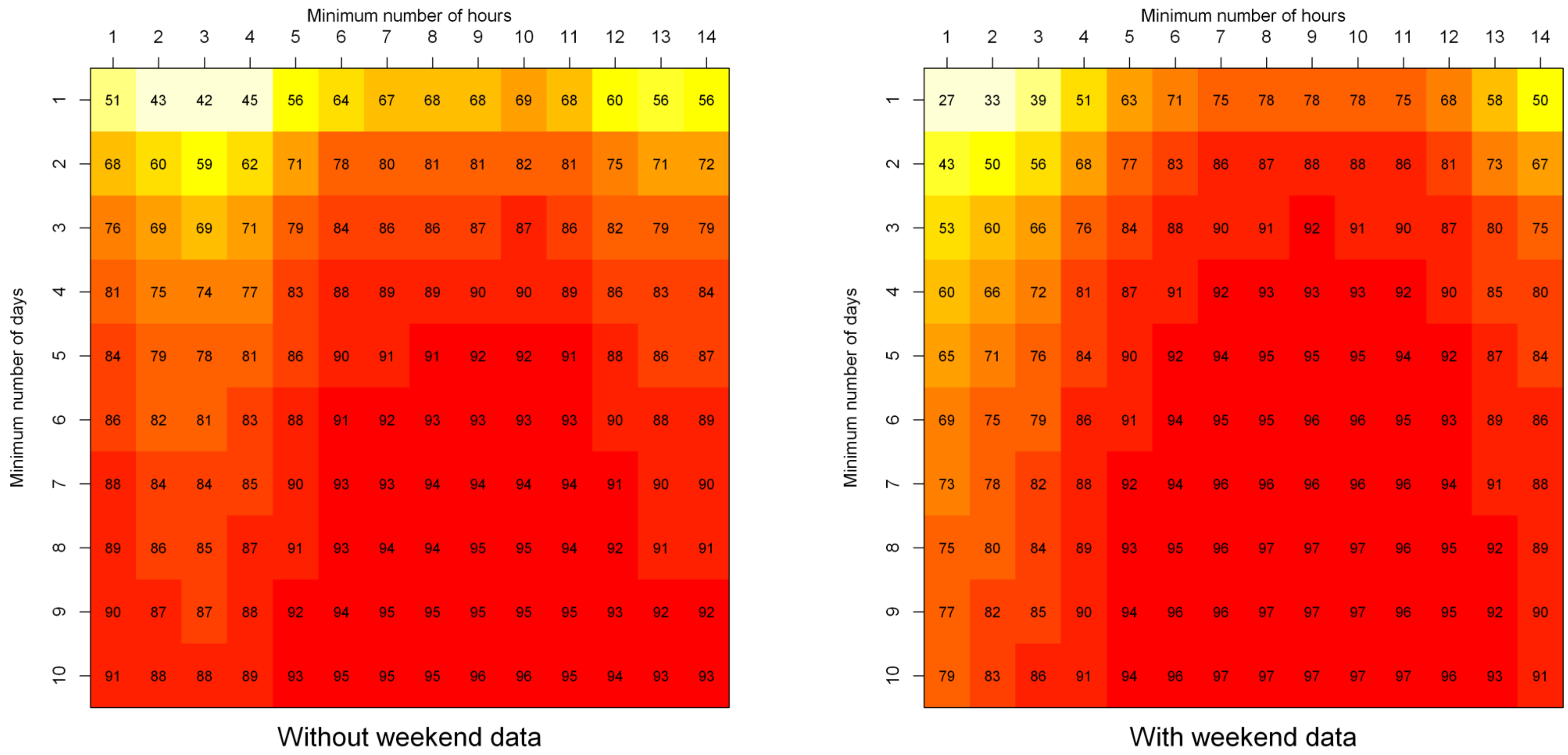
(Table 30 continued)

	≥ 8 hours	≥ 9 hours	≥ 10 hours	≥ 11 hours	≥ 12 hours	≥ 13 hours	≥ 14 hours
≥ 1 day	5290 2635, 2655	5290 2635, 2655	5290 2635, 2655	5226 2606, 2620	4858 2440, 2418	3567 1833, 1734	888 1037, 888
≥ 2 days	5263 2622, 2641	5256 2618, 2638	5226 2602, 2624	5052 2528, 2524	4207 2149, 2058	2248 1191, 1057	817 465, 352
≥ 3 days	5223 2598, 2625	5185 2580, 2605	5121 2551, 2570	4744 2391, 2353	3380 1758, 1622	1332 746, 586	374 208, 166
≥ 4 days	5147 2567, 2580	5081 2531, 2550	4954 2473, 2481	4277 2190, 2087	2549 1363, 1186	771 420, 351	210 121, 89
≥ 5 days	5020 2501, 2519	4899 2444, 2455	4579 2316, 2263	3508 1816, 1692	1694 911, 783	429 239, 190	127 67, 60
≥ 6 days	4687 2344, 2343	4395 2219, 2176	3842 1965, 1877	2431 1274, 1157	874 469, 405	231 134, 97	86 44, 42
≥ 7 days	3679 1864, 1815	3075 1593, 1482	2160 1146, 1014	1068 589, 479	323 185, 138	100 56, 44	37 19, 18
≥ 8 days	581 299, 282	370 201, 169	210 117, 93	109 63, 46	48 28, 20	27 15, 12	13 6, 7
≥ 9 days	102 57, 45	73 42, 31	44 26, 18	32 19, 13	20 11, 9	13 7, 6	8 3, 5
≥ 10 days	42 24, 18	32 18, 14	28 16, 12	19 11, 8	15 8, 7	8 4, 4	6 2, 4

Reliability coefficients increased as the minimum daily wear time and the minimum number of wear days increased in both children with and without weekend data (Figure 24). Reliabilities were slightly higher when only children with weekend data were included in analyses, compared to children with only weekday data, when wear time was defined as at least four hours per day up to 13 hours per day for all numbers of wear days. For example, when children with at least two days lasting at least six hours per day were included in analyses reliability was high in both children with and without weekend data but reached 78% in children with only weekday data compared to 83% in children with weekend data. The most reliable measure was achieved in children with only weekday data when they recorded at least ten days lasting from at least nine to at least ten hours per day (96%) and in children with at least one weekend day of data when they recorded at least eight days lasting from at least seven to 11 hours per day (97%).

Reliabilities calculated when including only children with weekend data available were similar to those calculated when not purposely sampling children based on whether or not they had weekend data for all combinations of minimum daily wear times and number of wear days. For example, the reliability of mean daily cpm calculated from children with at least two days of data lasting at least six hours per day was 83% in children with at least one weekend day of data compared to 82% when not purposely sampling children based on weekend wear.

Figure 24: Heatmaps illustrating reliabilities (%) for children with and without at least one day of weekend data according to minimum daily wear time and minimum number of wear days



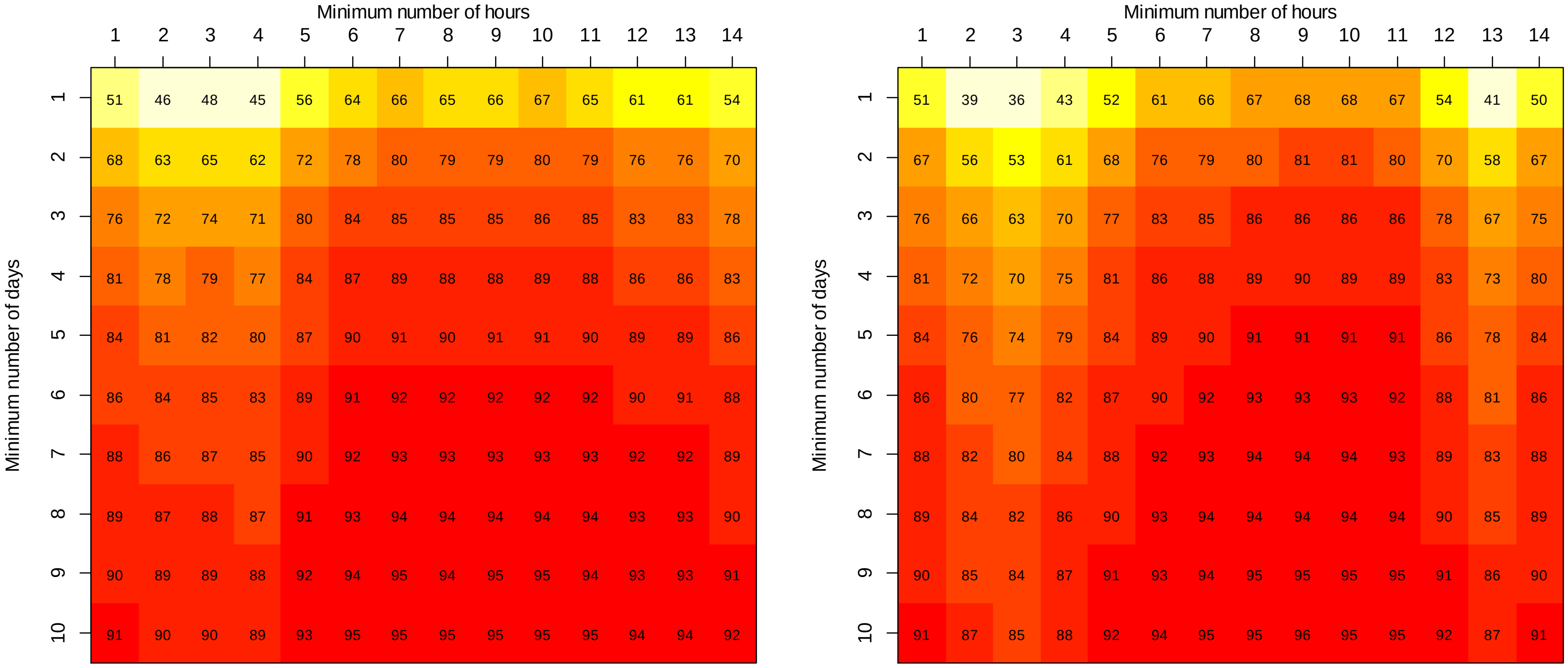
Gender

A total of 1,180 singleton boys (30.9% of all singleton boys returning data) and 1,234 singleton girls (31.7% of all singleton girls returning data) returned an accelerometer that contained at least one day of data (≥ one hour) but no weekend data. At least one weekend days' worth of data (≥ ten hours) was obtained from 2,635 singleton boys (69.1% of all singleton boys returning data) and from 2,655 singleton girls (68.3% of all singleton girls returning data).

Reliabilities (%) for mean daily cpm derived for boys and girls without at least one day of weekend data, and for boys and girls with at least one day of weekend data according to the minimum daily wear time and number of wear days are presented in Figure 25 and Figure 26. The reliability of PA measurement exhibited a small gender-related trend when purposely sampling children based on whether they did or did not have at least one weekend day of data. Measurement was slightly more reliable in girls than boys when analyses only included data from children with at least one weekend wear day using nearly all combinations of minimum daily wear time and number of wear days. In contrast, measurement tended to be slightly more reliable in boys than girls when analyses only included data from children with weekday wear days. For example, when children with only weekday data and at least two days lasting at least six hours per day were included in analyses reliability was moderately high in both genders but reached 78% in boys compared to 76% in girls. In contrast, when children with at least one weekend day of data and at least two days lasting at least six hours per day were included in analyses reliability was high in both genders but reached 81% in boys compared to 83% in girls.

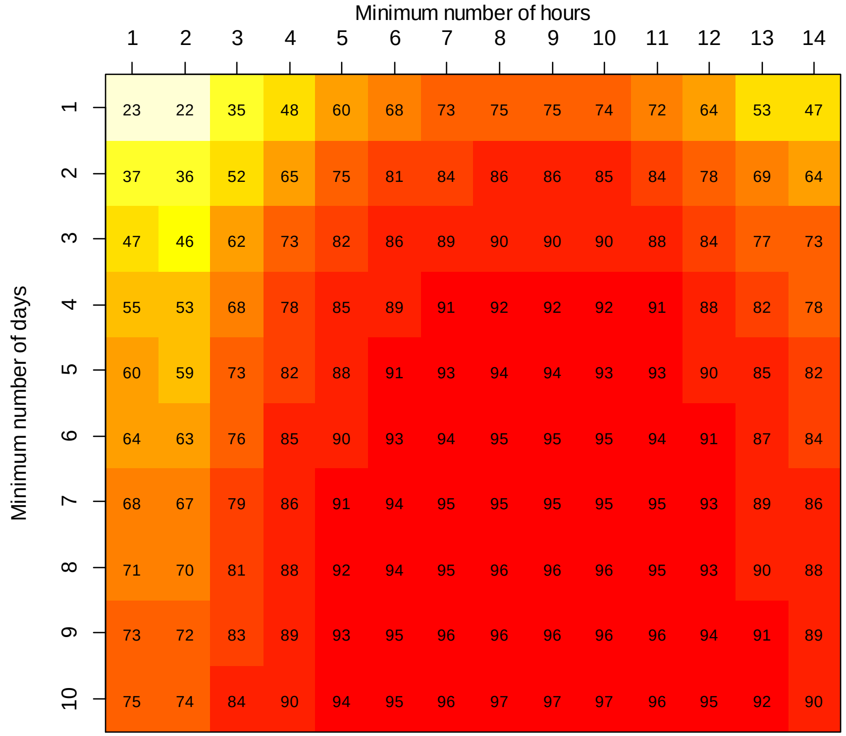
Reliabilities calculated when including only boys or girls with or without weekend data available were similar to those calculated when not purposely sampling by gender, but for the total sample based on whether or not they had weekend data for all combinations of minimum daily wear times and number of wear days. However, reliabilities calculated when including boys with only weekday data were slightly higher than those calculated for both genders with only weekday data. In contrast, reliabilities calculated when including only boys with at least one weekend day of data were slightly lower than those calculated for both genders with at least one weekend day of data. Reliabilities calculated when including girls with only weekday data were slightly lower than those calculated for both genders with weekday data: reliabilities were similar for girls and both genders with at least one day of weekend data.

Figure 25: Heatmaps illustrating reliabilities (%) for boys and girls without at least one day of weekend data according to minimum daily wear time and minimum number of wear days

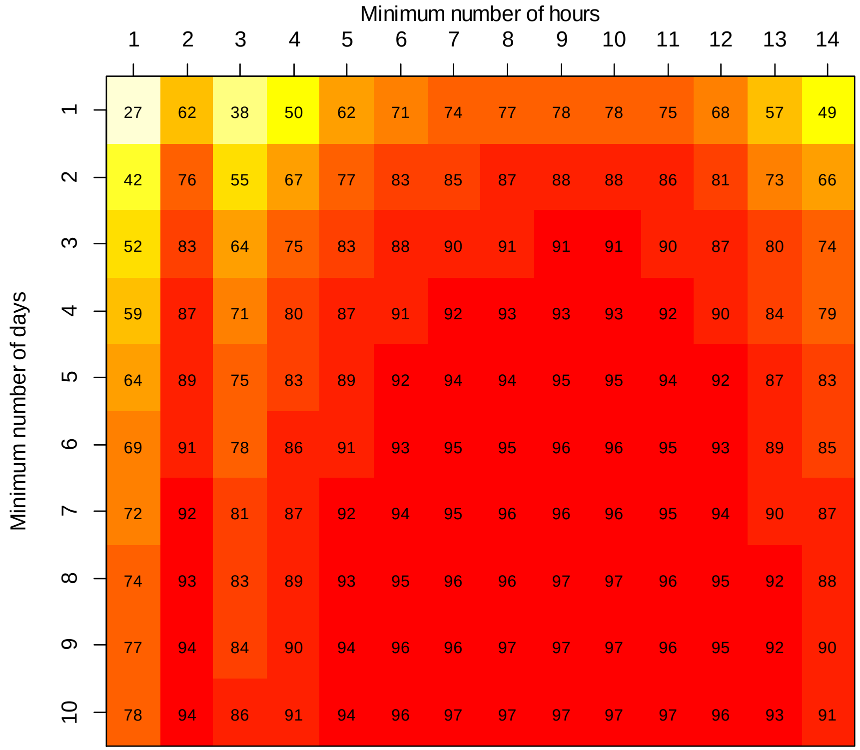


Boys Girls

Figure 26: Heatmaps illustrating reliabilities (%) for boys and girls with at least one day of weekend data according to minimum daily wear time and minimum number of wear days



Boys



Girls

6.3.5 Discussion

6.3.5.1 Summary of findings

A threshold of at least two days lasting at least six hours per day can be used to screen subjects who provide reliable estimates of PA in population studies of older primary school aged children. This threshold provided the highest sample size for a fixed minimum reliability of 80% (*n*=6,916; reliability 82%). The 80% threshold has also been used by previous studies exploring the influence of varying the wear time threshold on the reliability of PA measurement[120 188]. Both the minimum daily wear time and the minimum number of wear days required by each child for inclusion in analyses influenced the reliability of PA measurement. However, reliability coefficients increased as the minimum daily wear time increased from at least one hour per day up to, but no more than, at least eight hours per day. Reliabilities were similar for both genders, although measurement in girls was slightly more reliable than boys for nearly all combinations of minimum daily wear time and minimum number of wear days.

Reliabilities were slightly higher for children with weekend data compared to children with only weekday data. However, the purposeful sampling of children with at least one weekend day of data resulted in similar reliabilities for all wear time thresholds to those calculated when using the total sample independent of weekend wear. Therefore, our results suggest that population data should encourage the measurement of PA on weekend days, but the purposeful sampling of subjects which forces the inclusion of weekend data in *all* children is not necessary.

6.3.5.2 Comparisons with existing research

Only two previous studies have explored the influence of varying the minimum daily wear time and the minimum number of days of data required from each child to be included in analyses. In contrast to our study, Mattocks *et al*[138] and Penpraze *et al*[188] found that the minimum daily wear time had less influence on reliability than the number of wear days. Penpraze *et al*[188] found that measurement reliability remained relatively stable using at least three hours per day up to, but no more than, at least ten hours per day in five to six year old children. For example, the reliability of measurement using data from children with at least four days lasting from at least three to at least ten hours per day was 69%, but dropped to 38% when using data from children with at least four days lasting from at least 13 hours per day. The authors reported lower reliabilities than those calculated in the present study[188]: defining wear time as at least seven days lasting at least ten hours per day produced the highest reliability (80%, 95% CI=70%, 86%). Only a 51% reliability was reported by Penpraze *et al*[188] when using our recommended wear time threshold (≥ two days lasting ≥ six hours per day), however, this study used a small geographically clustered sample (*n*=76) and only included children with seven complete days of PA monitoring which has the potential to introduce bias in results.

Mattocks *et al*[138] also investigated the influence of varying the threshold used to define wear time on the reliability of accelerometer-determined PA measurement in 5,595 eleven year old children. They found that the reliabilities remained constant using varying daily wear durations (between seven and ten hours) but while the number of wear days required per child to be included in analyses remained constant. For example, when using daily wear durations of at least 10, 9, 8, and 7 hours per day and the maximum number of wear day's available, reliabilities were 45%, 44%, 44% and 43% respectively. The ALSPAC also reported lower reliabilities than our study using the same thresholds to define wear time: children with at least 12 days lasting at least seven hours per day of data produced the highest reliability (90%). However, the ALSPAC used a threshold of at least three days lasting at least ten hours per day to define minimum wear time despite the reliability of measurement reaching only 70% when using data from children meeting this threshold. It is possible that the reliabilities found by the ALSPAC are lower than this study because their sample included secondary-school aged children who are less likely to have consistent daily activity programmes but more likely to have weekly physical education lessons or sports clubs than the primary-school aged children participating in the MCS who have consistent daily breaks and lunch times.

The results of our study suggest that there are between- as well as within- day variation in our sample of children. Several non-population based studies have found differences in children's daily PA between different time periods[120 126 250]. Trost e*t al*[120] found two distinct time periods to characterise weekday PA activity in six to eight year olds (from 07:00 to 10:59, and 11:00 to 21:00). Participation in MVPA was consistent within each time block but different between the two periods, therefore requiring at least six hours per day to characterise daily PA will reduce the potential for bias by measuring activity in both time periods. Jago *et al*[250] reported three distinct time periods to characterise weekly PA in 12 year old children: children (particularly boys) were more active on weekend and weekdays between 15:00 and 19:00 than between 06:00 to 15:00 and 19:00 to 24:00. It is possible that the reliabilities found by Penpraze *et al*[188] differ to this study because their sample included younger children that do not have the same structure of a school day.

A number of articles have investigated the reliability of PA measurement using varying numbers of wear days without considering the influence of varying the daily wear length. The findings of these studies vary greatly, and are dependent on the age of the children and the study design. Studies have found that reliabilities of 80% were achieved when including children with a greater number of days of accelerometer data than calculated by our study. For example, at least five[113] to seven[188] wear days were required from preschool children (aged two to five years), four[120 129] to seven[28 129] wear days were required from children (aged 6 to 12 years), and five[134] to nine[120] wear days were required from adolescents (aged 13 to 18 years). Despite these findings, other large scale accelerometer studies have included children with only one day of data in analyses[64 134]. For example, the Trial Activity for Adolescent Girls study included children who provided at least one day of data lasting at least six hours in analyses[134].

Trost *et al*[120] found that between four and five, and eight and nine wear days (a day was included if zero counts were indicative of sleeping time) were required to achieve measurement reliabilities of at least 80% in children and adolescents respectively. Murray *et al*[134] found that five or six wear days would provide a reliable (80%) estimate of minutes of MVPA in 12 to 14 year old girls. Janz *et al*[186] found that reliabilities for cpm and the percentage of daily time spent in SB, MPA, and VPA ranged from 42% to 47%, 69% to 73% and 81% to 84% when including children in analyses with one, three or six wear days (ten hours per day) respectively. Treuth *et al*[28] found that a minimum of seven wear days (lasting at least 1,000 minutes per day) were required to reliably estimate children's habitual PA in eight to nine year old girls. Nader *et al*[129] calculated the reliability of PA measurement in 9, 11, 12 and 15 year olds: reliabilities of 73% and 81% for minutes of MVPA were found when including children with at least four and seven wear days in analyses respectively.

To my knowledge, there have been no published studies exploring the influence of gender on the reliability of accelerometer-determined PA. Many large scale accelerometer studies[123 167 166 160 163 149 161] require at least one weekend wear day for a child to be included in analyses. However, only a few studies have explored the influence of the distribution of wear days on the reliability of PA measurement in children[188]. In agreement with this study, Penpraze *et al*[188] found that the purposeful inclusion of children with weekend data had little effect on reliability estimates: using data provided by children with four days wear including a weekend day compared to using data provided by children with four week days of data reduced reliability estimates minimally from 84% to 82%. Mattocks *et al*[138] did not explore the influence of purposely sampling children based on weekend wear, but in agreement with other studies[64 109 242], they found that children's PA differed on weekend days compared to weekdays: mean weekday cpm were slightly higher than mean weekend cpm.

Only one previous large scale study has evaluated the influence of varying the number and distribution of accelerometer wear days on the reliability of population estimates of PA. In contrast to our study, McClain *et al*[229] found that stable estimates of population PA can be obtained from only one randomly selected day out of a possible sampled week in 2,532 adults (aged 20 years). However, in agreement with our study, they also found that the purposeful sampling of subjects which forces the inclusion of a weekend day is not necessary.

6.3.5.3 Strengths and limitations

This is the first study to explore the influence of varying the minimum daily wear time *and* the minimum number of wear days on the reliability of PA measurement in a large scale UK-wide study of children. It has been suggested that previous thresholds of minimum wear time may have been overestimated because of violations in the assumptions associated with the ICC formula[208 251]. However, we have shown that high reliability values can be attained from children with a relatively small number of days and hours of wearing time. We are also confident that the study design, accelerometer protocol, and analytical methodologies employed here enable us to define a robust definition of wear time. Accelerometer data often follow a skew distribution, and it is important to account for this asymmetry to achieve the normality assumption required to correctly compute the ICC. Our ICC values also take into account the MCS survey and non-response weights. Uniquely, we have also explored the influence of gender and the distribution of wear days on the reliability of PA measurement. In doing so, we used data from a large, contemporary, socially and ethnically diverse cohort of children from all four UK countries.

Our proposed wear time threshold may not be applicable for use in different ages[120]. PA levels vary according to age, and children's PA is very different to adult's PA in many respects[130]; it is therefore unlikely that without further research the findings of this study can be used in adult populations. Previous studies have found that the number of wear days required to provide reliable estimates of PA differs according to the child's age[120]. Reliability values may be dependent on the derived PA outcome variable. However, studies have found similar reliability values for PA measurement when accelerometer data were expressed as cpm or as the percentage of time spent in different activity intensities[186 188]. For example, Janz *et al*[186] found that the reliabilities varied by only 2% (ICC: 0.75 to 0.77) when accelerometer-determined activity was expressed as either cpm, or the frequency of SB, MPA or VPA. Our study used an epoch of 15 seconds to collect data. Even shorter epochs can now be used to obtain activity data for an extended number of days. As a result, our proposed wear time definition may not be applicable for use in studies using smaller epochs. The use of a 15 second epoch may influence the reliability of PA measures, particularly when deriving estimates of VPA.

6.3.5.4 Recommendations for study practice and further research

It is important that researchers using accelerometer data only analyse data from children that meet a pre-defined wear time threshold. Using the proposed threshold will enhance quality control processes by ensuring that only children who provide enough data to reliably estimate weekly PA are used in analyses without compromising sample size. If population studies do not screen accelerometer data prior to processing this may lead to unreliable estimates of children's habitual activity levels with implications for evidence used to set and assess adherence to government guidelines[60]. The proposed threshold is appropriate for use in boys and girls, although studies using samples of only girls may be able to use a less stringent definition than studies including both genders. It is important that subjects are asked to wear their accelerometer over an entire day, and that both weekdays and weekend days are requested in the monitoring period. However, the purposeful inclusion of children with weekend data in analyses is not necessary.

Future research should be aimed at calculating whether the proposed threshold is applicable across different age groups and in studies deriving different PA outcome variables. Furthermore, this study suggests that the inclusion of data from children with at least two days of accelerometer data (lasting at least six hours per day) out of a possible seven day monitoring period provides a reliable estimate of population-based estimates of PA. Further research is required to determine whether this is applicable in studies that ask children to wear their monitor for only two days. Bias may be introduced when data from children with only two wear days are included in analyses, especially if these days are not randomly sampled from a possible seven day week. Although beyond the scope of this study, the removal of children that do not meet the wear time threshold may be dealt with through imputation methods[133], and future research is needed to explore such approaches to adjust for potential bias introduced by removing unreliable data.

6.3.6 Conclusion

It is important for population-based studies to integrate a core set of quality control procedures prior to deriving activity outcome variables: this should include the screening of data using a wear time threshold. Using a threshold of at least two days lasting at least six hours per day will enhance data quality by ensuring that only data from children providing reliable estimates of PA are analysed, thus improving the validity of derived estimates of PA. This threshold is applicable in seven to eight year olds and in population-based studies that monitor children over a full week including the weekend. It is unnecessary to only include children with weekend data in analyses.

6.3.7 Key points

- Both the minimum daily wear time *and* the minimum number of wear days required by each child for inclusion in analyses influenced the reliability of PA measurement.
- A wear time threshold of at least two days lasting at least six hours per day is recommended in population-based studies to screen data where children are measured over a full week.
- The reliability of PA measurement exhibited a minimal gender-related trend: measurement was slightly more reliable in girls than boys for nearly all combinations of minimum daily wear time and minimum number of wear days.

- Reliabilities were slightly higher for children with weekend data compared to children with only weekday data.
- The purposeful sampling of children with at least one weekend day of data resulted in similar reliabilities for all wear time thresholds to those calculated when using the total sample independent of weekend wear. Therefore, sampling of subjects which forces the inclusion of weekend data in *all* children is not necessary.
- Further research is required to determine whether the proposed threshold is applicable across different age groups.

7 Chapter 7: Predictors of non-response

7.1 Chapter overview

This chapter describes a study investigating the biological, social, behavioural, and environmental factors relating to the child, and the child's family, that predict the following factors in the MCS4 main stage accelerometer study:

1. Study non-consent
2. Non-return of accelerometers
3. Non-receipt of reliable accelerometer data

7.2 Introduction

The use of a postal methodology to distribute and return accelerometers enabled the MCS to achieve higher population coverage than would have been possible using face-to-face distribution methods. However, this method led to a lower proportion of consenting children returning reliable data than obtained by other large scale studies in children using face-to-face distribution and return methods (Chapter 5)[61 64 130].

Accelerometer data was not obtained from a proportion of the MCS children because of non-consent, consent being obtained but the accelerometer not being returned, and the accelerometer being returned but not being worn for long enough. Although non-response is a problem for nearly all large scale studies, the use of a postal methodology may increase data loss and potentially introduce bias into study findings. Lack of face-to-face contact with researchers may reduce motivation for participation, or involve uncertainty for participants relating to the accelerometer wear or return protocol. There is also a dependence on external factors such as an efficient postal service. The concern for researchers is that children who provide reliable data have different characteristics to those that don't. As a result, inferences about the population that are based on the observed sample will not be the same as those based on the target sample[252].

Few studies have investigated predictors of non-consent in large scale accelerometer studies in children, and in those available, only the effects of gender[152] and ethnicity[64] have been investigated. No large scale accelerometer studies using postal distribution methods have evaluated predictors of consent, and only one has evaluated differences between children that did and did not return reliable data[17]. Gender, age and ethnic differences between children who did and did not provide reliable accelerometer data are well investigated in studies using face-to face distribution methods[17 64 123 130 132 138 145 149 180 181] but findings are inconsistent, possibly due to differences in study design, accelerometer protocol or study populations (e.g. age differences). There are also few studies[149 180] that have investigated PA differences between children that did and did not provide reliable accelerometer data, and none that have evaluated differences in SB.

Further research is needed to determine the factors associated with non-response in large scale studies using a novel postal distribution and return methodology. This would enable researchers to minimize non-response, and also reduce the effect of bias through modification of analytical methods. The MCS provides a unique data source that can address this evidence gap as the accelerometer data can be linked to a rich set of biological, social, behavioural and environmental factors relating to the child, and the child's family; these data are available for all cohort children independent of whether they provided study consent, returned their accelerometer or provided reliable data.

7.3 Aim

The aim of this study was to investigate the biological, social, behavioural and environmental predictors of non-response resulting from study non-consent, and non-return of accelerometers and reliable data in a UK-wide postal study of children's activity.

7.4 Methods

7.4.1 Subjects

All singleton children that took part in the MCS4 main stage interviews (*n*=13,681).

7.4.2 Statistical analysis

All analyses were conducted in STATA 12.1 and weighted using MCS survey and non-response weights to account for attrition between contacts and adjusted for the clustered sample design. Twins and triplets were not included in the analyses because data were unintentionally not coded to allow the interview and accelerometer data for twins and triplets to be accurately linked. Sample sizes and weighted percentages were calculated for the total sample, and stratified for consenting and non-consenting children, and for children who did and did not return their accelerometer and provide reliable accelerometer data, according to the following potential predictor variables (described in Section 4.5):

Biological

- Child's gender
- Child's ethnicity
- Child's BMI

Social

- Mother’s age at birth
- Maternal occupation
- Maternal highest academic qualification
- Lone parent status
- Number of children in the household
- Main household language
- Whether anyone smokes near the child
- Whether the mother is in work or not
- Main housing tenure
- Type of accommodation
- Household income

Behavioural

- Whether the child has any illnesses or disabilities that limits activity
- Number of days a week the child participates in sport or exercise
- Number of hours the child watches TV on weekdays
- Whether the child was ever breastfed

Environmental

- Access to garden
- Ward type
- Government office region
- Country

All potential predictor variables were entered into unadjusted logistic regression models. *P*-values were obtained from adjusted Wald tests. Multicollinearity was investigated to determine which variables should be included in the adjusted logistic regression models because several of the variables reported similar concepts. Multicollinearity occurs when two or more predictor variables in a multiple regression model are highly correlated[254]. When high multicollinearity is present, standard errors tend to be high, CIs tend to be very wide and *t*-statistics tend to be very small. As a result, coefficients will have to be larger to be statistically significant, therefore making it harder to reject the null hypothesis. This investigation was achieved by examining the bivariate correlations between all potential predictor variables, and calculating the variance inflation factors (VIF). The VIF is an index that measures how much the variance of an estimated regression coefficient is increased because of collinearity[255]. VIF values were calculated using the formula $1/(1-R^2)$ after regressing each potential predictor variable against all other variables (where R is the correlation coefficient between two variables); VIF values greater than 2.5 are often considered a concern[255]. Multicollinearity was evident between 'maternal occupation' (VIF: 2.83) and 'whether the mother was in work or not' (VIF: 2.54; correlation coefficient=0.78), and between 'government office region' (VIF: 2.49) and 'country' (VIF: 2.53; correlation coefficient= 0.77). Each of these variables was removed from the model, one at a time, and VIFs recalculated. The removal of 'whether the mother was in work or not' and 'government office region' reduced any signs of multicollinearity.

All remaining variables were entered into three separate adjusted logistic regression models to determine the predictors of data loss resulting from study non-consent, and non-return of accelerometers and reliable data. *P*-values were obtained from adjusted Wald tests to determine differences between the regression coefficients.

7.5 Results

7.5.1 Consent

7.5.1.1 Unadjusted analyses

Biological, social, behavioural and environment factors were all associated with study consent in the unadjusted models (Table 31). Pakistani, Bangladeshi, and Indian children were almost half as likely to consent compared to white children. Several social factors were associated with non-consent including mothers who were not working, mothers without a degree, households with only one child or an income of less than £10,400, households that spoke another language apart from English, and children who did not have people smoking near them. Children with a limiting illness or disability were half as likely to provide study consent compared to those without a limiting illness or disability. Children who exercised less than once a week or had never been breastfed were also less likely to consent. Consent was also less likely for children from ethnic wards, or those who lived in Yorkshire and Humberside, London, or Northern Ireland.

Table 31: Weighted percentages and sample sizes for total singletons interviewed (n=13,681), consenting (n=12,872) and non-consenting singletons (n=809), adjusted and unadjusted odds ratios (95% CI) and p-values for predictors of consent

	Weighted % (*n*)			**Unadjusted regressions**		**Adjusted regression**	
	Interviewed	**Consenting**	**Non-consenting**	**OR (95% CI)**	***p*-value**	**OR (95% CI)**	***p*-value**
ALL	100.0 (13681)	94.5 (12872)	5.5 (809)				
Biological							
Child's gender							
Male	51.4 (6950)	94.7 (6541)	5.3 (409)	1.07 (0.90, 1.28)	0.442	1.10 (0.91, 1.32)	0.318
Female	48.6 (6731)	94.4 (6331)	5.6 (400)	1		1	
Child's ethnicity							
White	85.5 (11373)	95.1 (10745)	4.9 (628)	1		1	
Mixed	3.2 (367)	91.9 (345)	8.1 (22)	0.59 (0.32, 1.08)	0.089	0.57 (0.30, 1.10)	0.093
Indian	1.9 (339)	91.8 (316)	8.2 (23)	0.58 (0.35, 0.96)	0.033	0.91 (0.45, 1.84)	0.793
Pakistani/Bangladeshi	4.7 (869)	92.1 (794)	7.9 (75)	0.61 (0.45, 0.82)	0.001	1.06 (0.67, 1.70)	0.779
Black or black British	3.2 (446)	92.8 (411)	7.2 (35)	0.67 (0.41, 1.09)	0.103	0.64 (0.36, 1.14)	0.126
Other	1.4 (186)	92.4 (173)	7.6 (13)	0.63 (0.32, 1.26)	0.190	1.06 (0.49, 2.26)	0.884
Child's BMI							
Under/normal weight	79.9 (10582)	94.9 (10011)	5.1 (571)	1		1	
Overweight/obese	20.1 (2759)	94.4 (2583)	5.6 (176)	0.90 (0.74, 1.10)	0.313	0.97 (0.79, 1.20)	0.802
Social							
Mother's age at birth (years)							
14-19	8.5 (1005)	93.9 (940)	6.1 (65)	0.87 (0.61, 1.26)	0.468	1.01 (0.69, 1.48)	0.962
20-29	45.4 (6103)	94.7 (5752)	5.3 (351)	1.02 (0.87, 1.19)	0.844	1.14 (0.95, 1.36)	0.159
30-39	43.4 (6184)	94.6 (5817)	5.4 (367)	1		1	
≥ 40	2.7 (389)	93.0 (363)	7.0 (26)	0.75 (0.48, 1.18)	0.215	1.01 (0.59, 1.73)	0.983
Maternal occupation							
Managerial & professional	22.5 (3173)	95.4 (3018)	4.6 (155)	1		1	
Intermediate	12.9 (1746)	95.7 (1666)	4.3 (80)	1.08 (0.73, 1.58)	0.707	1.21 (0.80, 1.85)	0.371
Small employers & own account workers	5.8 (751)	95.5 (716)	4.5 (35)	1.03 (0.68, 1.55)	0.885	1.15 (0.74, 1.77)	0.533
Lower supervisory & technical	2.7 (345)	95.7 (328)	4.3 (17)	1.08 (0.62, 1.88)	0.797	1.26 (0.67, 2.38)	0.467
Semi- routine & routine	18.1 (2385)	94.8 (2248)	5.2 (137)	0.88 (0.64, 1.21)	0.433	1.03 (0.73, 1.46)	0.847
Non-employed	37.9 (4993)	93.3 (4628)	6.7 (365)	0.68 (0.53, 0.88)	0.003	0.79 (0.60, 1.07)	0.119

Maternal academic qualification							
Degree(s)/ post graduate diplomas	18.6 (2756)	95.5 (2623)	4.5 (133)	1		1	
Higher education/ teaching qualifications/ diplomas	11.4 (1592)	94.9 (1512)	5.1 (80)	0.88 (0.63, 1.22)	0.441	0.81 (0.56, 1.17)	0.265
A/ AS/ S-levels	9.2 (1299)	94.9 (1231)	5.1 (68)	0.88 (0.61, 1.25)	0.467	0.84 (0.56, 1.26)	0.390
O-levels/ GCSE grades A-C	32.0 (4219)	94.6 (3958)	5.4 (261)	0.83 (0.63, 1.10)	0.191	0.81 (0.57, 1.13)	0.217
GCSE grades D-G	11.0 (1396)	94.2 (1308)	5.8 (88)	0.77 (0.52, 1.13)	0.182	0.72 (0.47, 1.10)	0.129
Other academic quals.	2.5 (358)	93.3 (335)	6.7 (23)	0.66 (0.39, 1.10)	0.109	0.73 (0.43, 1.24)	0.247
None of these	15.3 (2057)	93.3 (1902)	6.7 (155)	0.66 (0.48, 0.91)	0.012	0.91 (0.61, 1.35)	0.632
Lone parent status							
Non-lone parent	77.3 (10785)	94.7 (10157)	5.3 (628)	1		1	
Lone parent	22.7 (2896)	94.0 (2715)	6.0 (181)	0.87 (0.72, 1.05)	0.151	1.01 (0.78, 1.29)	0.916
Number of children in the household							
1	13.3 (1771)	92.9 (1649)	7.1 (122)	0.73 (0.59, 0.90)	0.004	0.82 (0.64, 1.05)	0.110
2-3	72.9 (9886)	94.8 (9325)	5.3 (561)	1		1	
≥ 4	13.8 (2024)	95.0 (1898)	5.0 (126)	1.05 (0.82, 1.35)	0.695	1.30 (0.99, 1.71)	0.062
Household language							
English only	89.8 (11786)	94.9 (11127)	5.1 (659)	1		1	
English and other	9.6 (1796)	91.3 (1656)	8.7 (140)	0.56 (0.43, 0.72)	<0.001	0.68 (0.46, 1.00)	0.052
Non English speaking	0.5 (99)	86.7 (89)	13.3 (10)	0.35 (0.14, 0.89)	0.027	0.45 (0.16, 1.31)	0.145
Whether anyone smokes near the child							
No	86.4 (11837)	94.4 (11126)	5.6 (711)	1		1	
Yes	13.6 (1759)	95.8 (1672)	4.2 (87)	1.37 (1.03, 1.82)	0.031	1.37 (1.02, 1.84)	0.037
Whether mother is in work or not							
In work or leave	61.6 (8511)	95.2 (8077)	4.8 (434)	1		NA	NA
Not in work or leave	38.4 (5170)	93.4 (4795)	6.6 (375)	0.71 (0.60, 0.84)	<0.001		
Main housing tenure							
Own outright, full or part mortgage/loan	63.1 (8996)	94.6 (8475)	5.4 (521)	1		1	
Rent local authority/housing association	24.9 (3092)	94.3 (2900)	5.8 (192)	0.93 (0.72, 1.20)	0.577	1.23 (0.90, 1.70)	0.197
Rent privately	9.8 (1177)	95.8 (1118)	4.2 (59)	1.30 (0.94, 1.80)	0.111	1.49 (1.01, 2.20)	0.045
Other	2.2 (277)	92.3 (258)	7.7 (19)	0.68 (0.38, 1.21)	0.188	1.07 (0.59, 1.94)	0.836
Type of accommodation							
House or bungalow	89.9 (12436)	94.6 (11708)	5.4 (728)	1		1	
Flat or maisonette	9.7 (1175)	94.5 (1101)	5.5 (74)	0.99 (0.70, 1.41)	0.952	1.05 (0.65, 1.68)	0.853

Studio, room, bedsit, other	0.4 (49)	99.7 (48)	0.3 (1)	17.2 (2.78, 106.5)	0.002	NA	NA
Household income							
<£10400	13.1 (1733)	92.6 (1603)	7.5 (130)	0.56 (0.39, 0.80)	0.001	0.73 (0.46, 1.16)	0.185
£10400-20800	26.8 (3794)	94.6 (3561)	5.4 (233)	0.78 (0.58, 1.06)	0.113	1.02 (0.71, 1.49)	0.896
£20800-31200	23.1 (3234)	94.4 (3035)	5.6 (199)	0.76 (0.57, 1.00)	0.052	0.99 (0.72, 1.37)	0.929
£31200-52000	24.9 (3359)	95.2 (3183)	4.8 (176)	0.88 (0.64, 1.22)	0.451	1.00 (0.71, 1.42)	0.996
>£52000	12.2 (1541)	95.7 (1474)	4.3 (67)	1		1	
Behavioural							
Disability or illness that limits activity							
No	93. 2 (12783)	94.8 (12066)	5.2 (717)	1		1	
Yes	6.8 (898)	90.8 (806)	9.2 (92)	0.54 (0.41, 0.71)	<0.001	0.65 (0.47, 0.90)	0.010
Frequency of sport or exercise							
3 or more days/week	19.9 (2705)	95.7 (2575)	4.4 (130)	1		1	
2 days/week	20.8 (2829)	95.7 (2693)	4.3 (136)	1.02 (0.76, 1.38)	0.899	1.12 (0.82, 1.52)	0.486
1 day/week	26.1 (3592)	94.7 (3383)	5.4 (209)	0.80 (0.61, 1.07)	0.132	0.87 (0.65, 1.19)	0.387
Less often or not at all	33.2 (4485)	93.1 (4161)	6.9 (324)	0.62 (0.46, 0.82)	0.001	0.77 (0.55, 1.06)	0.110
Hours per weekday child watchesTV							
less than an hour/not at all	19.3 (2684)	94.8 (2524)	5.2 (160)	1		1	
1-3 hours	64.8 (8748)	94.3 (8227)	5.7 (521)	0.91 (0.72, 1.14)	0.415	0.90 (0.70, 1.16)	0.425
3-5 hours	11.1 (1462)	95.9 (1388)	4.1 (74)	1.30 (0.92, 1.83)	0.136	1.37 (0.97, 1.93)	0.073
> 5 hours	4.8 (711)	94.9 (669)	5.1 (42)	1.02 (0.66, 1.56)	0.932	1.14 (0.72, 1.81)	0.581
Child ever breastfed							
No	33.6 (4394)	93.6 (4075)	6.4 (319)	0.77 (0.64, 0.93)	0.006	0.88 (0.72, 1.09)	0.236
Yes	66.5 (9287)	95.0 (8797)	5.0 (490)	1		1	
Environmental							
Access to garden							
No	7.4 (905)	95.6 (857)	4.4 (48)	1.27 (0.90, 1.81)	0.178	1.70 (1.01, 2.85)	0.045
Yes	92.6 (12755)	94.5 (12000)	5.5 (755)	1		1	
Ward type							
Advantaged	56.7 (5693)	95.1 (5408)	4.9 (285)	1		1	
Disadvantaged	37.0 (6326)	94.0 (5924)	6.0 (402)	0.80 (0.62, 1.05)	0.103	0.89 (0.66, 1.21)	0.466
Ethnic	6.3 (1662)	92.2 (1540)	7.8 (122)	0.60 (0.46, 0.80)	<0.001	0.75 (0.48, 1.17)	0.211
Government office region							
North East	3.6 (395)	93.4 (368)	6.6 (27)	0.42 (0.16, 1.06)	0.065	NA	NA
North West	10.8 (1125)	94.8 (1063)	5.2 (62)	0.54 (0.28, 1.03)	0.062		
Yorkshire and Humberside	8.9 (1013)	92.5 (938)	7.5 (75)	0.36 (0.18, 0.73)	0.005		
East Midlands	7.3 (734)	95.3 (705)	4.7 (29)	0.60 (0.27, 1.37)	0.226		

West Midlands	8.0 (1009)	95.7 (958)	4.3 (51)	0.66 (0.32, 1.34)	0.245		
East of England	9.3 (971)	96.7 (935)	3.3 (36)	0.86 (0.41, 1.77)	0.674		
London	11.1 (1403)	93.7 (1315)	6.3 (88)	0.44 (0.23, 0.85)	0.015		
South East	14.5 (1360)	94.6 (1288)	5.4 (72)	0.52 (0.26, 1.03)	0.060		
South West	8.2 (766)	97.1 (745)	2.9 (21)	1			
Wales	5.1 (1951)	94.3 (1844)	5.7 (107)	0.49 (0.26, 0.91)	0.024		
Scotland	9.3 (1598)	94.0 (1499)	6.0 (99)	0.46 (0.24, 0.88)	0.019		
Northern Ireland	4.0 (1354)	89.3 (1212)	10.7 (142)	0.25 (0.13, 0.46)	<0.001		
Isle of Man/Channel Islands	0.02 (2)	100 (2)	0 (0)	NA	NA		
Country							
England	64.2 (8786)	95.0 (8326)	5.1 (460)	1		1	
Wales	14.2 (1945)	94.2 (1838)	5.8 (107)	0.87 (0.65, 1.15)	0.313	0.97 (0.71, 1.33)	0.859
Scotland	11.6 (1599)	94.0 (1500)	6.0 (99)	0.83 (0.60, 1.17)	0.287	0.73 (0.51, 1.03)	0.077
Northern Ireland	9.9 (1351)	89.1 (1208)	10.9 (143)	0.43 (0.32, 0.59)	<0.001	0.46 (0.32, 0.65)	<0.001

Missing data: child’s ethnicity (101); child’s BMI (340); maternal occupation (288); maternal academic qualification (4); smoking near child (85); housing tenure (139); accommodation (21); household income (20); frequency of sport (70); TV viewing (76); access to garden (21)

7.5.1.2 Adjusted analyses

After controlling for other predictor variables, consent remained significantly less likely for children who did not have people smoking near them and children with a limiting illness or disability (Table 31). Consent was also less likely for children who had access to a garden, and those who lived in Northern Ireland.

7.5.2 Accelerometer return

7.5.2.1 Unadjusted analyses

Biological, social, behavioural and environmental factors were all associated with accelerometer return in the unadjusted models (Table 32). Accelerometer return was less likely from boys, and children who were overweight/obese, or mixed, Pakistani, Bangladeshi, or black ethnicity. Accelerometers were also less likely to be returned by younger mothers (<30 years at the birth of the cohort child), mothers who were in semi-routine occupations or were unemployed, mothers without a degree, lone parents, households with one or four or more children, households that spoke English and another language, children who had people smoking near them, children who lived in any type of rented accommodation, or not in a house or bungalow, and households with an income of less than £31,200. Parents of children with a limiting illness or disability, or who exercised one day a week or less, or watched TV for three hours or more on weekdays were also less likely to return their child's accelerometer as were children who had been breastfed. Accelerometers were also less likely to be returned by children without access to a garden, children from disadvantaged or ethnic wards, and those who lived in North East or North West England, Yorkshire and Humberside, West Midlands, London, or Northern Ireland.

Table 32: Weighted percentages and sample sizes for all consenting children sent an accelerometer (*n*=12,303), children who did (*n*=9,721) and did not (*n*=2,582) return their accelerometer, and adjusted and unadjusted odds ratios (95% CI) and *p*-values for predictors of accelerometer return

	Weighted % (*n*)			Unadjusted regression		Adjusted regression	
	Sent	**Returned**	**Not returned**	**OR (95% CI)**	***p*-value**	**OR (95% CI)**	***p*-value**
ALL	100.0 (12303)	78.4 (9721)	21.6 (2582)				
Biological							
Child's gender							
Male	51.2 (6233)	77.1 (4868)	22.9 (1365)	0.85 (0.77, 0.94)	0.002	0.79 (0.71, 0.88)	<0.001
Female	48.8 (6070)	79.8 (4853)	20.3 (1217)	1		1	
Child's ethnicity							
White	86.2 (10310)	79.7 (8277)	20.3 (2033)	1		1	
Mixed	3.1 (329)	71.0 (238)	29.1 (91)	0.62 (0.47, 0.83)	0.001	0.70 (0.52, 0.95)	0.022
Indian	1.9 (305)	79.3 (244)	20.7 (61)	0.98 (0.71, 1.34)	0.883	0.55 (0.35, 0.86)	0.008
Pakistani/Bangladeshi	4.4 (726)	65.2 (500)	34.8 (226)	0.48 (0.39, 0.59)	<0.001	0.44 (0.30, 0.64)	<0.001
Black or black British	3.1 (386)	69.2 (274)	30.8 (112)	0.57 (0.42, 0.77)	<0.001	0.68 (0.49, 0.95)	0.023
Other	1.4 (165)	80.8 (132)	19.2 (33)	1.07 (0.71, 1.62)	0.737	0.96 (0.51, 1.78)	0.890
Child's BMI							
Under/normal weight	80.1 (9671)	79.8 (7779)	20.2 (1892)	1		1	
Overweight/obese	19.9 (2483)	72.5 (1823)	27.5 (660)	0.67 (0.59, 0.75)	<0.001	0.67 (0.59, 0.77)	<0.001
Social							
Mother's age at birth (years)							
14-19	8.4 (895)	56.0 (496)	44.0 (399)	0.21 (0.17, 0.25)	<0.001	0.40 (0.32, 0.50)	<0.001
20-29	45.3 (5486)	74.7 (4133)	25.3 (1353)	0.48 (0.43, 0.53)	<0.001	0.64 (0.57, 0.73)	<0.001
30-39	43.7 (5578)	86.1 (4797)	13.9 (781)	1		1	
>40	2.6 (344)	85.5 (295)	14.5 (49)	0.95 (0.66, 1.37)	0.792	1.31 (0.87, 1.98)	0.194
Maternal occupation							
Managerial & professional	22.9 (2907)	85.8 (2494)	14.3 (413)	1		1	
Intermediate	13.3 (1621)	84.4 (1379)	15.6 (242)	0.90 (0.73, 1.11)	0.325	1.23 (0.99, 1.52)	0.063
Small employers & own account workers	6.0 (695)	82.5 (575)	17.5 (120)	0.78 (0.61, 1.01)	0.060	1.01 (0.78, 1.30)	0.966
Lower supervisory & technical	2.8 (318)	83.5 (264)	17.5 (54)	0.85 (0.60, 1.21)	0.358	1.65 (1.11. 2.43)	0.013
Semi- routine & routine	18.1 (2140)	78.4 (1672)	21.6 (468)	0.60 (0.51, 0.71)	<0.001	1.15 (0.96, 1.38)	0.128
Non-employed	37.0 (4377)	70.6 (3148)	29.4 (1229)	0.40 (0.34, 0.47)	<0.001	1.12 (0.92, 1.36)	0.266
Maternal academic qualification							

Degree(s)/ post graduate diplomas	19.0 (2525)	89.6 (2256)	10.4 (269)	1		1	
Higher education/ teaching qualifications/ diplomas	11.7 (1473)	82.9 (1227)	17.1 (246)	0.56 (0.45, 0.69)	<0.001	0.71 (0.57, 0.90)	0.005
A/ AS/ S-levels	9.4 (1187)	81.4 (969)	18.6 (218)	0.51 (0.40, 0.64)	<0.001	0.67 (0.52, 0.85)	0.001
O-levels/ GCSE grades A-C	32.1 (3787)	77.6 (2939)	22.4 (848)	0.40 (0.34, 0.48)	<0.001	0.64 (0.52, 0.78)	<0.001
GCSE grades D-G	10.8 (1242)	74.3 (920)	25.7 (322)	0.33 (0.27, 0.42)	<0.001	0.76 (0.59, 0.99)	0.039
Other academic quals.	2.3 (311)	76.2 (233)	23.8 (78)	0.07 (0.25, 0.55)	<0.001	0.84 (0.56, 1.27)	0.420
None of these	14.8 (1776)	63.6 (1177)	36.4 (599)	0.22 (0.17, 0.24)	<0.001	0.57 (0.45, 0.72)	<0.001
Lone parent status							
Non-lone parent	77.8 (9749)	82.0 (8047)	18.0 (1702)	1		1	
Lone parent	22.2 (2554)	65.5 (1674)	34.5 (880)	0.42 (0.37, 0.47)	<0.001	0.71 (0.55, 0.82)	<0.001
Number of children in the household							
1	12.8 (1558)	76.4 (1194)	23.6 (364)	0.77 (0.67, 0.89)	<0.001	1.07 (0.90, 1.28)	0.445
2-3	73.2 (8926)	80.7 (7263)	19.3 (1663)	1		1	
≥ 4	14.0 (1819)	67.9 (1264)	32.1 (555)	0.51 (0.44, 0.58)	<0.001	0.65 (0.55, 0.77)	<0.001
Household language							
English only	90.5 (10688)	78.9 (8500)	21.1 (2188)	1		1	
English and other	9.0 (1536)	73.6 (1161)	26.4 (375)	0.74 (0.62, 0.90)	0.002	1.20 (0.91, 1.59)	0.204
Non English speaking	0.5 (79)	72.0 (60)	28.0 (19)	0.69 (0.36, 1.32)	0.263	1.33 (0.68, 2.59)	0.410
Whether anyone smokes near the child							
No	86.1 (10640)	80.6 (8621)	19.4 (2019)	1		1	
Yes	13.9 (1617)	65.1 (1077)	34.9 (540)	0.45 (0.39, 0.52)	<0.001	0.76 (0.65, 0.68)	0.001
Whether mother is in work or not							
In work or leave	62.4 (7768)	83.0 (6454)	17.1 (1314)	1		NA	NA
Not in work or leave	37.6 (4535)	70.8 (3267)	29.2 (1268)	0.50 (0.44, 0.56)	<0.001		
Main housing tenure							
Own outright, full or part mortgage/loan	63.7 (8174)	86.4 (7037)	13.6 (1137)	1		1	
Rent for local authority or housing association	24.3 (2733)	63.8 (1758)	36.3 (975)	0.28 (0.24, 0.31)	<0.001	0.57 (0.48, 0.68)	<0.001
Rent privately	9.8 (1075)	66.8 (712)	33.3 (363)	0.31 (0.27, 0.37)	<0.001	0.53 (0.45, 0.64)	<0.001
Other	2.1 (238)	63.3 (161)	36.7 (77)	0.27 (0.20, 0.37)	<0.001	0.53 (0.37, 0.75)	<0.001
Type of accommodation							
House or bungalow	90.1 (11210)	79.8 (8974)	20.2 (2236)	1		1	
Flat or maisonette	9.5 (1033)	65.9 (708)	34.1 (325)	0.49 (0.42, 0.57)	<0.001	0.93 (0.74, 1.14)	0.435
Studio, room, bedsit, other	0.4 (46)	64.5 (32)	35.5 (14)	0.46 (0.23, 0.90)	0.024	0.41 (0.20, 0.85)	0.018
Household income							

<£10400	12.5 (1503)	61.4 (950)	38.7 (553)	0.21 (0.17, 0.27)	<0.001	1.14 (0.86, 1.51)	0.346
£10400-20800	26.6 (3381)	71.4 (2430)	28.7 (951)	0.34 (0.27, 0.41)	<0.001	1.28 (0.98, 1.66)	0.065
£20800-31200	23.1 (2915)	81.8 (2409)	18.2 (506)	0.61 (0.49, 0.75)	<0.001	1.27 (1.00, 1.60)	0.050
£31200-52000	25.2 (3065)	86.5 (2665)	13.5 (400)	0.86 (0.70, 1.06)	0.163	1.22 (0.99, 1.52)	0.070
>£52000	12.5 (1428)	88.1 (1265)	11.9 (163)	1		1	
Behavioural							
Disability or illness that limits activity							
No	93.7 (11555)	79.0 (9190)	21.0 (2365)	1		1	
Yes	6.3 (748)	69.5 (531)	30.5 (217)	0.61 (0.49, 0.75)	<0.001	0.78 (0.62, 0.96)	0.022
Frequency of sport/exercise							
3 or more days/week	20.3 (2483)	86.1 (2142)	13.9 (341)	1		1	
2 days/week	21.3 (2602)	84.1 (2186)	15.9 (416)	0.86 (0.70, 1.04)	0.119	0.97 (0.79, 1.19)	0.748
1 day/week	26.0 (3227)	79.2 (2562)	20.8 (665)	0.62 (0.52, 0.73)	<0.001	0.88 (0.72, 1.06)	0.178
Less often or not at all	32.4 (3955)	69.4 (2814)	30.7 (1141)	0.37 (0.31, 0.44)	<0.001	0.76 (0.63, 0.93)	0.007
Hours per weekday that child spends watching TV							
less than an hour/not at all	19.2 (2411)	81.4 (1967)	18.6 (444)	1		1	
1-3 hours	64.8 (7991)	78.8 (6268)	21.2 (1623)	0.85 (0.73, 0.99)	0.034	1.01 (0.86, 1.19)	0.885
3-5 hours	11.3 (1330)	73.9 (997)	26.1 (333)	0.65 (0.52, 0.81)	<0.001	1.01 (0.81, 1.26)	0.945
> 5 hours	4.8 (632)	72.8 (471)	27.2 (161)	0.61 (0.48, 0.79)	<0.001	0.95 (0.71, 1.26)	0.718
Child ever breastfed							
Yes	66.9 (8425)	82.5 (6994)	17.5 (1431)	0.49 (0.44, 0.55)	<0.001	0.78 (0.68, 0.89)	<0.001
No	33.1 (3878)	70.0 (2727)	30.0 (1151)	1		1	
Environmental							
Access to garden							
No	7.4 (803)	63.0 (521)	37.0 (282)	0.44 (0.37, 0.52)	<0.001	0.87 (0.70, 1.09)	0.225
Yes	92.6 (11486)	79.7 (9193)	20.4 (2293)	1		1	
Ward type							
Advantaged	57.7 (5237)	83.3 (4475)	16.7 (762)	1		1	
Disadvantaged	36.4 (5622)	71.6 (4184)	28.4 (1438)	0.50 (0.45, 0.57)	<0.001	0.83 (0.74, 0.94)	0.002
Ethnic	6.0 (1444)	71.7 (1062)	28.3 (382)	0.51 (0.41, 0.62)	<0.001	1.15 (0.91, 1.45)	0.243
Government office region							
North East	3.5 (339)	70.8 (247)	29.2 (92)	0.44 (0.28, 0.68)	<0.001	NA	NA
North West	10.9 (1025)	74.6 (769)	25.4 (256)	0.53 (0.38, 0.74)	<0.001		
Yorkshire and the Humberside	8.6 (892)	75.9 (679)	24.1 (213)	0.56 (0.39, 0.81)	0.002		
East midlands	7.4 (682)	81.9 (559)	18.1 (123)	0.81 (0.54, 1.21)	0.301		
West midlands	8.2 (913)	75.2 (694)	24.8 (219)	0.54 (0.39, 0.75)	<0.001		
East of England	9.6 (901)	82.4 (750)	17.6 (151)	0.84 (0.61, 1.17)	0.298		

London	10.8 (1230)	74.2 (946)	25.8 (284)	0.52 (0.38, 0.71)	<0.001		
South East	14.6 (1233)	81.6 (1022)	18.5 (211)	0.79 (0.58, 1.08)	0.143		
South West	8.3 (709)	84.8 (606)	15.2 (103)	1			
Wales	5.0 (1755)	76.3 (1340)	23.7 (415)	0.58 (0.43, 0.78)	<0.001		
Scotland	9.1 (1421)	78.5 (1152)	21.5 (269)	0.66 (0.48, 0.90)	0.009		
Northern Ireland	4.0 (1201)	79.5 (956)	20.5 (245)	0.70 (0.51, 0.94)	0.020		
Isle of Man/Channel Islands	0.02 (2)	61.4 (1)	38.6 (1)	0.29 (0.02, 4.50)	0.372		
Country							
England	64.7 (7936)	78.6 (6279)	21.4 (1657)	0.97 (0.80, 1.16)	0.715	0.89 (0.73, 1.10)	0.279
Wales	14.1 (1748)	76.2 (1337)	23.8 (411)	0.85 (0.67, 1.07)	0.168	0.78 (0.61, 0.99)	0.037
Scotland	11.5 (1422)	78.5 (1153)	21.5 (269)	0.96 (0.75, 1.23)	0.752	0.96 (0.72, 1.26)	0.749
Northern Ireland	9.8 (1197)	79.1 (952)	20.9 (245)	1		1	

Missing data: child's ethnicity (82); child's BMI (149); maternal occupation (245); maternal academic qualification (2); smoking near child (46); housing tenure (83); accommodation (14); household income (11); frequency of sport (36); TV viewing (39); access to garden (14)

7.5.2.2 Adjusted analyses

After controlling for other predictor variables, accelerometer return remained significantly less likely from boys, overweight/obese children, and those who were not white or ‘other’ ethnicity (Table 32). Younger mother’s (<30 years at the birth of the cohort child) were also less likely to return their child’s accelerometer. Accelerometers were also less likely to be returned by mothers who were in lower supervisory or technical occupations, mothers without a degree (excluding those with ‘other’ qualifications), lone parents, households with four or more children, children who had people smoking near them, those who lived in a studio, room or bedsit, and families that did not own, or have a mortgage on their own home. Behavioural factors that predicted accelerometer non-return included children with a limiting illness or disability, children who exercised less than once a week and those who had been breastfed. Accelerometers were also less likely to be returned by children from disadvantaged wards and those who lived in Wales.

7.5.3 Reliable data acquisition

7.5.3.1 Unadjusted analyses

All variables in the unadjusted models were associated with reliable data acquisition except residential country (Table 33). Within the sample who consented and were sent accelerometers, we were less likely to receive reliable data from boys, overweight/obese children, and those who were not white or ‘other’ ethnicity. The social factors associated with non-return of reliable data included younger mothers (<30 at the birth of the cohort child), mothers not in managerial, professional, lower supervisory or technical occupations, or not educated to degree level, households with one or four or more children, or that spoke English and another language, children who had people smoking near them, or who lived in a flat or maisonette, families who did not own, or have a mortgage on their own home or had an household income of less than £31,200. Lone parents were half as likely to return reliable accelerometer data compared to two parent families. We were also less likely to acquire reliable accelerometer data from children with a limiting illness or disability, those who exercised one day a week or less, or watched TV for three to five hours on weekdays, and children who had been breastfed. We were also less likely to acquire reliable data from children without access to a garden, children from disadvantaged or ethnic wards, and those who lived in North East or North West England, Yorkshire and Humberside, West Midlands, London, Wales, Scotland or Northern Ireland.

Table 33: Weighted percentages and sample sizes for all singletons sent an accelerometer (n=12,303), singletons whom we did (n=6,875) and did not (n=5,428) acquire reliable accelerometer data, adjusted and unadjusted odds ratios (95% CI) and p-values for predictors of reliable data acquisition

	Weighted % (*n*)			Unadjusted regression		Adjusted regression	
	Sent	**Reliable data obtained**	**Reliable data not obtained**	**OR (95% CI)**	***p*-value**	**OR (95% CI)**	***p*-value**
ALL	100.0 (12303)	55.8 (6875)	44.2 (5428)				
Biological							
Child's gender							
Male	51.2 (6233)	53.8 (3360)	46.2 (2873)	0.85 (0.77, 0.93)	0.001	0.80 (0.73, 0.89)	<0.001
Female	48.8 (6070)	57.9 (3515)	42.1 (2555)	1		1	
Child's ethnicity							
White	86.2 (10310)	58.0 (6002)	42.0 (4308)	1		1	
Mixed	3.1 (329)	50.1 (174)	50.0 (155)	0.73 (0.55, 0.95)	0.021	0.80 (0.61, 1.06)	0.118
Indian	1.9 (305)	47.7 (150)	52.3 (155)	0.66 (0.49, 0.89)	0.007	0.52 (0.33, 0.83)	0.005
Pakistani/Bangladeshi	4.4 (726)	34.9 (268)	65.1 (458)	0.39 (0.31, 0.48)	<0.001	0.47 (0.31, 0.70)	<0.001
Black or black British	3.1 (386)	39.8 (163)	60.2 (223)	0.48 (0.34, 0.67)	<0.001	0.58 (0.40, 0.83)	0.003
Other	1.4 (165)	53.9 (83)	46.1 (82)	0.85 (0.60, 1.19)	0.341	0.84 (0.52, 1.36)	0.485
Child's BMI							
Under/normal weight	80.1 (9671)	57.6 (5603)	42.4 (4068)	1		1	
Overweight/obese	19.9 (2483)	48.9 (1198)	51.1 (1285)	0.70 (0.64, 0.77)	<0.001	0.74 (0.67, 0.81)	<0.001
Social							
Mothers age at birth (years)							
14-19	8.4 (895)	35.2 (312)	64.8 (583)	0.31 (0.26, 0.38)	<0.001	0.51 (0.41, 0.63)	<0.001
20-29	45.3 (5486)	51.9 (2843)	48.1 (2643)	0.62 (0.57, 0.68)	<0.001	0.77 (0.70, 0.85)	<0.001
30-39	43.7 (5578)	63.4 (3501)	36.6 (2077)	1		1	
>40	2.6 (344)	63.6 (219)	36.5 (125)	1.01 (0.78, 1.30)	0.959	1.27 (0.95, 1.69)	0.104
Maternal occupation							
Managerial & professional	22.9 (2907)	64.5 (1863)	35.5 (1044)	1		1	
Intermediate	13.3 (1621)	59.1 (964)	40.9 (657)	0.79 (0.68, 0.92)	0.003	0.96 (0.82, 1.13)	0.623
Small employers & own account workers	6.0 (695)	58.7 (408)	41.3 (287)	0.78 (0.65, 0.94)	0.008	0.90 (0.74. 1.09)	0.275
Lower supervisory & technical	2.8 (318)	58.6 (191)	41.4 (127)	0.78 (0.59, 1.03)	0.079	1.19 (0.88, 1.61)	0.260

Semi- routine & routine	18.1 (2140)	55.1 (1175)	44.9 (965)	0.67 (0.60, 0.76)	<0.001	1.04 (0.90, 1.20)	0.563
Non-employed	37.0 (4377)	49.2 (2142)	50.8 (2235)	0.53 (0.47, 0.60)	<0.001	1.06 (0.92, 1.22)	0.437
Maternal academic qualification							
Degree(s)/ post graduate diplomas	19.0 (2525)	67.0 (1709)	31.0 (816)	1		1	
Higher education/ teaching qualifications/ diplomas	11.7 (1473)	60.9 (891)	39.1 (582)	0.70 (0.60, 0.82)	<0.001	0.81 (0.69, 0.96)	0.014
A/ AS/ S-levels	9.4 (1187)	59.8 (715)	40.2 (471)	0.67 (0.56, 0.80)	<0.001	0.79 (0.66, 0.95)	0.011
O-levels/ GCSE grades A-C	32.1 (3787)	54.9 (2063)	45.1 (1724)	0.55 (0.48, 0.62)	0.009	0.73 (0.62, 0.85)	<0.001
GCSE grades D-G	10.8 (1242)	50.4 (619)	49.7 (623)	0.46 (0.38, 0.54)	<0.001	0.74 (0.61, 0.90)	0.003
Other academic quals.	2.3 (311)	47.9 (141)	52.1 (170)	0.41 (0.30, 0.56)	<0.001	0.78 (0.56, 1.08)	0.136
None of these	14.8 (1776)	39.9 (737)	60.1 (1039)	0.30 (0.26, 0.35)	<0.001	0.59 (0.49, 0.70)	<0.001
Lone parent status							
Non-lone parent	77.8 (9749)	59.5 (5789)	40.5 (3960)	1		1	
Lone parent	22.2 (2554)	43.0 (1086)	57.0 (1468)	0.51 (0.46, 0.57)	<0.001	0.75 (0.65, 0.86)	<0.001
Number of children in the household							
1	12.8 (1558)	50.1 (779)	49.9 (779)	0.71 (0.63, 0.80)	<0.001	0.84 (0.73, 0.98)	0.022
2-3	73.2 (8926)	58.5 (5224)	41.5 (3702)	1		1	
≥ 4	14.0 (1819)	47.3 (872)	52.8 (947)	0.64 (0.56, 0.73)	<0.001	0.81 (0.70, 0.94)	0.005
Household language							
English only	90.5 (10688)	57.1 (6121)	42.9 (4567)	1		1	
English and other	9.0 (1536)	43.7 (714)	56.3 (822)	0.58 (0.49, 0.68)	<0.001	0.98 (0.76, 1.27)	0.900
Non English speaking	0.5 (79)	51.7 (40)	48.3 (39)	0.81 (0.49, 1.35)	0.420	1.60 (0.88, 2.87)	0.122
Whether anyone smokes near child							
No	86.1 (10640)	57.5 (6097)	42.5 (4543)	1		1	
Yes	13.9 (1617)	46.6 (768)	53.4 (849)	0.65 (0.56, 0.74)	<0.001	0.94 (0.82, 1.09)	0.444
Whether mother is in work or not							
In work or leave	62.4 (7768)	59.8 (4650)	40.2 (3118)	1		NA	NA
Not in work or leave	37.6 (4535)	49.2 (2225)	50.8 (2310)	0.65 (0.59, 0.72)	<0.001		
Main housing tenure							
Own outright, full or part mortgage/loan	63.7 (8174)	63.0 (5088)	37.0 (3086)	1		1	
Rent for local authority or housing association	24.3 (2733)	42.9 (1166)	57.1 (1567)	0.44 (0.40, 0.49)	<0.001	0.81 (0.71, 0.94)	0.005
Rent privately	9.8 (1075)	45.3 (481)	54.7 (594)	0.49 (0.42, 0.57)	<0.001	0.76 (0.64, 0.90)	0.001
Other	2.1 (238)	44.1 (105)	55.9 (133)	0.46 (0.35, 0.61)	<0.001	0.85 (0.62, 1.16)	0.305
Type of accommodation							
House or bungalow	90.1 (11210)	57.4 (6398)	42.6 (4812)	1		1	

Flat or maisonette	9.5 (1033)	41.7 (450)	58.3 (583)	0.53 (0.46, 0.61)	<0.001	0.86 (0.71, 1.04)	0.125
Studio, room, bedsit, other	0.4 (46)	47.4 (24)	52.6 (22)	0.67 (0.33, 1.33)	0.251	0.70 (0.34, 1.45)	0.334
Household income							
<£10400	12.5 (1503)	40.4 (614)	59.6 (889)	0.35 (0.30, 0.42)	<0.001	1.21 (0.96, 1.52)	0.107
£10400-20800	26.6 (3381)	47.0 (1603)	53.1 (1778)	0.46 (0.40. 0.54)	<0.001	1.17 (0.97, 1.42)	0.098
£20800-31200	23.1 (2915)	60.3 (1749)	39.8 (1166)	0.79 (0.68, 0.92)	0.002	1.32 (1.11, 1.56)	0.001
£31200-52000	25.2 (3065)	64.0 (1970)	36.0 (1095)	0.93 (0.81, 1.07)	0.304	1.17 (1.01, 1.36)	0.032
>£52000	12.5 (1428)	65.7 (938)	34.3 (490)	1		1	
Behavioural							
Disability or illness that limits activity							
No	93.7 (11555)	56.7 (6543)	43.3 (5012)	1		1	
Yes	6.3 (748)	43.3 (332)	56.7 (416)	0.58 (0.49, 0.69)	<0.001	0.70 (0.58, 0.83)	<0.001
Frequency of sport/exercise							
3 or more days week	20.3 (2483)	64.9 (1599)	35.1 (884)	1		1	
2 days/week	21.3 (2602)	63.8 (1642)	36.2 (960)	0.96 (0.82, 1.11)	0.554	1.03 (0.89, 1.20)	0.650
1 day/week	26.0 (3227)	55.0 (1768)	45.0 (1459)	0.66 (0.58, 0.75)	<0.001	0.83 (0.73, 0.95)	0.005
Less often or not at all	32.4 (3955)	45.9 (1858)	54.1 (2097)	0.46 (0.41, 0.52)	<0.001	0.75 (0.66, 0.86)	<0.001
Hours per weekday that child spends watching TV							
less than an hour/not at all	19.2 (2411)	57.4 (1401)	42.6 (1010)	1		1	
1-3 hours	64.8 (7991)	56.6 (4451)	43.4 (3440)	0.97 (0.86, 1.09)	0.601	1.10 (0.97, 1.25)	0.121
3-5 hours	11.3 (1330)	50.7 (687)	49.3 (643)	0.76 (0.64, 0.91)	0.003	1.06 (0.89, 1.28)	0.508
> 5 hours	4.8 (632)	53.0 (328)	47.0 (304)	0.84 (0.69, 1.05)	0.122	1.19 (0.93, 1.52)	0.162
Child ever breastfed							
Yes	66.9 (8425)	47.4 (1832)	52.6 (2046)	0.60 (0.54, 0.66)	<0.001	0.82 (0.74, 0.91)	<0.001
No	33.1 (3878)	60.0 (5043)	40.0 (3382)	1		1	
Environmental							
Access to garden							
No	7.4 (803)	40.7 (340)	59.3 (463)	0.52 (0.43, 0.62)	<0.001	0.96 (0.75, 1.22)	0.738
Yes	92.6 (11486)	57.1 (6532)	42.9 (4954)	1		1	
Ward type							
Advantaged	57.7 (5237)	61.7 (3336)	38.4 (1901)	1		1	
Disadvantaged	36.4 (5622)	48.7 (2895)	51.3 (2727)	0.59 (0.53, 0.66)	<0.001	0.85 (0.75, 0.96)	0.008
Ethnic	6.0 (1444)	43.0 (644)	57.0 (800)	0.47 (0.41, 0.54)	<0.001	1.05 (0.84, 1.33)	0.661
Regions in England							
North East	3.5 (339)	50.6 (183)	49.4 (156)	0.56 (0.37, 0.85)	0.006	NA	NA
North West	10.9 (1025)	48.7 (512)	51.3 (513)	0.53 (0.39, 0.70)	<0.001		

Yorkshire and Humberside	8.6 (892)	54.0 (468)	46.0 (424)	0.65 (0.46, 0.92)	0.015		
East midlands	7.4 (682)	61.3 (421)	38.7 (261)	0.87 (0.63, 1.22)	0.431		
West midlands	8.2 (913)	53.5 (488)	46.5 (425)	0.64 (0.47, 0.87)	0.004		
East of England	9.6 (901)	62.3 (563)	37.7 (338)	0.91 (0.69. 1.20)	0.509		
London	10.8 (1230)	48.7 (604)	51.3 (626)	0.52 (0.39, 0.71)	<0.001		
South East	14.6 (1233)	58.9 (743)	41.1 (490)	0.79 (0.62, 1.02)	0.069		
South West	8.3 (709)	64.4 (463)	35.6 (246)	1			
Wales	5.0 (1755)	56.0 (967)	44.0 (788)	0.70 (0.55, 0.90)	0.006		
Scotland	9.1 (1421)	54.8 (806)	45.2 (615)	0.67 (0.51, 0.88)	0.004		
Northern Ireland	4.0 (1201)	54.9 (656)	45.1 (545)	0.67 (0.51, 0.88)	0.005		
Isle of Man/Channel Islands	0.02 (2)	61.4 (1)	38.6 (1)	0.88 (0.06, 13.77)	0.927		
Country							
England	64.7 (7936)	78.6 (6279)	21.4 (1657)	1		1	
Wales	14.1 (1748)	76.2 (1337)	23.8 (411)	0.97 (0.85, 1.10)	0.598	0.98 (0.86, 1.12)	0.762
Scotland	11.5 (1422)	78.5 (1153)	21.5 (269)	0.94 (0.80, 1.12)	0.503	0.95 (0.79, 1.14)	0.570
Northern Ireland	9.8 (1197)	79.1 (952)	20.9 (245)	0.93 (0.78, 1.11)	0.411	0.92 (0.76, 1.13)	0.449

Missing data: child's ethnicity (82); child's BMI (149); maternal occupation (245); maternal academic qualification (2); smoking near child (46); housing tenure (83); accommodation (14); household income (11); frequency of sport (36); TV viewing (39); access to garden (14)

7.5.3.2 Adjusted analyses

After controlling for other predictor variables, reliable accelerometer data acquisition was significantly less likely from boys, overweight/obese children, and those who were not white, mixed, or 'other' ethnicity (Table 33). More social factors remained significantly associated with non-return of reliable data than consent including younger mothers (<30 at the birth of the cohort child), mothers without a degree (excluding those with 'other' qualifications), lone parent families, households with one or four or more children, and children who lived in any type of rented accommodation. We were also less likely to acquire reliable data from children with a limiting illness or disability, children who exercised once a week or less or had been breastfed, and children from disadvantaged wards.

7.6 Discussion

7.6.1 Summary of findings

A number of factors were associated with study non-consent, accelerometer non-return and non-receipt of reliable accelerometer data in this nationally representative cohort of UK children (Table 34). More differences were observed for the return of reliable data than in the consent to participate, likely to be due to the very high consent rate. In particular, a number of biological and social factors were related to non-return of reliable data that were not associated with non-consent. Social disadvantage was more apparent in children who did not return reliable data than for non-consenting children.

Table 34: Predictors of study non-consent and non-return of accelerometers and reliable accelerometer data in the Millennium Cohort Study

Study non-consent	Non-return of accelerometers and reliable data
	Biological • Boys • Non-white (excluding 'other' ethnicity) children • Overweight/obese children
	Social • Mothers younger than 30 at the birth of cohort child • Mothers without a degree • Lone parents • Households with >3 children • Children who lived in rented accommodation
Behavioural • Children with a limiting illness or disability • Children who did not have people smoking near them	*Behavioural* • Children with a limiting illness or disability • Children who exercised less than once a week • Children who had been breastfed
Environmental • Children who had access to a garden • Children who lived in Northern Ireland	*Environmental* • Children from disadvantaged wards

7.6.2 Comparisons with existing research

There are few accelerometer-based studies of children's PA that have investigated predictors of consent[64 152]. Van Sluijs *et al*[152] and Owen *et al*[64] investigated gender differences between children who consented to wearing an accelerometer in two large scale studies. In contrast to this study, girls were more likely to consent than boys in the SPEEDY study[152]. Owen *et al*[64] found no ethnic differences between consenting and non-consenting children participating in the CHASE study, which is consistent with our findings.

To my knowledge, there are no previous studies that have investigated predictors of accelerometer return, and only one large scale study using postal methods to distribute and return accelerometers has investigated predictors of reliable data acquisition[17]. Janz *et al*[17] found no differences between boys and girls according to the number of days of reliable data they provided. Other large scale studies using face-to-face distribution methods have investigated potential predictors of reliable data acquisition using a range of factors, but findings are inconsistent (section 3.5.2).

Previous studies have investigated whether biological factors are associated with the acquisition of reliable accelerometer data. In four studies, younger children were more likely to provide reliable accelerometer data than older children[130 138 180 181], whereas another three found no age differences[132 145 149]. In agreement with this study, boys were less likely to provide reliable data than girls in the ALSPAC[138] and the UK Children's Health and Activity Monitoring Program[123]. In contrast, the NHANES[130] and the SPEEDY[152] study reported that girls were less likely to return reliable data than boys: no gender differences in reliable data acquisition were reported in several other studies[132 149 181]. In contrast to our study, no ethnic differences according to reliable data acquisition were reported by previous studies[64 123 132 181]. The majority of previous studies report that weight status was not related to reliable data acquisition[123 141 145 149]. However, in agreement with our study, overweight children were less likely to return reliable data than non-overweight children in the ALSPAC[138], whereas overweight children were more likely to provide reliable data than non-overweight children in the Project EAST[132].

Few studies have investigated behavioural predictors of reliable data acquisition[145 149 181]. No previous studies have reliably investigated whether PA predicts non-response. However, the Physical Exercise and Appetite in Children Study reported that they were more likely to acquire reliable data from physically active children than those who were less active[149]. In contrast, Sirard *et al*[181] reported that PA levels did not predict whether children returned reliable accelerometer data. Both studies compared the PA levels of children who did and did not return reliable data; however, PA is not reliably estimated in children without reliable data. Only studies with an alternative measure of activity can accurately estimate PA differences in non-response. Few studies have investigated social and environmental factors as potential predictors of reliable data acquisition, although studies have looked at SES[149], child deprivation[123], local and area independent mobility[145], child[132] and parental[152] education, and free school meal status[180].

7.6.3 Strengths and limitations

This is the first large scale accelerometer study using a postal distribution methodology to investigate the predictors of non-response associated with study non-consent and non-return of accelerometers and reliable data. The MCS provided a range of biological, social, behavioural and environmental information on children, their families and their environment which enabled a broad range of potential predictors to be simultaneously investigated. As this is a contemporary cohort the findings of this study are applicable to the lives of young children now. In addition, multicollinearity was investigated to determine which variables should be included in the adjusted logistic regression models, which helps increase the reliability of the regression coefficients, CIs and *p*-values. Furthermore, a robust accelerometer wear time threshold has been used to define children with reliable data (section 6.3)[222].

However, our findings may not be applicable in different ages. PA levels vary according to age, and children's PA is very different to adult's PA in many respects[130]; it is therefore unlikely that without further research the findings of this study can be applied to adult populations. Age has also been shown to be related to the return of reliable accelerometer data in several studies[130 138 180 181]. In addition, although the UK country did not predict non-response in our study, findings may differ in other studies involving samples of children living in non-UK countries.

Many of the predictor variables in this study were based on parent-report measures, and therefore recall bias may have influenced the information collected. For example, maternal report of smoking near child may have been underreported, although any underestimate in this is likely to lead to an underestimate of the effect[256]. However, information collected within the MCS using parent-report methods has been shown to be valid and reliable[257]. Non-consent for children who did not have people smoking near them may reflect highly protective parents. Several factors that were not investigated within this study may also influence non-response, for example, who the cohort children were interviewed by, whether they were sent, or tried to return an accelerometer during a postal strike, or which reminder methods were sent to the family to encourage return of the accelerometer.

7.6.4 Recommendations for study practice and further research

This study has reported the biological, social, behavioural and environmental factors associated with non-response in a PA study using postal methods to distribute and return accelerometers. Researchers should be aware of these factors and recognise potential bias occurring as a result of this methodology so that future studies can implement strategies to reduce the threat of data loss. For example, we found that the language spoken by the cohort families at MCS4 did not influence consent. This may be because non-English speaking families were offered translated versions of all study documents, and a translator was made available at the study interview. However, consent was less likely from children who lived in Northern Ireland; this may be because a different fieldwork agency conducted the home interviews in Northern Ireland (Northern Ireland Statistics and Research Agency) compared to those conducted in England, Wales and Scotland (NatCen). Considerable efforts are required by researchers and parents to encourage boys, non-white and overweight children to wear and return their accelerometer as requested so that we can acquire reliable data from these populations. Lone parents and families with a large number of children may not have returned their child's accelerometer because they forgot, or did not have the time to do so. Therefore, it is crucial that studies issue timely reminders throughout fieldwork, and in particular, to these populations. Caution should also be taken if sampling children with a limiting illness or disability as non-response was very high among these children and may therefore bias study findings.

Further research should investigate whether the predictors of non-response identified in this study also predict non-response in other large scale accelerometer studies, across different age groups and countries, and in studies using different accelerometer distribution and return methods. If studies are unable to increase response in the populations identified in our study, then researchers need to be aware of their influence on the validity of findings. An important finding was that children who exercised less than once a week were less likely to return their accelerometer and reliable data. As a result, study findings may be biased as inferences about the PA levels of the population that are based on the observed sample may not to be the same as those based on the target sample. However, the PA predictor variable was based on parent-proxy report of their child's usual weekly frequency of sport or any other PA. The limitations associated with parent-proxy reports of children's PA have been well defined[258] (section 2.2.3.2). Although beyond the scope of the study, several statistical methods to deal with missing data have been developed and their performance in reducing estimation bias depends on the quality of the models that underpin them[259]. Current work is being undertaken to develop response propensity weighting adjustments in the MCS4 accelerometer study.

7.7 Conclusion

Researchers should consider the factors associated with non-response in large scale accelerometer studies that use postal distribution and return methods so that future studies can implement strategies to reduce the threat of data loss. Accelerometer studies in children that use this postal methodology need to encourage accelerometer and reliable data return from boys, overweight and non-white children, mothers who are young or who have few qualifications, families with only one parent or a large number of children, children who exercise less than once a week, and children living in various forms of disadvantaged circumstances. If studies are unable to increase response in these sections of the population then researchers should weight analyses to account for non-response.

7.8 Key points

- Consent was less likely for children with a limiting illness or disability, children who did not have people smoking near them, or had access to a garden, and children who lived in Northern Ireland.
- From those who consented, accelerometers and reliable data were less likely to be returned by boys, overweight/obese children, those who were not white, or ‘other’ ethnicity, younger mothers, mothers without a degree, families with only one parent, or a large number of children, children who lived in rented accommodation, had been breastfed or had a limiting illness or disability, and children from disadvantaged wards.
- Children who exercised less than once a week, according to parent-proxy report of PA were less likely to return reliable accelerometer data.
- If studies are unable to increase response in these sections of the population then researchers should weight analyses to account for non-response.
- Further research is needed across different age groups and countries, and in studies using different accelerometer distribution and return methods.

8 Chapter 8: Seasonal variation in children's activity

8.1 Chapter overview

This chapter describes a study investigating seasonal intra-individual variation in children's PA and SB in relation to a range of biological, social and environmental factors relating to the child or the child's parents. This study used repeated accelerometer measurements obtained in each of the four seasons during a single calendar year from children participating in the MCS4 seasonal accelerometer study.

8.2 Introduction

The implementation of effective interventions to increase PA and reduce SB depends on a thorough understanding of the determinants of these behaviours. There is substantial research on the biological, psychological and social determinants of activity[183 260]; less has focused on environmental factors, although some has sought to understand the household, school, and community characteristics that influence PA[184]. Environmental determinants that occur naturally such as the weather or seasons have received less attention. However, the importance of seasonal changes in health has been known for a long time:

'Whoever wishes to investigate medicine properly should proceed thus: in the first place to consider the seasons of the year, and what effects each of them produces for they are not at all alike, but differ much from themselves in regard to their changes'

Hippocrates (circa 400 BC); translated by Jones (1923)[261]

A season is a division of the year marked by changes in weather, ecology and hours of daylight, which have the potential to influence PA and SB. Periods of low temperatures, high rain fall, reduced number of sun hours, strong winds and snow may reduce the likelihood of children being physically active. Although the meteorological and temporal factors associated with seasons cannot be changed, the ability to identify their associations with low PA levels and/or high periods of SB is important for the design of public health interventions aimed at promoting PA and reducing SB, especially if there are interactions with variables characterising the child's environment.

It is also important to account for seasonal influences on PA and SB, as large scale cross-sectional studies often rely on single measurements made in different individuals and in different seasons. If substantial seasonal variation exists, measurements at a single time point may introduce bias from between-season differences in the assessment of habitual activity levels.

Seasonal variation in PA appears to be location-specific[221], which may reflect regional variations in climate. As the meteorological factors associated with seasons in a specific region cannot be altered, there may be a role for future research to study other factors associated with variation of PA and SB throughout the seasons. This will enable us to understand what encourages a child to be more or less physically active in specific seasons.

UK studies have reported seasonal variation in children's overall PA, with levels being highest in summer and lowest in winter[64 104 111 260]. However, few studies have evaluated seasonal variation in SB or in PA intensities independently of total PA[221] (section 3.5.4).

Limited research has also investigated possible interactions of seasons with other factors known to influence PA and SB in children, such as gender, age, ethnic group, weight status and geographic location[13 183 185]. It is possible that these factors may differentially influence variation of activity across seasons. For example, an evaluation of regional differences in pedometer-determined PA between urban and rural primary school-aged children living in Cyprus found an interaction between season and rural/urban regions: rural children were more active in summer, and urban children were more active in winter[198]. Rowlands *et al*[111] also found gender-specific differences in the seasonal variation of PA. No studies have reported whether seasonal variation in activity is associated with weight status or ethnicity. It may therefore be possible that the influence of season on PA and SB is modified across specific ethnic groups, or in overweight children compared to under/normal weight children.

Small sample sizes, varying study designs and the use of different seasonal definitions and statistical methods have made conclusions about seasonal variation in PA levels difficult to define. There are also few studies that have followed a repeated measures study design[108 111 260], which is the most appropriate framework for the assessment of between-season, and between-subject differences. Rowlands *et al*[111] also emphasized the need for studies to investigate intra-individual variation in children's PA in larger, more generalizable samples across more than one location. Additional studies of children's seasonal activity are therefore needed that use large samples, employ a repeated measures study design, use comparable definitions of season, and use a consistent standardised approach to accelerometer measurement. These studies should aim to investigate the influence of season on levels of accelerometer-determined SB and PA of varying intensities, and to identify factors that may interact with seasonal effects on these behaviours.

8.3 Aim

The aim of this study was to investigate the biological, social and environmental factors associated with intra-individual variation across seasons in children's accelerometer-determined PA and SB.

8.4 Methods

8.4.1 Subjects

Accelerometer data obtained as part of the MCS seasonal accelerometer study (section 4.3.3) were used in all analyses for this study. All consenting singleton children who returned reliable accelerometer data (≥ two days, ≥ six hours/day) in at least one season were included in analyses (*n*=687).

8.4.2 Statistical analyses

The main outcome measures were mean daily PA (cpm) and the mean daily time spent in SB, VPA and MVPA. For the mean minutes of SB, VPA and MVPA, which were related to the wear time period of the accelerometer, the summary measures for each child were calculated as a weighted mean of the daily values, with weight calculated as the powered inverse of the ratio between observed wear time and standard wear time. Standard wear time was fixed at 735 minutes, which was the mean wear time across all reliable days. The power values were chosen to minimize the correlation between summary variables and daily wear time. All PA and SB were slightly skewed; however, transformation of the data did not substantially improve normality. Therefore, medians and interquartile ranges were derived for all activity variables (given their non-normal distributions).

Repeated measures ANOVAs were used to determine whether seasonal differences in SB and PA outcome measures were present for the total sample (*n*=687). Scheffé's post-hoc tests were conducted using the STATA command `pwcompare` to determine pairwise differences in PA and SB between seasons.

Multi-level models, including a random effect corresponding to unaccountable within-child variation, were fitted to investigate intra-individual variation in the outcome variables across seasons using the STATA command `xtmixed`; this provided estimates of regression coefficients, between- and within-child variance, and ICCs. The multi-level models were fitted with a random effect term on child identity to account for repeated child measurements. Following this, forward stepwise model selection procedures were used to decide which of the following fixed-effects covariates should also be included in the models (described in Section 4.5):

- Child's gender
- Child's ethnicity
- Child's BMI
- Maternal occupation
- Maternal highest academic qualification
- Lone parent status
- Access to garden
- Ward type
- UK country

- Season of measurement [winter (1st November 2008 to 31st January 2009), spring (1st February to 30th April 2009), summer (1st May to 31st July 2009), autumn (1st August to 31st October 2009)]

The models were fitted using maximum likelihood methods. As the models were nested within each other and had the same random effects terms, the model selection strategy was based on likelihood ratio test (LRT) statistics comparing the unadjusted models with the adjusted models. Interactions between season and the selected covariates were then added to the model and post-hoc tests were conducted to see if the interactions were significant. LRTs were used to confirm that all significant interactions should remain in the models' fixed effects terms.

Multi-level models assume that level-1 (population) and level-2 (child) residuals are normally distributed and homoscedastic[262]. To examine the error distributions, histograms of level-1 and level-2 residuals, and scatterplots of standardized residuals against their normal scores, and of predicted values against residuals were obtained[263]. The residuals appeared to be normally distributed but the constant residual variance (homoscedasticity) assumption was not met. Thus heteroscedasticity was therefore modelled explicitly, as a function of the confounding variables[264]; these adjustments were included in all the multi-level models fitted. The multi-level models were extended to allow the within-child variance to depend on the included fixed-effect covariates. This improved the goodness-of-fit of the models, and provided separate within-children variances according to the covariates; for example, separate gender variances, and their effect on the model could now be analysed.

The MCS survey and non-response weights were not used in the analyses because the seasonal sample was a separate sub-group of the MCS children on which the MCS weights were created. The proportion of children with missing data was very small (<2% for all variables) so multiple imputation methods were not used in any analyses.

8.5 Results

8.5.1 Fieldwork and sample characteristics

Overall, a total of 709 out of 1,289 (55.0%; 691 singletons) invited parents gave consent for their child to participate in the MCS4 seasonal accelerometer study.

Following verification of the ICH consent variable (section 5.5.2.1), four of these children were identified by the CLS as non-consenters. Two of these children returned an accelerometer containing reliable data that was worn during spring, summer and autumn. These children were excluded from the analyses.

Figure 27 shows, for each season, the number of children who were sent and returned an accelerometer, and the number of children for whom reliable data was obtained. Overall, 418 children (406 singletons) returned reliable accelerometer data in all four seasons.

Figure 27: Children who were sent and returned an accelerometer, and reliable data acquired in the seasonal accelerometer study

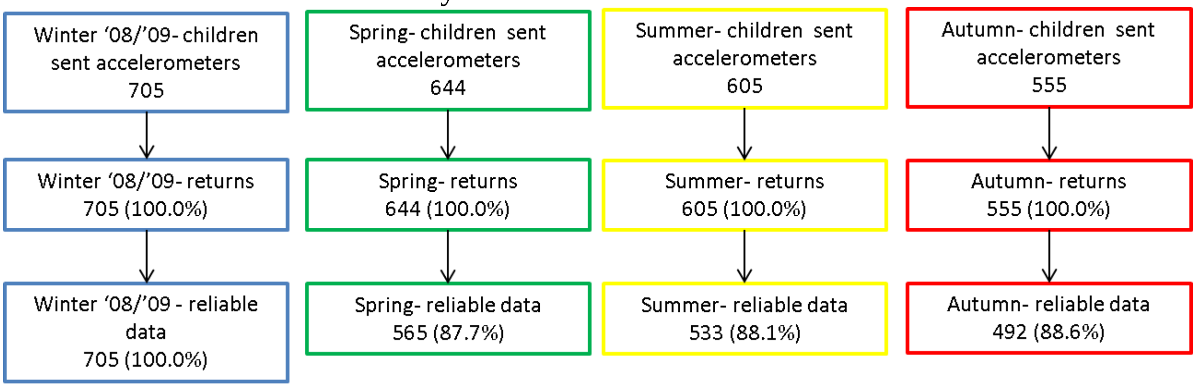


Table 35 reports the sample characteristics for all consenting singletons with reliable data in the main stage accelerometer study (*n*=6,875), for singletons participating in the seasonal study with reliable accelerometer data in at least one season (*n*=687), and for singletons with reliable data in all four seasons (*n*=406).

Within the MCS sample who returned reliable data, Pakistani/Bangladeshi children, children whose mothers were in lower supervisory or technical occupations, children whose mothers' highest academic qualifications were GCSE or O-levels, or had no academic qualifications, children from lone parent families, and children from disadvantaged or ethnic wards were significantly less likely participate in the seasonal study (all $p<0.05$). In contrast, children whose mothers were in intermediate job occupations, were employed by small employers or were their own account workers, children who had access to a garden or lived in Scotland or Northern Ireland were significantly more likely to participate in the seasonal study (all $p<0.05$).

The characteristics of children who returned reliable data in all four seasons were similar to the total seasonal sample. Within the sample who returned reliable data in at least one season, Pakistani/Bangladeshi children and those from ethnic wards were less likely to return reliable data in all four seasons (all $p<0.05$). Children whose mothers worked for small employer's or were their own account workers were more likely to return reliable accelerometer data in all four seasons than the total seasonal sample ($p<0.05$).

Table 35: Sample characteristics of singletons participating in the main stage accelerometer study, the seasonal accelerometer study and those with data in all four seasons

	Singletons with reliable data in the main stage study (*n*=6,875)	All singletons in the seasonal study (*n*=687; ≥ 1 season of reliable data)	Singletons with reliable data in all 4 seasons (*n*=406)
Biological	Percentage (*n*)	Percentage (*n*)	Percentage (*n*)
Child's gender			
Male	48.9 (3360)	47.7 (328)	49.8 (202)
Female	51.1 (3515)	53.3 (359)	50.3 (204)
Child's ethnicity			
White	87.8 (6002)	91.8 (628)	93.8 (381)
Mixed	2.5 (174)	1.6 (11)	1.0 (4)
Indian	2.2 (150)	2.6 (18)	2.5 (10)
Pakistani/Bangladeshi	3.9 (268)	1.9 (13)**	0.7 (3)*
Black or black British	2.4 (163)	1.3 (9)	1.2 (5)
Other	1.2 (83)	0.7 (5)	0.3 (2)
Child's BMI			
Under/normal weight	82.4 (5603)	83.5 (565)	83.7 (340)
Overweight/obese	17.6 (1198)	16.5 (112)	15.0 (61)
Social			
Maternal occupation			
Managerial & professional	27.6 (1863)	32.0 (216)	29.3 (119)
Intermediate	14.3 (964)	16.7 (113)**	17.0 (69)
Small employers & own account workers	6.1 (408)	7.4 (50)**	8.9 (36)*
Lower supervisory & technical	2.8 (191)	2.1 (14)**	1.7 (7)
Semi- routine & routine	17.4 (1175)	15.6 (105)	14.3 (58)
Non-employed	31.8 (2142)	26.2 (177)	26.9 (109)

Maternal academic qualification			
Degree(s)/ post graduate diplomas	24.9 (1709)	31.2 (214)	32.5 (132)
Higher education/ teaching qualifications/ diplomas	13.0 (891)	14.6 (100)	14.8 (60)
A/ AS/ S-levels	10.4 (715)	13.1 (90)	13.6 (55)
O-levels/ GCSE grades A-C	30.0 (2063)	25.2 (173)**	23.2 (94)
GCSE grades D-G	9.0 (619)	7.9 (54)**	7.6 (31)
Other academic quals.	2.1 (141)	1.6 (11)	1.8 (8)
None of these	10.7 (737)	6.6 (45)**	6.4 (26)
Lone parent status			
Non-lone parent	84.2 (5789)	88.9 (611)	90.4 (367)
Lone parent	15.8 (1086)	11.1 (76)**	9.6 (39)
Environmental			
Access to garden			
No	5.0 (340)	3.2 (22)	2.5 (10)
Yes	95.1 (6532)	96.8 (664)**	97.5 (396)
Ward type			
Advantaged	48.5 (3336)	56.3 (387)	58.1 (236)
Disadvantaged	42.1 (2895)	37.6 (258)**	37.4 (152)
Ethnic	9.4 (644)	6.1 (42)**	4.4 (18)*
Country			
England	64.7 (4450)	49.9 (343)	51.7 (210)
Wales	14.0 (965)	11.9 (82)	11.3 (46)
Scotland	11.7 (806)	28.5 (196)**	28.1 (114)
Northern Ireland	9.5 (654)	9.6 (66)**	8.9 (36)

Missing data main stage: child's ethnicity (35); child's BMI (74); maternal occupation (132); access garden (3)
Missing data seasonal study: child's ethnicity (3); child's BMI (10); maternal occupation (12); access garden (1)
Missing data reliable data in 4 seasons: child's ethnicity (1); child's BMI (5); maternal occupation (8)
* $p<0.05$ differences between all singletons in the seasonal study and singletons with reliable data in all seasons
** $p<0.05$ differences between all singletons in the main stage study and all those in the seasonal study

8.5.2 Differences between seasons

Summary statistics for all PA and SB summary variables are reported in Table 36. There were significant seasonal differences in daily PA, and the daily time spent in SB, VPA and MVPA (ANOVA; all $p<0.0001$). Pairwise comparisons revealed that there were PA differences between all seasons except between winter and autumn for all PA and SB measures, and between spring and summer for SB, VPA and MVPA (Scheffé's post-hoc tests, $p>0.05$).

Table 36: Daily median (IQR) for sedentary behaviour and physical activity measures in the four seasons.

	Daily median (IQR)			
Activity measure	**Winter**	**Spring**	**Summer**	**Autumn**
Counts per minute	497 (429, 580)	585 (500, 708)	568 (486, 674)	493 (422, 584)
Time spent in sedentary behaviour	411 (381, 440)	389 (354, 417)	382 (348, 419)	415 (385, 444)
Time spent in vigorous physical activity	16 (12, 23)	22 (15, 30)	20 (14, 29)	16 (11, 23)
Time spent in moderate and vigorous physical activity	53 (42, 68)	67 (52, 86)	65 (51, 82)	55 (43, 68)

8.5.3 Intra-individual variation in physical activity and sedentary behaviour

8.5.3.1 Mean daily physical activity

The forward stepwise modelling procedure resulted in season of measurement, gender, ethnicity, BMI, maternal occupation, maternal academic status, and country being included as fixed-effect covariates in the final model for mean daily PA, in addition to a random-effect for the child. LRTs confirmed that an interaction between season and country significantly improved the model's goodness-of-fit (*p*=0.001; Table 37).

Table 37: Between- and within-child variation, intraclass correlation coefficients and likelihood ratio test statistics for model justification of mean daily physical activity

Null model	Single-level model	Multi-level model with random child effect	Adjusted[a] multilevel model with random child effect
Compared model	Multi-level model with random child effect	Adjusted[a] multi-level model with random child effect	Adjusted model[a] with interactions[b] (final model)
Between-child variation (SD)	10326.96 (101.62)	8356.10 (91.41)	8376.66 (91.52)
Within-child variation (SD)	11607.23 (107.74)	9242.44 (96.14)	9074.62 (95.26)
ICC (CI)	0.47 (0.43, 0.51)	0.47 (0.43, 0.52)	0.48 (0.44, 0.52)

LRT	539.84	1119.83	29.53
p-value	<0.001	<0.001	0.001

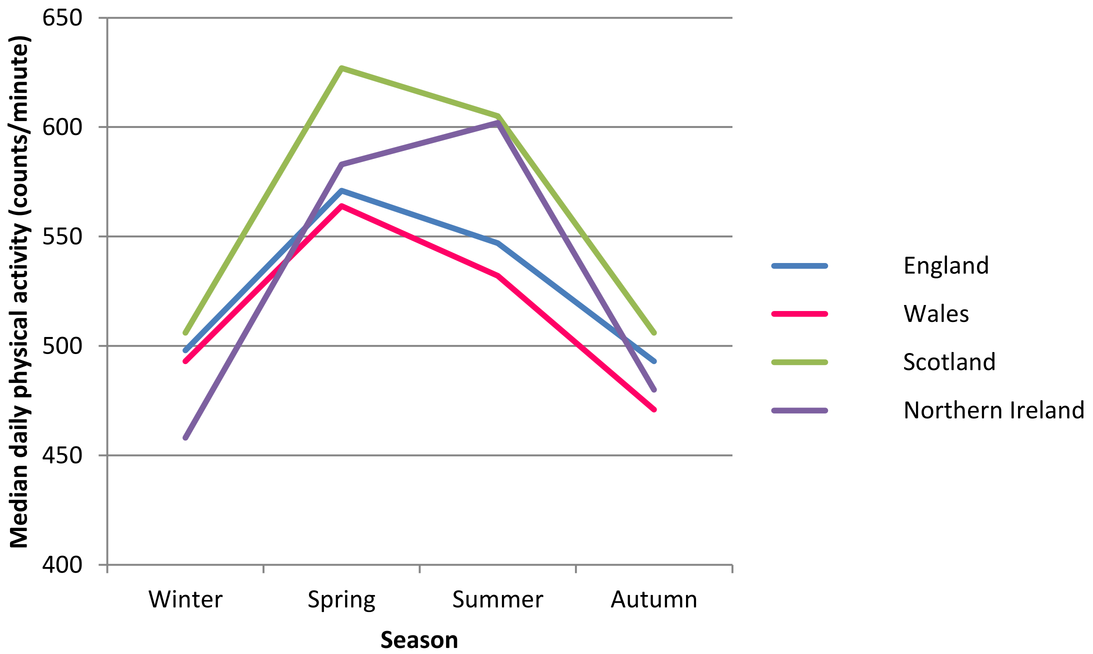
[a]Model adjusted for season, child's gender, child's ethnicity, child's BMI, maternal occupation, maternal academic status and country
[b]Model adjusted for interaction between season and country

The unadjusted ICC estimate for mean daily PA was 0.47 (Table 37), which indicates that 47% of the variance in PA levels can be attributed to differences between children, and 53% within children but between seasons. The ICC values were the same whether unadjusted or adjusted for all covariates (0.47). Thus, 47% of the variance in mean daily PA that was not explained by the fixed-effects covariates was due to time-invariant subject-specific characteristics. The total variance for the unadjusted and adjusted model was 21,934.19 and 17,598.54, respectively. Therefore, 20% = (21,934.19 - 17,598.54) / 21,934.19 of the total variance in mean daily PA was explained by the fixed-effects covariates.

After controlling for covariates, mean daily PA was significantly higher during spring and summer than winter ($p<0.001$; Table 38; fixed effects). In addition, children whose mothers were in lower supervisory or technical occupations were significantly more active than children whose mothers were in managerial and professional roles ($p=0.008$). In contrast, girls, Indian children, overweight/obese children, and those who lived in Northern Ireland, were significantly less active than boys, white children, underweight/normal weight children, and those who lived in England respectively (all $p<0.05$). For example, mean daily PA was estimated to be 75.96 cpm lower for girls than boys, 28.30 cpm lower for overweight/obese children than underweight/normal weight children, and 37.59 cpm lower for children who lived in Northern Ireland than children who lived in England. There was also a significant interaction between season and country of residence (Appendix V; $p=0.002$).

Figure 28 shows the median of the mean daily PA in each season by country. After controlling for covariates, levels of mean daily PA increased during spring for children who lived in Scotland (p=0.025), increased during summer and autumn for children who lived in Northern Ireland (p=0.001 and p=0.003 respectively), and decreased during autumn for children who lived Wales (p=0.035; Table 38; fixed effects). There were no significant interactions between season and gender, ethnicity, BMI, maternal occupation or maternal academic status (Appendix V; p>0.05).

Figure 28: Median of the mean daily physical activity (counts per minute) in each season by country



The within-child variances corresponding to seasonal changes in mean daily PA differed significantly according to the child's gender, ethnicity, BMI, mothers' occupation, and country of residence (all $p \leq$ 0.001; Table 38; random effects).The estimated within-child variances were highest for boys, Pakistani/Bangladeshi children, under/normal weight children, children whose mothers were in lower supervisory or technical occupations, and children who lived in Northern Ireland or Scotland.

Table 38: Estimated regression coefficients and *p*-values for mean daily physical activity from final model with separate variances for confounders

Fixed effects	*Coefficient (CI)*	*p-value*
Intercept	531.32 (505.96, 556.69)	<0.001
Season		
Winter	1	
Spring	88.26 (72.60, 103.93)	<0.001
Summer	65.02 (49.21, 80.82)	<0.001
Autumn	10.38 (-6.00, 26.75)	0.214
Child's gender		
Boys	1	
Girls	-75.96 (-92.61, -59.30)	<0.001
Child's ethnicity		
White	1	
Mixed	36.55 (-36.62, 109.72)	0.328
Indian	-82.71 (-138.98, -26.44)	0.004
Pakistani/Bangladeshi	-45.14 (-108.44, 18.15)	0.162
Black or black British	-29.34 (-104.48, 45.79)	0.444
Other	-4.98 (-100.88, 90.91)	0.919
Child's BMI		
Under/normal weight	1	
Overweight/obese	-28.30 (-51.17, -5.43)	0.015
Maternal occupation		
Managerial & professional	1	
Intermediate	-11.10 (-36.95, 12.79)	0.400
Small employers & own account workers	-4.41 (-38.51, 29.69)	0.800
Lower supervisory & technical	85.27 (21.85, 148.70)	0.008
Semi-routine & routine	20.62 (-7.25, 48.50)	0.147
Non-employed	-14.18 (-37.61, 9.24)	0.235
Maternal academic status		
Degree(s)/ post graduate diplomas	1	
Higher education/ teaching qualifications/ diplomas	12.64 (-6.81, 32.09)	0.203
A/ AS/ S-levels	50.17 (16.95, 83.39)	0.003
O-levels/ GCSE grades A-C	-70.63 (-259.52, 118.26)	0.464
GCSE grades D-G	176.07 (-41.87, 394.01)	0.113
Other academic qualifications	-49.96 (-116.59, 16.68)	0.142
None of these	35.12 (-2.88, 73.11)	0.070

Country		
England	1	
Wales	-2.53 (-35.14, 30.07)	0.879
Scotland	12.49 (-11.91, 36.89)	0.316
Northern Ireland	-37.59 (-73.56, -1.62)	0.041
Season:country		
Spring-Wales	-12.91 (-48.45, 22.64)	0.477
Spring-Scotland	29.93 (3.83, 56.03)	0.025
Spring-Northern Ireland	20.72 (-19.36, 60.81)	0.311
Summer-Wales	-20.46 (-57.13, 16.20)	0.274
Summer-Scotland	24.89 (-1.84, 51.62)	0.068
Summer-Northern Ireland	70.84 (29.87, 111.82)	0.001
Autumn-Wales	-40.59 (-78.25, -2.93)	0.035
Autumn-Scotland	4.07 (-23.45, 31.59)	0.772
Autumn-Northern Ireland	62.40 (21.18, 103.62)	0.003
Random effects	*Variance (SD)*	*Adjusted p-value (LRT)*
Child's gender		
Between subject	8314.47 (91.18)	
Within subject		<0.001 (21.69)
Boys	10642.77 (103.16)	
Girls	7586.34 (87.10)	
Child's ethnicity		
Between subject	8341.49 (91.33)	
Within subject		<0.001 (29.00)
White	9179.84 (95.81)	
Mixed	7194.11 (84.82)	
Indian	3213.84 (56.69)	
Pakistani/Bangladeshi	18998.3 (137.83)	
Black or black British	5861.22 (76.56)	
Other	2791.13 (52.83)	
Child's BMI		
Between subject	8448.76 (91.92)	
Within subject		0.001 (15.86)
Under/normal weight	9568.57 (97.82)	
Overweight/obese	6259.86 (79.12)	
Maternal occupation		
Between subject	8102.70 (90.02)	
Within subject		<0.001 (37.16)
Managerial & professional	7581.31 (87.07)	
Intermediate	7556.55 (86.93)	
Small employers & own account workers	8719.47 (93.38)	
Lower supervisory & technical	22144.57 (148.81)	
Semi-routine & routine	12961.14 (113.85)	
Non-employed	9330.11 (96.59)	
Country		

Between subject	8463.37 (92.00)	<0.001 (41.56)
Within subject		
England	7676.91 (87.62)	
Wales	6923.53 (83.21)	
Scotland	10650.34 (103.20)	
Northern Ireland	14565.75 (120.69)	

8.5.3.2 Sedentary behaviour

Season, gender, maternal occupation and ward type were all included as fixed-effect confounders in the final model for the weighted mean daily time spent in SB, in addition to a random-effect for child (Table 39).

Table 39: Between- and within-child variation, intraclass correlation coefficients and likelihood ratio statistics for model justification of mean daily time spent in sedentary behaviour

Null model	Single-level model	Multi-level model with random child effect
Comparison model	Multi-level model with random child effect	Adjusted[a] multi-level model with random child effect
Between-child variation (SD)	1195.94 (34.58)	1144.22 (33.83)
Within-child variation (SD)	1251.01 (35.37)	982.58 (31.35)
ICC (CI)	0.49 (0.45, 0.53)	0.54 (0.50, 0.60)
LRT	549.08	409.49
p-value	<0.001	<0.001

[a]Model adjusted for season, child's gender, maternal occupation and ward type

The unadjusted ICC for the mean daily time spent in SB was 0.49 (Table 39), which indicates that 49% of the variance in daily SB can be attributed to differences between children, and 51% to differences within children across seasons. The ICC values were slightly higher when adjusted for all covariates (0.54). The total variance for the unadjusted and adjusted model was 2,446.95 and 2,126.8, respectively. Therefore, 13% = (2,446.95 – 2,126.8) / 2,446.95 of the total variance in the mean daily time spent in SB was explained by the fixed-effects covariates.

After controlling for confounders, the mean daily time spent in SB was significantly lower during spring, summer, and autumn than winter (p<0.001; Table 40; fixed effects). Girls spent significantly more time in SB than boys (p< 0.001). For example, on average, girls spent 17.30 minutes longer sedentary per day than boys. There were no significant interactions between season and gender, maternal occupation or ward type (Appendix V; p>0.05).

The amount of within-child between season variances in SB differed significantly according to the child's gender and maternal occupation (all $p\leq$ 0.04; Table 40; random effects). The estimated within-child variance in SB was highest for boys and children whose mothers were in semi-routine and routine occupations or were not employed.

Table 40: Estimated regression coefficients and p-values for mean daily time spent in sedentary behaviour from final model with separate variances for confounders

Fixed effects	*Coefficient (CI)*	*p-value*
Intercept	403.36 (396.05, 410.66)	<0.001
Season		
Winter	1	
Spring	-24.36 (-28.01, 029.71)	<0.001
Summer	-26.90 (-30.62, -23.17)	<0.001
Autumn	5.60 (1.71, 9.48)	<0.005
Child's gender		
Boys	1	
Girls	17.30	<0.001
Maternal occupation		

Managerial & professional	1	
Intermediate	1.78 (-7.02, 10.57)	0.692
Small employers & own account workers	-9.50 (-21.31, 2.32)	0.115
Lower supervisory & technical	-15.42 (-36.74, 5.90)	0.156
Semi- routine & routine	-8.41 (-17.53, 0.71)	0.071
Non-employed	-1.06 (-8.82, 6.71)	0.790
Ward type		
Advantaged	1	
Disadvantaged	-5.00 (-11.25, 1.25)	0.117
Ethnic	11.53 (-1.56, 24.62)	0.084
Random effects	*Variance (SD)*	*Adjusted p-value (LRT)*
Child's gender		
Between subject	1142.04 (33.79)	
Within subject		0.003 (8.85)
Boys	1091.37 (33.04)	
Girls	878.55 (29.64)	
Maternal occupation		
Between subject	1146.79 (33.86)	
Within subject		0.040 (11.63)
Managerial & professional	836.06 (28.91)	
Intermediate	972.00 (31.18)	
Small employers & own account workers	982.84 (31.35)	
Lower supervisory & technical	795.29 (28.20)	
Semi- routine & routine	1172.50 (34.24)	
Non-employed	1070.01 (32.71)	
Ward type		
Between subject	1144.07 (33.82)	
Within subject		0.181 (3.42)
Advantaged	964.42 (31.06)	
Disadvantaged	1041.82 (32.28)	
Ethnic	754.23 (27.46)	

8.5.3.3 Vigorous physical activity

Season, gender, BMI, maternal occupation, and country were all included as fixed-effect confounders in the final model for the weighted mean daily time spent in VPA, in addition to a random-effect for child (Table 41). LRTs confirmed that a significant interaction between season and country significantly improved the model's goodness-of-fit (p=0.012; Table 41).

Table 41: Between- and within-child variation, intraclass correlation coefficients and likelihood ratio test statistics for model justification of mean daily time spent in vigorous physical activity

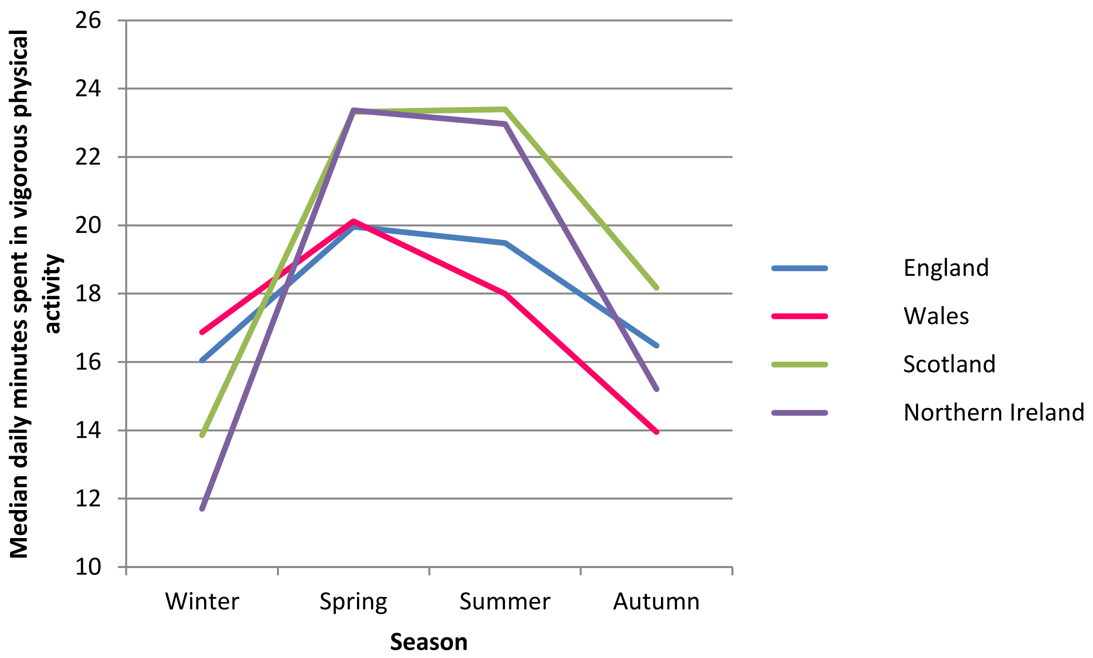
Null model	Single-level model	Multi-level model with random child effect	Adjusted[a] multi-level model with random child effect
Comparison model	Multi-level model with random child effect	Adjusted[a] multi-level model with random child effect	Adjusted model[a] with interactions[b] (final model)
Between-child variation (SD)	74.09 (8.61)	63.89 (7.99)	64.20 (8.01)
Within-child variation (SD)	61.65 (7.85)	55.68 (7.46)	54.85 (7.41)
ICC (CI)	0.55 (0.51, 0.59)	0.53 (0.49, 0.58)	0.54 (0.50, 0.60)
LRT	731.06	297.62	21.82
p-value	<0.001	<0.001	0.01

[a]Model adjusted for season, child's gender, child's BMI, maternal SES, and country
[b]Model adjusted for interaction between season and country

The ICC values for the mean daily time spent in VPA were similar whether unadjusted or adjusted for all covariates (Table 41). The unadjusted ICC was 0.55, which indicates that 55% of the variance in VPA levels can be attributed to differences between children, and 45% within children between seasons. A total of 53% of the variance in the mean daily time spent in VPA that was not explained by the fixed-effects covariates was due to time-invariant subject-specific characteristics. The total variance for the unadjusted model and the model adjusted for all covariates were estimated as 135.74 and 119.57 respectively. Therefore, 12% = (135.74 – 119.57) / 135.74 of the total variance in mean daily VPA was explained by the fixed-effects covariates.

Mean daily time spent in VPA was significantly higher during spring and summer than winter (all $p \leq 0.001$; Table 42; fixed effects). In addition, girls and overweight/obese children on average, participated in significantly less VPA than boys and underweight/normal weight children respectively (all $p<0.05$). For example, the mean daily time spent in VPA was estimated to be 6.23 minutes less for girls than boys, and 3.45 minutes less for overweight/obese children than underweight/normal weight children. The significant interaction between season and country of residence (Appendix V; $p=0.012$) showed that levels of VPA increased during spring, summer and autumn for children who lived in Northern Ireland, but decreased during Autumn for children who lived in Wales (all $p\leq$ 0.035; Table 42; fixed effects). Figure 29 shows the median daily time spent in VPA in each season by country. There were no significant interactions between season and gender, BMI, or maternal occupation (Appendix V; $p>0.05$).

Figure 29: Median of the mean daily minutes spent in vigorous physical activity in each season by country



The within-child variances corresponding to seasonal changes in VPA differed significantly according to the child's gender, BMI, mothers' occupation, and country of residence (all $p \leq 0.004$; Table 42; random effects). The estimated within-child variance was highest for boys, under/normal weight children, children whose mothers were in lower supervisory or technical occupations, and children who lived in Northern Ireland.

Table 42: Estimated regression coefficients and *p*-values for mean daily time spent in vigorous physical activity from fitting final model with separate variances for confounders

Fixed effects	*Coefficient (CI)*	*p-value*
Intercept	21.17 (19.36, 22.97)	<0.001
Season		
Winter	1	
Spring	4.26 (3.10, 5.41)	<0.001
Summer	3.12 (1.95, 4.29)	<0.001
Autumn	0.24 (-0.99, 1.46)	0.705
Child's gender		
Male	1	
Female	-6.23 (-7.62, -4.84)	<0.001
Child's BMI		
Under/normal weight	1	
Overweight/obese	-3.45 (-5.33, -1.57)	<0.001
Maternal occupation		
Managerial & professional	1	
Intermediate	-0.50 (-2.57, 1.56)	0.632
Small employers & own account workers	-0.08 (-2.87, 2.71)	0.956
Lower supervisory & technical	8.96 (3.95, 13.96)	<0.001
Semi- routine & routine	1.53 (-0.60, 3.66)	0.159
Non-employed	-1.05 (-2.88, 0.79)	0.263
Country		
England	1	
Wales	0.06 (-2.56, 2.67)	0.967
Scotland	0.87 (-1.04. 2.78)	0.371
Northern Ireland	-1.64 (-4.49, 1.21)	0.259
Season:country		
Spring-Wales	-0.12 (-2.79, 2.56)	0.933
Spring-Scotland	1.80 (-0.13, 3.72)	0.067
Spring-Northern Ireland	4.03 (1.14, 6.93)	0.006
Summer-Wales	-0.52 (-3.27, 2.24)	0.712
Summer-Scotland	1.14 (-0.83, 3.10)	0.256
Summer-Northern Ireland	4.29 (1.31, 7.27)	0.005

Autumn-Wales	-3.05 (-5.89, -0.22)	0.035
Autumn-Scotland	-0.73 (-2.78, 1.32)	0.486
Autumn-Northern Ireland	3.38 (0.34, 6.42)	0.030
Random effects	*Variance (SD)*	*Adjusted p-value (LRT)*
Child's gender		
Between subject	62.43 (7.90)	
Within subject		<0.001 (102.71)
Male	75.77 (8.70)	
Female	35.61 (5.97)	
Child's BMI		
Between subject	65.14 (8.07)	
Within subject		<0.001 (20.98)
Under/normal weight	58.25 (7.63)	
Overweight/obese	35.11 (5.93)	
Maternal occupation		
Between subject	50.03 (7.68)	
Within subject		<0.001 (44.09)
Managerial & professional	53.01 (7.28)	
Intermediate	38.04 (6.17)	
Small employers & own account workers	80.14 (8.95)	
Lower supervisory & technical	184.33 (13.58)	
Semi- routine & routine	73.23 (8.56)	
Non-employed	49.55 (7.04)	
Country		
Between subject	64.40 (8.02)	
Within subject		0.004 (13.15)
England	51.03 (7.14)	
Wales	59.99 (7.75)	
Scotland	51.91 (7.21)	
Northern Ireland	78.08 (8.84)	

8.5.3.4 MVPA

The forward stepwise modelling procedure resulted in season of measurement, gender, BMI, and country being included as fixed-effect confounders in the final model for the weighted mean daily time spent in MVPA, in addition to a random-effect for child (Table 43). LRTs confirmed that a significant interaction between season and gender, and season and country should be included in the model's fixed-effects (all $p \leq 0.009$; Table 43).

Table 43: Between and within-child variation, intraclass correlation coefficients and likelihood ratio test statistics for model justification of mean daily time spent in moderate to vigorous physical activity

Null model	Single-level model	Multi-level model with random child effect	Adjusted[a] multi-level model with random child effect
Comparison model	Multi-level model with random child effect	Adjusted[a] multi-level model with random child effect	Adjusted model[a] with interactions[b] (final model)
Between-child variation (SD)	302.35 (17.39)	244.43 (15.63)	245.38 (15.66)
Within-child variation (SD)	257.54 (16.05)	202.18 (14.22)	196.90 (14.03)
ICC (CI)	0.54 (0.50, 0.58)	0.55 (0.51, 0.59)	0.55 (0.51, 0.59)
LRT	690.00	530.87	41.04
p-value	<0.001	<0.001	<0.001

[a]Model adjusted for season, child's gender, child's BMI, and country
[b]Model adjusted for interaction between season and country, and season and gender

The unadjusted and adjusted ICCs for the mean daily time spent in MVPA were 0.54 and 0.55, respectively (Table 43). This indicates that, after controlling for confounders, 55% of the variance in MVPA levels can be attributed to differences between children, and 4,l5% within children between seasons. The total variance for the unadjusted MVPA model and for the model adjusted for all covariates was 559.89 and 446.61 respectively. Therefore, 20% = (559.89 – 446.61) / 559.89 of the total variance in mean daily MVPA was explained by the fixed-effects covariates.

After controlling for confounders, the mean daily time spent in MVPA was significantly higher during spring and summer than in winter (p<0.001; Table 44; fixed effects). In addition, girls and overweight/obese children participated in significantly less MVPA than boys and underweight/normal weight children, respectively (all $p \leq 0.011$). For example, the mean daily time spent in MVPA was estimated to be 14.35 minutes less for girls than boys, and 4.65 minutes less for overweight/obese children than underweight/normal weight children. There was a significant interaction between season and child's gender, and between season and country of residence (Appendix V; p=0.003). Figure 30 and Figure 31 show the median daily time spent in MVPA in each season by child's gender and country. After controlling for covariates, levels of MVPA increased significantly during spring and summer for children who lived in Northern Ireland, decreased during autumn for children who lived in Wales, and decreased during spring and summer for girls (all $p \leq 0.042$; Table 44; fixed effects). There were no significant interactions between season and BMI (Appendix V; p>0.05).

Figure 30: Median of the mean daily time spent in moderate and vigorous physical activity in each season by gender

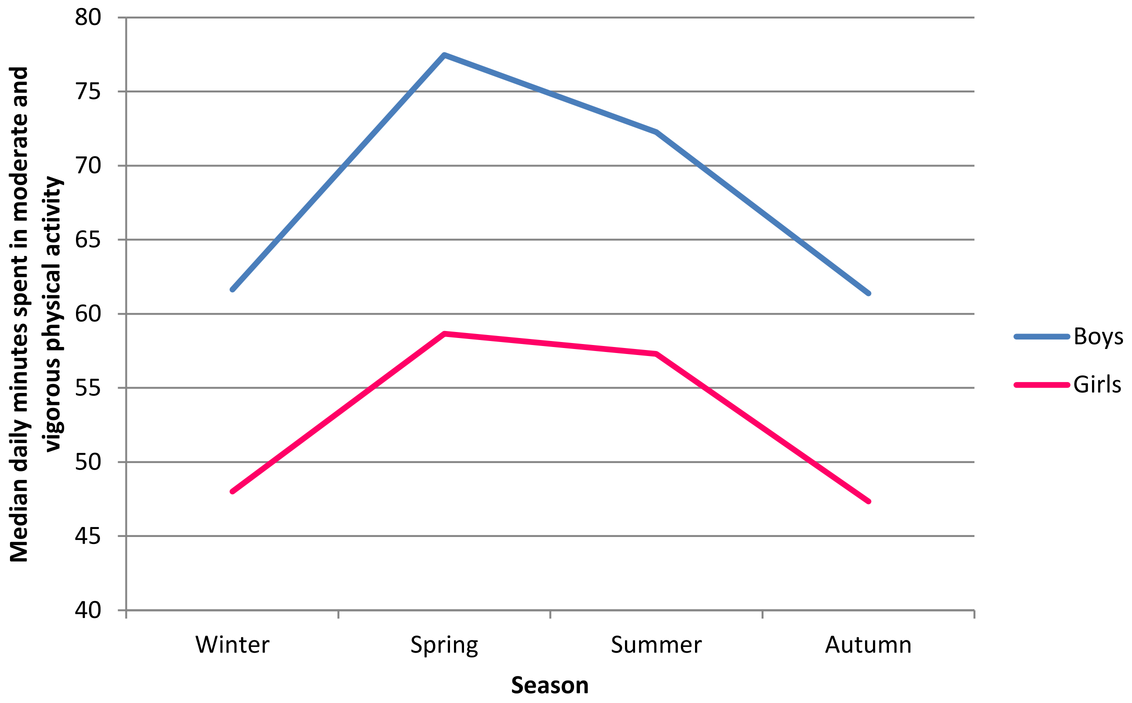
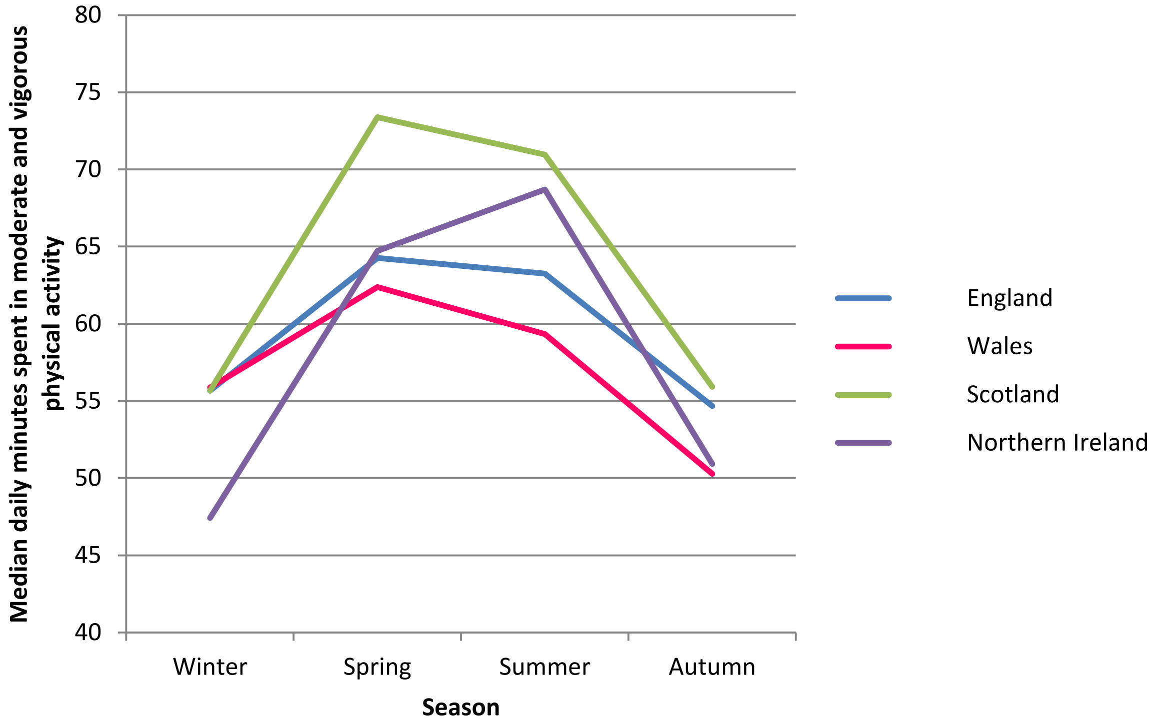


Figure 31: Median of the mean daily time spent in moderate and vigorous physical activity in each season by country



The within-child variances corresponding to seasonal changes in MVPA differed significantly according to the child's gender, BMI, and country of residence (all $p \leq 0.003$; Table 44; random effects). The estimated within-child variance was highest for boys, under/normal weight children, and children who lived in Northern Ireland or England.

Table 44: Estimated regression coefficients and *p*-values for mean daily time spent in moderate to vigorous physical activity from final model with separate variances for confounders.

Fixed effects	*Coefficient (CI)*	*p-value*
Intercept	44.08 (41.95, 46.21)	<0.001
Season		
Winter	1	
Spring	15.57 (12.48, 18.67)	<0.001
Summer	12.28 (9.19, 15.37)	<0.001
Autumn	2.19 (-1.03, 5.40)	0.182

Child's gender		
Male	1	
Female	-14.35 (-17.54, -11.16)	<0.001
Child's BMI		
Under/normal weight	1	
Overweight/obese	-4.65 (-8.25, -1.05)	0.011
Country		
England	1	
Wales	-0.20 (-5.23, 4.83)	0.937
Scotland	2.38 (-1.30, 6.07)	0.205
Northern Ireland	4.74 (-10.16, 0.67)	0.086
Season:child's gender		
Spring-Female	-5.51 (-8.83, -2.18)	0.001
Summer-Female	-3.74 (-7.11, -0.36)	0.030
Autumn-Female	-1.44 (-4.97, 2.08)	0.422
Season:country		
Spring-Wales	-1.23 (-6.38, 3.91)	0.638
Spring-Scotland	3.81 (0.08, 7.54)	0.045
Spring-Northern Ireland	5.72 (0.21, 11.24)	0.042
Summer-Wales	-2.21 (-7.52, 3.09)	0.414
Summer-Scotland	3.35 (-0.45, 7.15)	0.084
Summer-Northern Ireland	11.04 (5.38, 16.69)	<0.001
Autumn-Wales	-5.81 (-11.28, -0.34)	0.037
Autumn-Scotland	-2.74 (-6.71, 1.24)	0.177
Autumn-Northern Ireland	4.90 (-0.89, 10.69)	0.097
Random effects	*Variance (SD)*	*Adjusted p-value (LRT)*
Child's gender		
Between subject	239.05 (15.46)	
Within subject		<0.001 (62.39)
Male	255.84 (16.00)	
Female	143.46 (11.98)	
Child's BMI		
Between subject	246.69 (15.71)	
Within subject		0.003 (8.79)
Under/normal weight	205.36 (14.33)	
Overweight/obese	150.34 (12.26)	
Country		
Between subject	244.55 (15.64)	
Within subject		<0.001 (3091.95)
England	200.01 (14.14)	
Wales	196.40 (14.01)	
Scotland	179.31 (13.39)	
Northern Ireland	233.72 (15.29)	

8.6 Discussion

8.6.1 Summary of findings

In this UK-wide study there was substantial intra-individual variation across seasonal measurements in children's accelerometer-determined PA: the ICC for mean daily PA was 0.48. There was slightly less intra-individual variation in the weighted mean daily time children participated in SB, VPA and MVPA: ICCs were 0.54, 0.54, and 0.55 respectively. The ICCs for all derived activity variables remained unchanged, or were similar after adjustment for potential confounding variables suggesting that these estimates were not markedly affected by the socio-demographic factors considered.

In general, children were most active during spring, followed by summer, and least active during autumn and winter. Levels of VPA and MVPA were highest during spring and summer and lowest during autumn and winter. Levels of SB were highest during autumn and winter, but lowest during spring and summer.

Boys, underweight/normal weight children, and children whose mothers were employed in lower supervisory occupations were the most active, but they also showed more intra-individual variation across seasonal measurements in their mean daily PA. Gender and weight differences in intra-individual variation indicate that season impacts PA in boys and underweight/normal weight children to a greater extent than girls and overweight/obese children. Although girls and overweight/obese children were less active in general, their PA levels were more consistent across the seasons.

Differences in mean daily PA between seasons were influenced by the UK country of residence. Levels of mean daily PA increased during spring for children who lived in Scotland, increased during summer and autumn for children who lived in Northern Ireland, and decreased during autumn for children who lived in Wales. Time spent outdoors is associated with PA levels[102]. Country differences in daily PA between seasons may relate to country differences in the amount of time that children spend outdoors. For example, children living in Scotland may be more accustomed to the colder weather, and as a result, may be more inclined to be outside and active during spring than children living in other UK countries. Children living in Northern Ireland may be more active during autumn (defined by this study as August to October) because they tend to have considerably longer school holidays during this period than those in England, Scotland and Wales. The longer holiday period in Northern Ireland may offer more opportunities for children to be active at sports camps and courses, whilst also giving children the chance to spend more time outdoors. Differences in daily PA between seasons were not influenced by the child's gender, ethnicity, BMI, maternal occupation or maternal academic status, and therefore, levels of PA in certain seasons were not enhanced in any of these sub-populations.

Boys and underweight/normal weight children participated in more daily MVPA and VPA than girls and overweight/obese children respectively, and they showed more variation in these behaviours. Children who lived in Northern Ireland also showed more variation in their VPA and MVPA than those who lived in other UK countries. Differences in MVPA and VPA between seasons were also influenced by the UK country. Levels of VPA and MVPA increased during spring and summer for children who lived in Northern Ireland and decreased during autumn for children who lived in Wales, and VPA increased during autumn for children who lived Northern Ireland. Levels of MVPA decreased during spring and summer for girls. Seasonal differences in MVPA and VPA were not influenced by BMI, or maternal occupation.

Boys were less sedentary than girls but they also showed more intra-individual variation in their SB. Children whose mothers were in semi-routine and routine occupations or were not employed also showed greater intra-individual variation in their SB than those whose mothers were employed in other occupations. Seasonal differences in daily SB were not influenced by ward type, gender or maternal occupation.

8.6.2 Comparisons with existing research

Only two previous studies have investigated intra-individual variation across seasons in children's accelerometer-determined PA and SB[108 111]. Mattocks *et al*[108] evaluated this in 11 year old children by obtaining four repeated accelerometer measurements over a full calendar year. After adjusting for gender, age, BMI, and month of measurement, these authors reported slightly higher ICCs for total PA (cpm) and minutes of SB (0.53 and 0.59 respectively), but slightly lower ICCs for minutes of MVPA and VPA (0.45 and 0.55 respectively) than those calculated in the present study. Intra-individual ICCs were also calculated for boys and girls separately, and in contrast to our study, the ALSPAC found that girls showed greater variation than boys in their mean daily PA and MVPA. In agreement with our study, Mattocks *et al*[108] reported that boys showed greater intra-individual variation than girls in VPA, whereas boys showed slightly less intra-individual variation in SB.

Rowlands *et al*[111] considered the influence of gender on intra-individual variation of PA in children. The authors reported higher ICCs for total PA (cpm) and VPA than in the present study. However, they also found that boys showed significantly greater intra-individual variation than girls in their mean daily PA and time spent in VPA: ICCs for total PA and VPA for boys and girls were 0.63 and 0.86, and 0.67 and 0.90 respectively.

To my knowledge, no previous published studies have investigated between-season differences or intra-individual variation in PA or SB in relation to any of the other biological, social, and environmental factors investigated in the present study. However, seasonal differences in children's PA have been investigated, without considering the impact of these factors (section 3.5.4). Seasonal differences in PA have been reported in the majority of studies, particularly in children living in the UK[61 64 104 111 260]. In agreement with the present study, previous evidence suggests that children's PA in the UK is highest during summer and lowest during winter[61 64]. Findings from other countries are inconsistent. For example, one study from the USA reported higher levels of PA in summer than winter[112], however, a different American study reported higher levels of PA in autumn than summer[103], and one found no association between season and PA levels[102].

Few studies have evaluated seasonal differences in children's SB[104 109 260]. In contrast to the present study, Fisher *et al*[104] found that Scottish children were more sedentary in spring than summer. King *et al*[260] found that SB was higher in spring, autumn and winter than summer in UK children. In contrast, Nilsson *et al*[109] reported that levels of SB in European children were not influenced by season of measurement.

8.6.3 Strengths and limitations

The MCS4 seasonal accelerometer study is the first large scale study to obtain repeated accelerometer measurements of PA in a socially diverse population of children from all four UK countries. This is also the first study to investigate the biological, social and environmental factors associated with intra-individual variation across all four seasons in children's accelerometer-determined PA and SB. This was possible due to the breadth of information collected in this contemporary cohort. Uniquely, we have not only explored the influence of potential explanatory factors on intra-individual variation in children's total PA and MVPA, but also on SB, therefore addressing a gap in the evidence. Furthermore, we have used a standardised accelerometer data processing protocol[210]including the use of a wear time threshold (section 6.3)[222] and EHCV threshold (section 6.2)[223].

Our findings may not be applicable for different age groups; several studies have shown that seasonal differences in PA are more apparent in younger than older children[106 107 113]. For example, Kristensen *et al*[107] reported that ten year old children were more physically active in spring than winter or autumn, but found no seasonal differences in the PA levels of 14 to 16 year olds.

In addition, our analyses did not account for PA that cannot be accurately assessed by accelerometers such as swimming and cycling. These activities may differentially affect intra-individual variation in children's PA, although excluding any measurement occasions on which children reported any swimming or cycling had little effect on the ICC values reported in the ALSPAC study[108]. The children in this study will have matured over the course of the study period and will have matured at different rates[265]. It may be that the development and increasing age of children in the current study had an effect on their PA. However, children in our study were pre-pubertal so it is likely that growth would have less influence than in pubertal children.

8.6.4 Recommendations for study practice and further research

Additional research is needed in different countries and within different regions of larger countries. Characteristics that define seasons including the weather, ecology, and hours of daylight vary according to country, and even within different regions of large individual countries. Future research should also be aimed at investigating whether the findings of this study are applicable to older children and in adult populations. Future studies should also investigate whether intra-individual variation, and between season differences, vary according to the type, and time of day as children's PA varies within and between days[109].

Studies have found that parent-proxy reports of children's screen viewing time is associated with family TV viewing behaviours, snacking, and having a TV in the bedroom[80]. Additional research could investigate whether these influence seasonal differences and/or variation in SB. Furthermore, UK country of residence was associated with intra-individual variation in PA – future research could explore locale according to more detailed geographic identifiers such as the electoral ward or according to alternative geographic variables such as the urban-rural classification, neighbourhood satisfaction, and deprivation score. One review[266] found that only two previous studies[198 267] have explored the influence of season on the PA levels of children living in different geographic locations.

One factor that may also influence seasonal variation in PA and SB, which has not been explored here, is the effect of policy aimed at increasing PA and/or reducing SB. It is possible that policy put into action in one season may influence children's activity in proceeding seasons. For example, the UK Government's 'Change4Life' campaign was implemented during January 2009 and, as a result, any study measuring children's PA after this date may be influenced by the programme[268]. Additional quantitative work could also be conducted to help understand the reasons for seasonal variation in children's PA. For example, exploring children's perception of the weather, or how they perceive their environment, and the impact that this has on their desire to be physically active or sedentary throughout the seasons of the year.

This study has reported the biological, social and environmental factors associated with intra-individual variation across seasons in children's PA and SB. It may be that groups of children who were less stable in their PA and SB across seasons may be more amenable to change than children with less intra-individual variation. Boys, under/normal weight children and children living in Northern Ireland could be targeted to increase their overall levels of PA. Children participated in approximately 10 minutes more MVPA during spring and summer than autumn and winter, but were less sedentary during these months, on average, by 30 minutes. The influence of these differences in absolute values of SB and PA on health outcomes has not been investigated, but alarmingly these equate to seasonal differences of over an hour in MVPA per week, and three and a half hours of SB per week. This study therefore provides evidence that these interventions should be aimed at increasing PA during autumn and winter in UK children, particularly in children living in Wales, and aimed at reducing SB during autumn and winter.

Researchers that obtain accelerometer measurements at a single time point should be aware of these factors and also recognise the potential bias occurring as a result of substantial seasonal variation. A single-measurement occasion may not adequately characterize children's habitual PA and SB, particularly in populations with high between- and within-child variation across seasons. Alternatively, seasonal measurement bias may be dealt with using adjustment weights during analyses; further research is needed to explore suitable weights to adjust for bias introduced by within- and between-child variance in activity across seasons.

8.7 Conclusion

There is substantial intra-individual variation in UK children's PA and SB when objectively measured during all four seasons of a single calendar period. Children who were less stable in their activity across seasons may be more amenable to change than children with less intra-individual variation. Furthermore, this study has provided evidence that a single-measurement occasion may not adequately measure children's PA and SB.

8.8 Key points

- Children were most active during spring, followed by summer, and least active during autumn and winter. MVPA and VPA were highest during spring and summer and lowest during autumn and winter.
- Levels of SB were highest during autumn and winter and lowest during spring and summer.
- Children's PA and SB showed substantial intra-individual variation across seasons.

- Intra-individual variation in SB was highest among boys and children whose mothers were in semi-routine and routine occupations or were not employed.
- Intra-individual variation in mean daily PA, MVPA and VPA was highest among boys, under/normal weight children and children who lived in Northern Ireland.
- Seasonal differences in all PA measures were influenced by the UK country of residence and seasonal differences in MVPA were influenced by child's gender.
- Mean daily PA, VPA and MVPA increased during summer for children who lived in Northern Ireland, and decreased during autumn for children who lived in Wales.
- Levels of MVPA decreased during spring and summer for girls.
- Children who were less stable in their activity across seasons may be more amenable to change. Interventions aimed at reducing SB and/or increasing PA may therefore be particularly helpful for these groups.
- A single-measurement occasion may not adequately measure children's habitual activity, therefore researchers should consider adjusting for within-and between-child variance in SB and PA across seasons.
- Additional research is needed in different countries and within regions of larger countries.

9 Chapter 9: Thesis discussion

9.1 Chapter Overview

This chapter summarises: i) the main findings of the research presented in this thesis; ii) reflects on their limitations and implications; iii) discusses the strengths and limitations of the MCS data and the accelerometer fieldwork; iv) highlights areas for further research, and; v) provides general conclusions and reflections on this thesis. A brief update on new research evidence is also provided.

9.2 Key research findings

The research presented in this thesis has addressed some of the methodological uncertainties in using accelerometers to measure PA and SB in large scale epidemiological studies in children. A detailed literature review of published research evaluating methodological issues in children's large scale accelerometer a study was conducted. Few studies were identified that evaluated predictors of non-response in children's accelerometer studies, and in those that were available, findings were inconsistent. Few studies had also explored the influence of varying the minimum daily wear time threshold on the reliability of accelerometer-determined PA measurement, and none had investigated the identification of EHCV during accelerometer data processing. Furthermore, research exploring the possible interactions of season with other factors known to influence PA and SB, such as gender, age, ethnic group, weight status, and geographic location, was scarce.

Three original research studies using data from the MCS were conducted to address these gaps identified in the evidence base and have been presented in this thesis. Analyses were conducted to determine: (i) accelerometer data processing thresholds; (ii) predictors of consent, accelerometer return, and reliable data acquisition, and; (iii) factors associated with intra-individual variation of PA and SB across the four seasons.

This research has provided evidence that using a proposed minimum threshold of 11,715 cpm will enable researchers to identify EHCV in the ActiGraph GT1M. We also found that using data from children with at least two days lasting at least six hours per day should provide reliable estimates of children's habitual PA. Separate analyses revealed a range of biological, social, behavioural and environmental factors associated with non-response in a UK-wide accelerometer study using postal distribution and return methods. Finally, substantial intra-individual variation in children's PA and SB across the four seasons was observed. Intra-individual variation in SB across the four seasons was greatest in girls and children from ethnic wards, whereas PA varied most in boys, under/normal weight children and children who lived in Northern Ireland.

9.3 Reflections on the limitations and implications of this research

Literature review

The detailed literature review presented in chapter 3 provides a useful resource for researchers by summarising findings from a wide range of studies and identifying important gaps in the evidence base. However, the heterogeneity in study samples, design, accelerometer protocols, statistical methods and outcome measures included in this review limited interpretation and meant that it was not possible to carry out a meta-analysis of the results. Only I undertook the reviewing process and no robust indicator of methodological quality was carried out due to the lack of uniformity across research methodology. Greater interpretation of the results could have been attempted, in particular, considering whether significant differences in results were large enough to represent either practical or physiological importance. A number of studies had very small sample sizes and therefore their findings may be of limited use. Studies with small sample sizes were included in the literature review because there was a lack of previous studies addressing several of the research objectives. As this review was restricted to published studies only, publication bias may be present.

Identifying extreme high count values

We advise that quality control processes should be undertaken during accelerometer fieldwork, and prior to data analyses, as EHCV and error count values can be recorded by the Actigraph GT1M. However, errors count values that have previously occurred in the 7164 (e.g. five digit values and all one values[211]) did not occur in the newer GT1M model. Furthermore, only 0.1% of all accelerometer files recorded negative values, and 0.3% recorded all zero count values. Although we recommend that error count values are evaluated during fieldwork so that failing monitors are not reissued, it is likely that the small proportion of error files would not make a substantial difference to derived PA outcome variables. In addition, files containing all zero counts would be removed prior to analyses according to the wear time threshold criteria. However, the proposed EHCV threshold will improve the validity of VPA estimates in children's studies using the ActiGraph GT1M by ensuring that only plausible data are analysed. The differences in VPA estimates observed when varying the method used to define and exclude EHCV were relatively small (6.9 minutes vs. 6.5 minutes) and may not be large enough to influence health outcomes. Therefore, this data cleaning step may be less crucial than the removal of children with unreliable data, particularly in studies using different accelerometer models and adult populations who would need to determine their own EHCV threshold.

Defining minimum wear time

It is important that researchers only analyse accelerometer data from children that meet a pre-defined wear time threshold. A threshold of at least two days lasting at least six hours per day is applicable in pre-pubertal children and in population-based studies that monitor children over a full week. Using this proposed threshold will enhance quality control processes by ensuring that only children who provide enough data to reliably estimate weekly PA are used in analyses. However, our proposed wear time threshold was determined based on reliability coefficients calculated from cpm, and not from the amount of time spent in PA intensities and/or SB. It is likely that reliability will be influenced by the derived PA outcome variable. This study would therefore have been strengthened by investigating reliability in relation to MVPA or SB. As a result, the use of this threshold may not be appropriate for studies evaluating the time spent in PA intensities and SB. Therefore, calculations based on derived estimates of MVPA and SB in the MCS may not be as reliable as those using cpm.

Although gender differences in reliability coefficients were minimal, this research may have also been improved by investigating reliability in relation to other socio-demographic characteristics such as ethnicity or SES, or behavioural characteristics such as the type of school children attended or self-reported levels of PA. Studies have shown ethnic and social differences in children's PA[183], and the research presented in this thesis found differences between these characteristics in reliable data acquisition.

Our analyses suggest that it is unnecessary for researchers to only include children with weekend data in analyses. We investigated the purposeful inclusion of children with weekend data using a constant definition of minimum weekend wear time (≥10 hours/day). In contrast, we varied the minimum daily wear time in all other analyses to investigate the influence of this variation. The minimum weekend wear time criterion was chosen because it is the most commonly used daily wear time threshold in other large-scale studies. However, findings relating to the purposeful inclusion of children with weekend data may have differed if the weekend wear time threshold varied. Therefore, this research would have been improved by investigating the inclusion of children with and without weekend data according to varying minimum weekend wear time thresholds.

The wear time threshold proposal may have also been improved by cross referencing the accelerometer data with information obtained from the timesheets. At the time of writing this thesis, the data from the timesheets had not been extracted and coded. Parents reported the time children put on, and took off, the accelerometer on their timesheet, and this information could have, at the very least, been used to verify days when the accelerometer was not worn.

Predictors of non-response

The analyses of predictors of non-response found evidence for factors associated with non-consent, and non-return of accelerometers and reliable data. This information could be used in other studies, using similar postal methods, to identify children who may require additional efforts to encourage consent and reliable data acquisition whilst also reducing non-response bias. Nevertheless, I acknowledge that due to the large sample size of the MCS, very small differences may be detected as significant; however, these differences may not be practically important or have any decision-making purpose. For example, consent was more likely to be obtained from children who had people smoking near them, however, the difference in consent rate between those who did and did not have people smoking near them was 95.8% and 94.4% respectively. There was also little practical difference in the consent rate between children who did and did not have access to a garden (94.5% vs. 95.6% respectively). In contrast, very large statistical differences in reliable data acquisition were observed between ethnicities. Reliable data were obtained from 58% of white children who were sent an accelerometer but from only 35% and 40% of Pakistani/Bangladeshi and black children, respectively. In addition, reliable accelerometer data was acquired from only 40% of children whose mothers had no academic qualifications, but from 67% of mothers with degrees. Consideration on the proportion of difference that represents practical importance could have been made for the purpose of making recommendations for future studies.

This study may have been improved by combining the potential determinants of consent, accelerometer return and reliable data acquisition into one plausible model. It is likely that the extent to which reliable data was acquired combines factors influencing both consent and return. Furthermore, bivariate correlations could have been further investigated, for example, the ethnic minority groups that were less likely to consent may also have also spoken another language apart from English. This may also help to explain why the low consent rates for non-employed and non-qualified mothers disappeared in the adjusted model. Other factors such as housing tenure or ethnicity may influence these differences. Analyses could have been further advanced by investigated differences between those who did not return reliable data ('non-compliers'), those who returned reliable data ('standard compliers'), and those who wore their accelerometer for all seven days ('perfect compliers'). Fieldwork methods could have been investigated as potential predictors, for example, the time elapsed between the interviews and receiving the accelerometer, or the number of reminders distributed. Results of this would further help to advise researchers in the most effective fieldwork protocols.

Seasonal variation in children's activity

The seasonal analyses enhance our understanding of the factors associated with variation of PA and SB across the four seasons. The identification of such factors may help inform public health interventions aimed at increasing PA and/or reducing SB, as children who are less stable in their activity across seasons may be more amenable to change.

Even if these interventions are impractical or costly to implement, the findings also hold methodological importance for researchers. As substantial intra-individual variation in children's PA and SB across seasons was identified, a single-measurement occasion may not adequately measure children's habitual activity. We are unsure whether a specific season provides a superior measurement of annual PA, although the seasonal data could be used to determine whether one particular season provides a reliable estimate of PA as determined by estimates based on measurements from all four seasons. Nevertheless, researchers should be aware of the factors associated with intra-individual variation and also recognise potential bias occurring as a result of this. If studies are unable to collect data over more than one season then researches should consider adjusting for seasonal variation in children's SB and PA.

The seasonal analyses could have been extended by investigating the influence of changing the seasonal definition, or exploring seasonality on a month-by-month basis. Seasonal patterns could have also been assessed by means of applying sine and cosine functions as continuous predictors in regression models.

The sub-sample of MCS children who participated in the seasonal study comprised those who returned reliable accelerometer data in the main stage accelerometer study. Differences between children who returned reliable data in the main stage accelerometer study and those who participated in the seasonal study were investigated; however, the seasonal sample was not compared to the MCS cohort. Socio-demographic differences between children who participated in the main stage accelerometer study and the seasonal study were found, and, although not explored, there may also have been differences between the seasonal sample and the wider MCS sample. This research may therefore have been enhanced by investigating any differences between these samples, and if necessary, developing adjustment weights that could be applied to analyses to control for any bias. We could have also investigated seasonal differences between children who were measured in different seasons using the main stage accelerometer data. Seasonal comparisons could have then been made between the repeat measures study and the cross-sectional results from the main stage.

Analyses could have also been expanded by incorporating the timesheet data in analyses. For example, the time children spent swimming or cycling may have differed according to the season of measurement. We also asked parents to specify whether their child was on school holidays or whether it was term time whilst their child wore the accelerometer. This may help to explain why children living in Northern Ireland were more active during summer and whether this was related to a longer school holiday period.

Despite the limitations discussed in this section, these studies have addressed a number of the methodological uncertainties in large scale accelerometer-based studies of childhood activity. It should therefore help to improve the accuracy of accelerometer data processing protocols, raise awareness of the factors associated with non-response in this large scale postal study, and also provide evidence that a single-measurement occasion may not adequately measure children's PA and SB. Advice has also been given for other researchers to help maximise return rates, and reduce data and accelerometer loss in studies adopting this method of data collection. The MCS was the first large-scale study to use a postal methodology to distribute and return accelerometers and would have learnt from the experience of previous studies. Researchers may therefore take the advice detailed in this thesis, and adopt similar data collection and processing protocols in future studies. Improving the accuracy of accelerometer data collection and processing protocols will enable children's PA and SB to be measured more accurately, so that researchers are able to advance the understanding of compliance to recommendations, their determinants and relation to health outcomes. Such research can help to identify optimal patterns of activity associated with future health and well-being and inform interventions to help populations meet these optimal patterns. This is essential as there is increasing evidence that PA patterns are established in childhood[299], that maintenance of an active lifestyle in adult life is protective against many chronic diseases[300-302], and that levels of children's PA have declined with successive generations in developed countries[303].

9.4 Strengths and limitations of the MCS and accelerometer fieldwork

Additional strengths and limitations of each study have been discussed in each relevant chapter. This section focuses on the wider overarching strengths and limitations of the MCS and the accelerometer study fieldwork.

The MCS4 is the first large scale longitudinal cohort study to objectively measure PA and SB in a socially and ethnically diverse population of children from all four UK countries. The MCS was disproportionately stratified to ensure an adequate representation of all four UK countries, disadvantaged areas and ethnic minority groups. The MCS has also collected a wide range of biological, social, behavioural and environmental information relating to the child and the child's family that could be linked to the accelerometer data and used for the analyses presented in this thesis. A small amount of the MCS children had missing data for some of the explanatory variables used in this work and multiple imputation techniques were not carried out, which I acknowledge as a limitation. Furthermore, many of the MCS variables were also based on parent-report measures, and therefore recall bias may have influenced the information collected. However, self-reported information collected within the MCS has been shown to be reliable[269 270].

This is also the first large scale accelerometer study to report the use of a postal methodology to distribute and return accelerometers. The MCS accelerometer study was tested in two pilot studies to ensure a robust and feasible accelerometer fieldwork methodology. Additional strengths include the use of the ActiGraph accelerometer to measure PA and SB, which is the most commonly used accelerometer in PA research. We also selected a 15 second epoch in order to capture the most detailed information possible for the wear time period required. We are confident that both children and parents understood how and when they should wear and return their accelerometers as they received detailed information at the home interview and in the information leaflets. We also implemented a reminder system to aid the return of as many accelerometers as possible. The implementation of the timesheet and the offer of a feedback certificate with graphs showing their child's PA may have also encouraged correct wear.

We are confident that our personalised data processing software was the most feasible software to accurately process our large volume of data in order to derive the summary PA and SB variables[220]. We are also confident that using our own dataset to investigate data processing decisions, combined with the advanced analytical methodologies employed, enabled us to define a robust data processing standard operating procedure[210].

However, there are also several limitations to the MCS accelerometer data. Many are associated with the more general use of the type of accelerometer used and have been previously discussed, including their inability to accurately access swimming, cycling, or load bearing activity, and no clearly defined activity intensity thresholds. Newer, tri-axial accelerometers can address some of the limitations of bi- and uni-axial accelerometers and have been shown to provide reliable estimates of children's EE and PA[271]. However, additional studies are required to further validate tri-axial accelerometers in children under free-living conditions[271]. The ActiGraph GT1M was the latest model available at the time of the MCS4 accelerometer fieldwork; however, this model did not permit the use of an epoch shorter than 15 seconds for the wear time length we required. An even shorter epoch can now be used with newer and consequently more expensive accelerometers. However, the complexity in data management and modelling concurrent with fully exploiting these devices' capacity is considerably larger than the already complicated computational and statistical issues dealt with in this thesis.

Although the predictors of non-response in the MCS4 main stage accelerometer study were investigated, differences between those who did and did not consent to the MCS4 were not explored. However, sample weights were applied to make the data representative to the UK population. Statisticians at the ICH are also developing non-response weights for use with the PA data to account for missing accelerometer data. Despite these limitations, the MCS4 has provided a rich source of PA and SB data that will be publicly archived alongside weights for missing accelerometer data.

9.5 Literature review update

The literature review presented in chapter 3 included all published articles up to, and including the end of September 2010. The searches outlined in section 3.4.1 were re-run at the end of September 2012, before submission of this thesis, to identify any additional research studies that have published articles in the last two years. Three additional large scale (≥ 250) accelerometer studies in children were identified[272-274]. The Gateshead Millennium Study is a longitudinal study exploring the nature, time, and extent of changes in PA and SB in British children before adolescence[272]. Accelerometer data were collected from 405 children aged seven years in 2006/7 and again when the children were aged nine years. The Canadian Health Measures Survey collected accelerometer data in 2007 to 2009 to determine the PA levels of 6 to 19 year old Canadian children[273]. The ENERGY-project conducted a cross-sectional accelerometer study involving 1,082 children aged between 10 and 12 years who lived in Belgium, Greece, Hungary, Switzerland, and the Netherlands in order to develop an obesity prevention intervention among school children[274 275]. The International Children's Accelerometry Databaseproject has also been developed which has pooled and processed raw accelerometer data to create comparable outcome variables in 32,000 children aged between 3 and 18 years across studies from Europe, USA, Brazil, and Australia[211].

Two more articles were identified that investigated the minimum number of hours per day and/or the minimum number of days of data required from each child to provide reliable estimates of PA[276 277]. Ojiambo *et al*[277] calculated the reliability of PA in 86 seven year old children from Ghent, Glasgow, Gothenburg and Zaragoza: the number of wear days required to achieve 80% reliability for total PA (cpm), SB and MVPA was reported to be 7.4 to 8.5 days. Dencker *et al's*[276] study involving 696 seven year old children reported that the number of hours used to define minimum daily wear time heavily influenced the number of days that were required in analyses.

No additional studies were identified that examined predictors of consent and/or reliable data acquisition in children's PA studies, or that investigated seasonal variation in accelerometer-determined PA or SB in children. Previous evidence in the areas explored in this thesis are therefore still limited, and none of the additional studies identified compromise the originality of the research presented.

9.6 Directions for future research

In addition to the specific recommendations for future research that have been discussed throughout this thesis, further investigation into the following areas of research would enhance accelerometer protocols, and increase the accuracy of SB and PA measurement in large scale studies in children.

Other methodological issues

There are several other methodological uncertainties relating to accelerometer studies that were not addressed within this thesis. Firstly, few studies have accurately assessed accelerometer placement and epoch length in primary school aged children, and in those available, sample sizes are small[97 99]. Additional studies are therefore needed that investigate where accelerometers should be placed on the body, and also the range of epochs that provide the most accurate estimation of PA and SB in large samples of pre-pubertal children. Further research is also required to systematically evaluate the most effective reminder strategies to encourage the correct wear and timely return of accelerometers. There is currently no consensus on the best thresholds to define SB and PA in children. A wide range of thresholds are available, highlighting the lack of agreement regarding interpretation of accelerometer output. Greater efforts are needed to reach a consensus on the best way to define SB and PA in different intensities so that levels of PA and SB, adherence to public health guidelines, and associations with health can be advanced.

Other accelerometers

Further research is required to determine whether the accelerometer data processing thresholds suggested in this thesis are applicable in other ActiGraph models and in other brands of accelerometers. Rothney *et al*[49] found differences in count outputs from the ActiGraph 7164 and the GT1M accelerometers when undergoing mechanical testing. However, studies in free-living children show that the ActiGraph GT1M and 7164 models do not result in meaningful differences in activity counts[278]. Studies have also found a strong agreement in children's accelerometer-determined PA using the ActiGraph GT1M, GT3X, and GT3X+[279]. In contrast, Paul *et al*[280] found that PA measured using the Actical and the ActiGraph 7164 accelerometers were not directly comparable.

Activity not measured by accelerometers

One of the major limitations associated with the use of a single, waist mounted accelerometer is its inability to accurately measure certain types of PA. Within the MCS, parents reported the time their child spent swimming and cycling on PA timesheets, so further research could incorporate these data to investigate whether the inclusion of children with high levels of swimming and/or cycling influences overall PA findings. Limited research has investigated the influence of including children with high levels of self-reported swimming and/or cycling in analyses, although one previous study revealed no differences in results with or without their inclusion[281].

New devices

The emergence of new technology has led to important developments in the field of PA measurement including global positioning systems (GPS), high frequency movement sampling, and combined motion sensors. The introduction of GPS into movement sensors enables information about the location and domain of PA to be combined with accelerometer-determined measurement of the frequency, intensity and duration of PA[282]. Although there are still relatively few published studies using GPS in the field of children's PA, the reliability of GPS has been demonstrated in different environments[283]. GPS technology may further our understanding of the relationship between environmental attributes and PA at the population level, and in doing so, advance the understanding of seasonality in PA[146 284]. For example, GPS determined time spent outdoors has been shown to be positively associated with accelerometer-determined PA in children[146]. These data found that children's PA levels were higher outdoors than when they were indoors, and outdoor PA was also higher during summer than winter. Another study that collected GPS combined with accelerometer measurements in children found that outdoor use patterns varied by season, with street use increasing during spring, and park and playground use increasing during summer[285]. Nevertheless, GPS monitoring also has further issues relating to data processing that require further investigation.

Accelerometers have also been combined with physiological measures such as HR[57 59 286], skin temperature, and galvanic skin response[287] to help improve the accuracy of EE estimation[288]. In general, the combined use of HR and movement sensors has been shown to be more accurate than either method used in isolation in controlled environments in children[57 283]. However, the analysis of combined sensor monitors requires the understanding of advanced statistical techniques. For example, Zakeri *et al*[289] developed cross-sectional time series models to predict EE from HR and accelerometer output, while Brage *et al*[290] used branched equation modelling to improve the estimates of PA EE using combined HR and accelerometry.

Multi-sensor systems that involve attaching multiple sensors to the body have also been developed. For example, the Intelligent Device for Energy Expenditure and Activity captures movement from five sensors attached to the chest, thighs, and feet. The device uses an artificial neural network to recognise 32 different types of activities such as jumping, walking, running and stair climbing[291]. The energy costs of specific activities are assigned from a published compendium of PA that is available for adults[4] but limited for children[292]. Although these methods may further our understanding of PA and SB, further research is required to predict the energy cost of specific activities over the full range of PA intensities during free-living conditions[283 293].

Advances in statistical modelling

Modern statistical methods may help to resolve some of the issues relating to accelerometer data processing, in particular the use of activity count thresholds.

Statistical methods for analysing latent variables make it possible to detect unobserved underlying patterns in movement[294], and may therefore offer considerably increased precision to estimate EE through the application of activity-specific regression equations or through the identification of specific activities using multiple features of the accelerometer output[283]. These approaches to data analysis not only use numerical data summaries but also use other information available from the accelerometer, such as the SD of counts per time unit to classify PA mode. For example, discriminant analysis uses the multivariate mean and variance covariance matrix of the data to classify PA type[295]. Pattern recognition approaches including probabilistic artificial neural networks[291] and hidden Markov chains models[296] can also help to extract information on the PA type, duration, and intensity. Studies have shown that pattern recognition methods may perform better than traditional threshold methods in quantifying the time spent at different PA intensities[297] and have also successfully identified various types of PA[295].

The use of these methods requires further development, for example, hidden Markov chain modelling needs to recognize more activities and incorporate individual characteristics and environmental factors into models[283].

Other populations

The findings of the research presented in this thesis may differ in other age groups and in children living in different countries. Study consent rate and reliable data acquisition can vary according to age in large scale accelerometer studies[129 165]. Furthermore, children's PA levels vary by age[298] and country[158]. Research presented in this thesis also revealed that, within the UK, consent and intra-individual variation in PA across seasons varied by country. Further research is therefore warranted to determine whether the findings presented in this thesis are applicable across different age groups and in children living in different countries.

9.7 Thesis reflection

It is hoped that this thesis can provide a reference for other large scale accelerometer studies to help guide their data collection and processing methods, as well as providing guidance for future public health interventions. Defining the data processing protocols was a necessary step for the MCS accelerometer study team. All future publications written by the ICH using the accelerometer data will use the activity summary variables that are based on the proposed data processing protocols. The summary activity data that will be publicly archived will also use these protocols. Although some of the findings of this research appear to be age-specific, the methodology used to propose the data processing protocols and to determine the best data collection methods could be replicated in future MCS sweeps or by other studies using older samples.

There are a number of different aspects of my research that I would change if I were to start it again. I think that it would have been possible to expand each of the research objectives and concentrate on just one of these in detail. This may have reduced some of the study limitations and addressed some of the further research suggested. For example, if this thesis only focused on the data processing procedures investigated in Chapter 6, the analyses could have been expanded to investigate the reliability of accelerometer determined MVPA or SB, as well as investigating other data processing decisions such as the identification of non-wear periods. Writing this thesis has improved my ability to communicate scientific evidence; however, I feel that it could be improved further by writing more concisely, particularly in the literature review chapter. The interpretation of study findings and their purpose in the real world setting could have also been expanded at some points. Changes that I would make to the data collection include setting up a verified fieldwork database prior to the start of the project, trying to obtain ethical approval to offer a financial incentive to all children who wear and return their accelerometer, and sending a reminder text to parents every morning during the monitoring period.

A major strength of the work presented in this thesis is that I was involved in all stages of research including data collection, cleaning, processing, analysis, and interpretation. This project has also enabled me to produce and judge publications in peer-reviewed journals, and generate reports and presentations for collaborators and fieldwork agencies, and in doing so, has improved both my critical thinking and writing abilities. I have also further advanced my understanding of a wide range of statistical methods and increased my ability to use statistical software to undertake analyses.

9.8 Concluding remarks

The detailed information provided by accelerometers makes them an invaluable tool to understand the complex nature of PA and SB. However, the interpretation of data remains a challenge and a number of methodological uncertainties remain regarding collection and processing protocols. This thesis has identified some of the gaps in the evidence and investigated these issues using accelerometer data collected in a UK-wide prospective study of children. This research attempts to enhance the understanding of accelerometer methodology and provides related advice that should be implemented in future large-scale studies in children. Technical advances in accelerometer development will continue to give researchers the ability to obtain detailed measures of activity. However, it is important that researchers continue to develop reliable and accurate accelerometer data collection and processing protocols to help maintain the pace at which we can improve the quality of children's PA and SB measurement and its interpretation to health outcomes.

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Appendices

Appendix A: Pilot study report

Institute of Child Health
University College London

Pilot Report of the MCS4 Age 7 Physical Activity Monitor Mailing

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Contents

1. Introduction

As part of the pilot of the Millennium Cohort Study Fourth Sweep (MCS4) researchers at the Institute of Child health (ICH), University College London, took direct measurements of the children's physical activity using an Actigraph activity monitor. All children interviewed for MCS4 were invited to take part in wearing an activity monitor, and all parents/ guardians were asked for written consent.

Soon after the interviews, participant details were given securely to ICH, and the activity monitors were posted out to the families. Children were instructed to wear the activity monitor at all times for seven consecutive days, except for when sleeping, bathing, showering, swimming, or participating in vigorous activities. The parents/ guardians were also sent a timesheet, and asked to record any periods when their child did not wear the activity monitor. After the seven days, the parents/ guardians were asked to post the monitor and timesheet back to ICH. The data were then downloaded using ActiLife Software, and a feedback certificate with a summary of their child's activity was sent to the family.

2. Timetable

The time below shows a record of the dates that the physical activity project occurred:

	Start	End
Sample Details to ICH	20/04/2007	N/A
Activity monitors sent	24/04/2007	15/05/2007
Activity monitors returned	04/05/2007	15/06/2007
Feedback certificates sent	25/05/2007	01/06/2007

3. Sample

A total of 38 parents/ guardians and their children were interviewed at MCS4 Pilot 1 (March/ April 2007). 26 of these took part in the first pilot from the age 5 survey, and the remaining 12 were newly recruited from the general population.

All children were invited to take part in wearing an activity monitor, of which 31 out of 38 (79%) children agreed and their parents/guardians gave written consent.

After mailing out the activity monitors the number of children who continued to take part was 29. Two families decided that they did not want their children to take part at all and returned their unopened activity monitor pack, but did not explain why.

4. Fieldwork

At the interviews the families were shown a 'dummy' activity monitor, which was generally well received by both parents and children. Written consent was obtained from all parents who agreed for their children to participate in the activity monitoring. The majority of the children and parents/ guardians were excited about receiving the monitors and some of the children mentioned they felt quite special that they were being asked to do the task.

The parents/ guardians who did refuse for their children to wear the activity monitor were mainly concerned about their child being singled out from the rest of their peers and being a potential target for bullying. The children refused to elaborate on why they did not want to wear the monitor, even when probed by the interviewer.

The parents/ guardians that gave consent to their child wearing an activity monitor were given the following documents to read prior to being sent their activity monitor pilot mailing:

1. information leaflet
2. timesheet for parent and child to complete
3. letter for the child's class teacher

Interviewers mentioned that they face time constraints when in an interview situation and felt that some parents/guardians had started to 'switch off' when it came to explaining the monitor, especially with the amount of information provided for this section.

5. Content

5.1 Activity monitor mailing

Once participant details were given securely to ICH activity monitor packs were sent. These comprised of 7 enclosures:

1. parent cover letter
2. information leaflet
3. physical activity monitor and belt
4. timesheet for parent and child to complete
5. letter for the child's class teacher
6. feedback questionnaire for parent and child to tell us their views
7. pre-paid 1st class envelope (padded) for posting back the monitor and completed documents

5.2 Returned enclosures

The parents/ guardians were asked to return the following enclosures in the pre – paid envelope as soon as possible after the seven day monitoring period:

1. physical activity monitor and belt
2. timesheet
3. feedback questionnaire

5.3 Feedback certificate mailing

Upon receiving the returned enclosures at ICH parents/guardians were sent feedback certificates for their children that summarised their activity levels. The feedback certificate mailing comprised of the following enclosures:

1. Feedback certificate showing a graph summarising the child's activity levels
2. Information sheet to explain the graph on the feedback certificate
3. Feedback questionnaire for the parent and child to tell us their views on the feedback certificate
4. pre-paid 1st class envelope for posting back the completed feedback questionnaire

6. Findings from Pilot Mailing (Activity monitor mailing)

Activity monitor related mailing and returns have been securely logged in detail at ICH. The data is stored in password protected files so that named children cannot be matched to descriptive data. The data from the feedback questionnaires has also been securely entered onto a spreadsheet.

6.1 Sent documents

Parents/ guardians were told that their child's activity monitor would be posted to them 2-4 weeks after the interview, unless they requested a later start date, for example, if they were going on holiday.

- *How many children have been sent their activity monitors?*

All those that gave consent at the interview have been sent their activity monitors.

- *How long after the interview date were the activity monitors sent?*

The activity monitor sample details were received at ICH on 28/03/07 (23 days after the first interview and 10 days after the last interview).

The table below shows how many days after the interviews took place the monitors (n=31) were sent.

Interval from interview by NatCen to sending at ICH (days)	No. of monitors	Percentage (%)
16	1	3
17	2	6
18	0	0
19	0	0
20	0	0
21	1	3
22	6	18
23	3	9
24	2	6
25	6	18
26	3	9

27	2	6
28 (4 weeks after interview)	1	3
28+	4	12
Total	*31*	*100*

- *What were the reasons for sending the 4 monitors later than 4 weeks after the interview ?*

  1. *Requested at the interview to be sent later (on holiday).*
  2. *Rang ICH after receiving the monitor requesting that the monitor be sent back at a later date (booked holiday since interviews).*
  3. *Rang ICH after receiving the monitor explaining that they had lost all monitor documents. As a result monitor was returned and reprogrammed then sent at a later date with new documents.*
  4. *Delay in receiving contact details of family from NatCen.*

6.2 Returned documents

6.2.1 Activity monitor

Parents/ guardians were asked to return the activity monitors and belts as soon as possible after the seven day monitoring period. If the monitors were not returned within 21 days of being sent, a reminder letter was sent. Subsequent reminders were sent 28 days and 35 days after sending the activity monitors.

- *How many parents/ guardians have returned the physical activity monitors*?

At present, 26 out of 31 (84%) activity monitors have been returned. All of these were attached to a belt.

- *How many parents/ guardians have received reminder letters*?

At present, 5 families have been sent all 3 reminder letters, of which one has returned their monitor. The 4 families that haven't returned their monitors have also received numerous telephone calls. We are awaiting two monitors whose parents/ guardians promised to return the monitor, but the other two parents/ guardians were not available so answering phone messages were left. One family returned their monitor after receiving their first reminder letter. The remaining one activity monitor to be returned to ICH is not due back yet. This was sent at a later date to the other monitors because the family details were received at a later date by ICH.

- *How long did it take the parents/ guardians to return the activity monitors*?

The table below shows how many days it took for the monitors (n = 24) to be returned. The table does not include the 2 monitors that were not worn.

Interval from sending at ICH to receiving back at ICH (days)	No. of monitors	Percentage (%)

10	2	8
11	0	0
12	2	8
13	7	29
14	5	21
15	2	8
16	0	0
17	0	0
18	3	13
19	1	4
20	0	0
21 – 27	1	4
> 28	1	4
Total	*24*	*100%*

- *Were there any damage to the activity monitors?*

There was no functional damage to the activity monitors. In two activity monitors the USB port protector was missing. None of the belts have been damaged. Some belts have started to fray where Velcro had been attached to the belt

6.2.2 Timesheets

Parents/ guardians were sent a timesheet (Appendix 1) and asked to write the dates that the monitor was worn, the time the monitor was put on in the morning and taken off at night, any periods spent swimming or cycling, and any other periods when the monitor was not worn. They were also asked whether the week was typical for their child in terms of their usual activity. They were asked to return the completed timesheet with the activity monitor as soon as possible after the seven day monitoring period. A copy of the timesheet was also given to the parents/ guardians at the interview, but they were asked to complete the timesheet sent to them, as this contained a reference number for office use.

- *How many parents/ guardians returned the timesheets?*

A completed timesheet was returned for all of the children that wore the activity monitor.

- *Did the parents/ guardians complete the correct timesheets?*

Two parents/ guardians filled in the timesheet given to them at the interview. Although the timesheets had no identification, the timesheet and activity monitor were sent together, and as a consequence could easily be matched.

- *Were the timesheets completed correctly ?*

Nearly all parents/ guardians completed the timesheet correctly. One timesheet did not have the dates that the monitor was worn, but instead the days of the week. Also, most families only wrote in a yes when asked if their child took the activity monitor off at all during the day, but did not write in no if they didn't. One parent/ guardian did not fill this in at all.

- *Did the children start wearing their monitor two days after it was mailed out?*

All monitors were programmed to turn on automatically at 5am two days after they had been posted out. When the monitors are turned on, a flashing light is visible. Parents/guardians were told that their child should start wearing the activity monitor the morning after it had been received. Parents/ guardians were also informed that if the monitor had been delayed in the post, they may find that the monitor is already flashing when they receive it. However, their child should still start to wear it the following morning after it had been received, and continue to wear it every day for 7 days (the monitor should remain on for at least seven days).

The table below shows how many days after sending the monitors children started to wear them (n=22). The table does not include the 2 monitors that were not worn or the 2 monitors that had no valid data (see section 6.3 Data quality).

Interval from sending by ICH to children wearing (days)	No. of children	Percentage (%)
2	16	73
3	3	14
4	3	14
Total	*22*	*100*

6.2.3 Feedback questionnaires

Parents/guardians were asked to complete and return the feedback questionnaire in the pre-paid envelope with the activity monitor and completed timesheet.

How many parents/ guardians returned the feedback questionnaire?

At present, 19 feedback questionnaires out of 26 returned activity monitors have been received.

There was no identifier printed on the questionnaire so if it was returned separately from other documents it was difficult to know which child it related. However, it was possible to match all questionnaires to a family.

6.2.4 Other comments

One parent/ guardian misplaced the activity monitor mailing documents, and phoned to request a second set of documents. They were asked to return their monitor, which was then programmed to start at a later date, and sent at a later date with new documents.

The parents/ guardians of two children who were sent monitors, rang to ask if they could receive their activity monitors at a later date because they were on holiday through the programmed time. They had not booked their holidays at the time of the interview. The monitors were both sent back, and programmed and sent at a later, more convenient start date.

Two children encountered problems with the flashing of their activity monitors. Both parents/ guardians rang to say that their children's monitors were not flashing when supposed to. They were asked to continue wearing the monitors as requested. One monitor did not flash because 'flash mode' was not enabled, but still recorded valid data. The other monitor was programmed incorrectly, and consequently did not record any valid data.

6.3 Evidence from the feedback questionnaires

Responses from 19 feedback questionnaires have been logged, and the answers are shown below.

Q1. On the whole, how did you feel about your child being asked to wear an activity monitor for a week? Do you feel that you understood why and how the activity monitor was worn? Was there anything else you would have liked to have known?

- I think the results will be interesting and all explained well.
- No problems.
- I had no problems with child wearing the monitor. In fact he really enjoyed it.
-would be interesting to know more about how the monitor works.
- My child was happy to take part with this task. She understood why she needed to wear the monitor.
- I felt happy for my child to wear the activity monitor. I did understand why/how this was worn. I was quite happy with all the information provided.
- Fine.
- Felt fine. It was easy to put on and she forgot she was wearing it after a while.
- Yes
- Child was very happy to wear the monitor.
- Full information was provided.
- I was very happy for my child to wear his activity monitor (and so was he!) I did understand why and how the monitor was worn and I had no further concerns or questions about the use of the monitor.
- Time consuming - difficult to remember. Not sure parents would bother to accurately record/wear belt use. Glad it's over!
- I was perfectly happy for my son to wear the monitor and I felt everything was explained clearly.

Q2. Overall, how easy or difficult did you find it to understand the letter, information leaflet and teacher letter?

Very easy	11	58%
Easy	8	42%
Difficult	0	0%
Very difficult	0	0%
Total	*19*	*100%*

Q3. Overall, how easy or difficult did you find it to understand and complete the timesheet?

Very easy	14	74%
Easy	3	16%

Difficult	2	11%
Very difficult	0	0%
Total	*19*	*100%*

Q4. Overall, how confident or unconfident are you that the information on the timesheet is accurate?

Very confident	6	32%
Confident	11	58%
Unconfident	2	11%
Very unconfident	0	0%
Total	*19*	*100%*

Q5. Was your child able to provide the information needed to fill out the timesheet on days when they were at school?

Always	15	79%
Sometimes	1	5%
A little	3	16%
Not at all	0	0%
Total	*19*	*100%*

Q6. Which of these statements best describes your child's activity during the monitoring week?

My child was much more active than usual	0	0%
My child was a little more active than usual	2	11%
My child was as active as usual	15	79%
My child was a little less active than usual	2	11%
My child was a lot less active than usual	0	0%
Total	*19*	*100%*

Q7. If your child was more or less active than usual, was this change in activity mainly because their activity was being monitored?

Yes	1	20%
No	4	80%
Don't know	0	0%
Total	*5*	*100%*

Q8. In relation to your child's teacher, which of these statements describes their opinion on your child wearing the monitor at school?

-He/ she did allow my child to wear the monitor

Yes	18	95%
No	0	0%
Don't know	1	5%
Total	*19*	*100%*

-He/ she did inform me if my child took the monitor off during the school day

Yes	7	37%
No	8	42%
Don't know	2	11%
Total	*19*	*100%*

Q9. Do you have any other comments on the letter, leaflet, time sheet, teacher information letter or teacher involvement?

- I didn't feel that I could ask the teacher everyday how long monitor was on and off. I have had to rely on my daughters information.
- Timesheet needs to allow for other pedalled activity (my child has a pedal go-cart and what about scootering?).
- My daughter's teacher was pleased to help in any way and encouraged her. My daughter talked about it in class.
- Everything was clearly explained and easy to understand.
- Could all the pieces of paper come in a folder with a clear summary of what to give to whom and when printed on front.
- It was quite fun, he quite enjoyed being a bit different for the week. There were so many bits of paper especially with it happening at the same time as the teacher questionnaire. As you can see I forgot to fill in this form - which would have been better to send with the activity monitor, rather than beforehand. I also failed to give one form to the school until they asked for it.

Q10. In relation to returning the activity monitor, were you confused about when and how you were supposed to return it?

Very confused	0	0%
A little confused	0	0%
Not confused at all	18	100%
Total	*18*	*100%*

Q11. Were you confused about when you had to start wearing the activity monitor?

Very confused	0	0%

A little confused	6	32%
Not confused at all	13	68%
Total	*19*	*100%*

Q12. Did your child wear his/ her activity monitor at all the required times?

Yes	14	74%
No	5	26%
I am not sure	0	0%
Total	*19*	*100%*

Q13. Did your child find the activity monitor comfortable or uncomfortable to wear?

Very comfortable	2	11%
Quite comfortable	13	68%
Quite uncomfortable	4	21%
Very uncomfortable	0	0%
Total	*19*	*100%*

Q14. Did your child find the activity monitor belt too big or too small to wear?

Too big	3	16%
Too small	0	0%
The right size	16	84%
Total	*19*	*100%*

Q15. Was your child able to put the belt on, and take if off on their own?

Yes	18	95%
No	1	5%
Total	*19*	*100%*

Q16. Do you have any other comments regarding the comfort, ease and convenience of wearing the activity monitor?

- The belt would slip around occasionally so whether it recorded properly I don't know.
- At first it was a great novelty then a burden- she hated wearing it because it got in the way, and was uncomfortable. Remembering to put it back on after getting changed as she's always changing her clothes.
- He did get fed up wearing it. I decided to let him not wear it after his evening wash/ bath. Approximately

1.5hr prior to his bedtime.
- My child found the monitor quite uncomfortable and regularly complained of a belly ache.
- My child was a little uneasy about having to wear the monitor at school at first but was fine by the end.
- My child didn't adjust the belt or undo it. She just pulled it up from her feet to her waist. This may stretch the belt over time.
- It wasn't particularly comfortable wearing it all day, and difficult to avoid him fiddling with the belt.
- It was fine.
- The little black plastic plug at the side of the monitor kept coming out. It was not sitting comfortably. I had to twist the strap to tighten it to fit properly on my daughter.
- My child had no complaints about wearing the monitor- he was happy to put it on himself and it did not bother him during the day (I think he forgot he was wearing it!)

6.4 Data quality

The table below shows the number of valid days (wearing the monitor for a minimum of 600 minutes per day) of data for the children (n=24) that wore the activity monitor.

No. of valid days	No. of monitors	Percentage (%)
7	10	42
6	4	17
5	2	8
4	5	21
3	0	0
2	0	0
1	1	4
0	2	8
Total	*24*	*100%*

Apart from 3 activity monitors the data obtained is promising. The table shows that all of the other activity monitors had at least four valid days of data, including ten children that had seven valid days of data.

These results are backed up by the feedback questionnaire which also revealed that nearly all children wore the monitor at all the required times.

One parent/ guardian decided that they did not want their child to take part in wearing the monitor after one day, because their child complained that the belt was too tight. This is the monitor that only had one valid day of data. One monitor had no valid days because of a programming mistake, which should not occur in the main stage. The only other monitor that had no valid days was because the child did not wear the monitor for a long enough period of time each day.

The results from the feedback questionnaire also showed that nearly all children were as active as usual whilst wearing the activity monitor, consequently maintaining their normal daily activities. There were only 5 children that slightly changed their activity levels, and only 1 child did this because their activity was being monitored.

7. Findings from Pilot Mailing (Feedback Certificate mailing)

7.1 Sent documents

Parents/ guardians were told that their child would receive a certificate summarising their activity levels 4-6 weeks after sending back the activity monitor.

The feedback certificates are produced by downloading and saving the activity data from the monitors using ActiLife software. This data is then processed by a macro that was used in the ALSPAC study, which produces a certificate with a personalised graph summarising the child's first day of activity.

- *How many children have been sent their feedback certificates?*

At present, 24 out of 24 children that wore and returned their activity monitors have been sent their feedback certificates.

- *How long after the activity monitor return date were the feedback certificates sent?*

The table below shows how many days after the activity monitors were returned (n=24) the feedback certificates were sent

Interval between receiving monitor back at ICH to sending feedback certificate (days)	No. of monitors	Percentage (%)
≤14	5	21
15 - 21	18	75
22 – 28 (4 weeks)	1	4
29 – 35 (5 weeks)	0	0
36 – 42 (6 weeks)	0	0
> 42	0	0
Total	24	100%

- *Were there any complications sending the feedback certificates ?*

One unanticipated problem was that there were 3 monitors that did not have enough valid data (discussed in data quality) to run the macro and produce personalized feedback certificates. These children were still sent feedback certificates, however, the graphs showed a typical child's activity levels, rather than their own. An information sheet was sent that apologised for their child not having a personalized graph and explained what the graph on their child's certificate did show.

7.2 Returned documents – feedback questionnaire

Parents/guardians were asked to complete and return the feedback questionnaire on the feedback certificate in the pre-paid envelope supplied.

How many parents/ guardians returned the feedback questionnaire?
At present, 12 feedback questionnaires out of 24 sent feedback certificates have been received.

7.3 Evidence from the feedback questionnaires

Responses from 12 feedback questionnaires have been logged, and the answers are shown below.

Q1. Did you find the feedback certificate useful?

Very useful	3	25
Quite useful	5	42
Quite useless	4	33
Very useless	0	0
Total	*12*	*100%*

Q2. Did your child find the feedback certificate useful?

Very useful	2	17
Quite useful	8	67
Quite useless	2	17
Very useless	0	0
Total	*12*	*100%*

Q3. Do you or your child have any other comments on the feedback certificate?

- It would have been useful if we'd had feedback about whether the amount of exercise was very good/ sufficient/ not enough. The sheet explaining the graph and giving ideas what to look for was useful. He really wanted to know what day it was he was looking at. It would have been even more interesting to see a print out for every day so that you could make comparisons. Or even just your most active day & your most inactive day.
- She really enjoyed understanding why the activity monitor was used and to see how active she is.
- The certificate helps in keeping my son committed to the research. It would have been useful to show my son what the normal activity levels are and how he compares.
- Does it mean she is an active child? Does it reach/ exceed your expectations? How does it compare? Will you produce some local/ national results?
- I think 'interesting' is more appropriate that useful, i.e. what use does the certificate have?
- It was interesting to see the active and the quiet periods.
- It would be nice to have more days so that we can see how active our child instead of just one day.
- It would have been nice to know which day if possible or perhaps a summary of the week.
- I would have preferred it to say how my sons activity compared to the average they would expect as I know what sports he plays and when he has PE so the graph showed what's expected. What I wanted to know was is he active enough?!
- It would have been good to know which day it was. What the average of the group was, so I could compare my child against an average. She liked the fact that it was a 'certificate'.
- He like to look at the activity levels and try to work out what he was doing at those times.
- She felt very pleased to receive the certificate!

There were no identifier's printed on the questionnaires, so when they were returned it was not possible to know which family they had been returned by.

8. Conclusions and Recommendations for Dress Rehearsal

8.1 Timetable

It is anticipated that the main stages of the activity monitor dress rehearsal will be as follows:

	Start	End
Sample Details to ICH	Late 07/2007	08/2007
Activity monitors sent	08/2007	09/2007
Activity monitors returned	+10 days	+ 21 days
Feedback certificates sent	?	?

8.2 Sample

An estimated 100 families taking part in the MCS4 dress rehearsal interviews will be invited to take part in the physical activity monitoring dress rehearsal. These families will be different to those who took part in the pilot.

8.3 Acceptability

In general, the findings from the pilot study show a reasonable degree of acceptability from parents and children in relation to the wearing of the physical activity monitor for the purposes of measuring activity levels (please see diagram 1).

At the interview most parents/ guardians (82%) agreed and gave consent for their children to take part in wearing the activity monitor. Nearly all (94%) children that were sent activity monitors packs took part in wearing the monitor.

There were many positive comments regarding the activity monitors, with most children being pleased and excited about wearing them. The parents/ guardians who did refuse for their children to wear the activity monitor were mainly concerned about their child being singled out from the rest of their peers and being a potential target for bullying.

In order to increase acceptability at the interview stage it is recommended that the number of documents and the amount of information that parent/ guardians receive is reduced. It is suggested that the only document they receive is the information leaflet. It is also recommended that the interviewers are given a summary sheet (similar to that sent to the parents/guardians on the back of the timesheet) to help them explain the essentials, and that if any further information is required from the parents/ guardians they should ring ICH. This will hopefully help to save time and maintain the parents/ guardians interest.

It would also be helpful if interviewers could reassure the children and parents/guardians that there were no children being singled out at school, or being bullied as a result of wearing the activity monitor in the pilot study. In fact, most children really enjoyed wearing them. It is also suggested that parents/guardians and/or the children are given the option to be able to change their mind if they decline to take part in the activity monitoring at the interview, but at a later stage (possibly after reading through the information leaflet) decide that they do wish to take part.

8.4 Feasibility

In general, the findings from the pilot study show that direct collection of children's physical activity levels using Actigraph physical activity monitors in cohort members is feasible. In particular, that posting physical activity monitors to subjects can be a reliable and efficient way of obtaining valid data on children's activity levels.

This is represented by all but three monitors having at least four valid days of data, including ten children that had seven valid days of data. Also, nearly all the children maintained their normal daily activity levels, and only one of the children changed their activity level because they were wearing the monitor. Furthermore, monitors are being returned at an acceptable time, with only four monitors awaiting late return.

8.5 Changes to documents

Initial feedback from the interviews on the documents provided to parents explaining the activity monitor was positive, especially with regards to content and reasons for this aspect of the study.

8.5.1 Parent cover letter

In general, the parent cover letter was well received and all parents/ guardians said that they found the letter 'very easy' or 'easy' to understand.

The only suggested change that should be made for the dress rehearsal will be that the line 'Please use the timesheet enclosed, rather than the one given to you by the interviewer, as it contains a reference number for office use' will be taken out. This is because it is recommend that timesheets are not given at the interview stage to ensure that timesheets without identification are not filled out.

8.5.2 Information leaflet

The information leaflet was also positively received and nearly all parents/ guardians found it 'easy' or 'very easy' to understand.

In addition, all parents/ guardians were 'not confused at all' about when and how they were supposed to return the monitor. Furthermore, they were 'not confused at all' about when they had to start wearing the monitor, suggesting that the information sheet served its purpose. However, there were three parents/ guardians who said they were a 'little confused' as to when they should start wearing the monitor.

It is suggested that the section entitled 'When should my child wear the activity monitor?' should be reviewed and amended so that the start date is made clearer.

8.5.3 Physical activity monitor and belt

Belt

Overall, feedback from the initial interviews regarding fitting the monitor to the child was positive. In all cases but one the belt was of an adequate size (for the one exception, the child was rather thin and the belt was too big). One larger child was concerned prior to the fitting that the belt would be too small. However, this did not prove to be the case at the interview.

Information received from the feedback questionnaire was conflicting regarding the comfort, size and ease of wearing the activity monitor. Most children did find the activity monitor 'quite comfortable' to wear and 'the right size'. Furthermore, nearly all parents/ guardians stated that their child was able to put the belt on and take it off on their own. There were also several comments mentioning how happy their child was to wear the monitor, and that they had encountered no problems.

One child refused to take part after wearing the monitor for one day because he felt that the belt was much too tight. In addition, the feedback questionnaire revealed that the activity monitor belt was 'too big' to wear for three children. However, two of these children still thought that the belt was 'quite comfortable to wear'. Furthermore, three children also felt that the activity monitor was 'quite uncomfortable' to wear. In one of these children the belt was too big. The other two families emphasized in writing how uncomfortable the belt was, but did not explain why. Two families also commented that the belt would move around frequently.

To help make the belts more comfortable to wear, and resolve any problems with the sizes of the belts there are two alternative recommendations. The first recommendation is that that the upper size limit of 70 cm waist circumference for the belts is raised. There were two pilot children in the waist category 66- 70 cm, as against four in the 61- 65 cm category. It has been suggested that the upper limit for the belts is raised to 72 cm, even though both 70 cm and 72 cm are above the 99.9th centile in age-matched growth charts. Alternatively, a variety of sized belts could be manufactured (possibly three different sizes). Waists sizes will then determine which sized belt will be sent to the family for their child.

Activity Monitor

An additional unanticipated issue with the activity monitor was regarding the USB port protectors. In two of the returned monitors the USB port protectors were missing. One parent/ guardian also commented that the USB protector kept coming out. This is of particular concern because the protectors are needed in order to prevent any damage to data collection and download. It is recommended that for the dress rehearsal the protectors are taped down to prevent this problem occurring. In addition, it is recommended that it is established whether spare protectors can be purchased, and if so, this should be done.

Another problem that occurred with the activity monitors was regarding the personalised stickers that were put on the back of the monitors. Each monitor had the child's first name, an ID number and a number to call if the monitor was found by anyone. Some families had tried to remover the stickers, presumably because they have their child's name on them. However, they are not removed easily, and as a consequence this would not be feasible to apply and remove stickers for each different child that uses the monitor. It is therefore suggested that the child' name is not put on the monitor, just a unique monitor number and a return telephone number. This would mean that the stickers would not need to be removed for different children. It is also recommended that parents are asked in the documents not to remove the sticker on the back of the monitor.

8.5.4 Timesheet and summary

Feedback regarding the timesheet from the initial interviews was positive, with parents understanding the importance of accurately recording the activities of the child. One or two parents did comment that the timesheet should be more child-friendly, therefore enabling the cohort children to fill it out themselves. Although interviewers expressed doubts over whether parents would remember to fill the sheets in, all families returned their completed timesheets and nearly all families correctly filled in the timesheets.

Findings from the feedback questionnaire found that nearly all parents/ guardians found the timesheet 'very easy' or 'easy' to understand and complete, although one family did say that it was 'difficult' to understand and complete. Also, nearly all were either 'very confident' or 'confident' that the information on the timesheet was accurate. Furthermore, nearly all parents/ guardians felt that their child was able to provide the information needed to fill out the timesheet on days when they were at school.

Only two parents/ guardians felt that the information on the timesheet was 'inaccurate', and two stated that their child could provide only 'a little' information to fill out the timesheet on days when they were at school. One comment made by one family was that the timesheet needed to allow for other pedalled activities such a go-carts and scooters, that would not be measured accurately as activity by the activity monitors.

Recommendations for changes to the timesheet would be to make the timesheet more appealing to children with the use of colours and pictures. An extra row should be added to take into account how many minutes children spent doing other activities in which the monitor was taken off (allowing for vigorous activities). In addition, the time spent on other pedalled activities (e.g. go-carts and scooters) should be included into the minutes spent cycling.

The completion of whether the child took the activity monitor off during the day (yes or no answer) and then the corresponding 'for how many minutes' were not filled in very successfully. To avoid any confusion this will therefore be replaced with a single question asking how many minutes their child forget to wear the activity monitor during the day.

The pilot timesheets did not have any identification on them, and therefore if returned to ICH separately to the activity monitor may have caused problems. As a result of this an identification label was stuck on the timesheet. This information should be added onto the timesheet before printing so that no label is needed. Finally, timesheets should not be given out at the interview stage to ensure that families do not fill in timesheets without identification information.

8.5.5 Letter for child's class teacher.

In general, the letter for child's class teacher was well received and most parents/ guardians said they found it 'easy' or 'very easy' to understand.

At the interviews there was some concern over the burden caused by the child wearing the activity monitor would put on the child's teacher. However, the feedback questionnaire revealed that all of the teachers of participating children did allow them to wear the monitor. One family even commented how their child's teacher was pleased to help in any way and encouraged their child.

Information relating to whether the children's teachers' informed parents if children took the monitors off during the school day was inconclusive. This is to be expected as we did not ask the parents to ask their children's teacher to do this. Half of all families said that their child's teacher did not inform them if their child took the monitor off during the school day, and nearly half said that their child's teacher did inform them when their child took the monitor off during the school day. One family commented that they didn't feel that they could ask the teacher everyday how long the monitor was put on and taken off, and that they had to rely on their child's information. This is not concerning, as reported previously, nearly all families felt that their child was able to provide the information needed to fill out the timesheet on days when they were at school. As a result no recommended changes to the letter for the child's class teacher are to be made for the dress rehearsal. Question 8 in the feedback questionnaire which asks whether the child's teacher informed the parents if their child took the monitor off during the school day should be removed as we have not asked teachers to do this in the teacher letter.

8.5.6 Feedback questionnaire (activity monitor mailing)

We have received no negative comments regarding the feedback questionnaire. As a result it is recommended that this will still be sent for the dress rehearsal in order to obtain further information for the main stage. Recommended changes are the deletion of question 8 (as previously discussed) and also two grammatical changes. In addition, an identifier (presumably the child's name) should be added to the feedback questionnaire, so that each questionnaire can be matched with a child if the monitor and questionnaire are returned separately.

8.5.7 Feedback certificate

There were mixed responses from the feedback questionnaire regarding the feedback certificate.

Three parents found the feedback certificate 'very useful', and five parents found it 'quite useful'. In contrast, four parents found the feedback certificate 'quite useless'. Two out of twelve children also found the feedback certificate 'quite useless'.

There were comments that the certificate was 'interesting' rather than 'useful'. Parents also commented that their children really liked the idea of receiving a certificate. In addition, parents felt that it was a good idea to have a sheet explaining the graph as their children liked to look at the graph and work out what they were doing at certain times of the day. One parent felt that the certificate helped keep their child committed to the research.

Half of all parents that returned feedback forms said that they would like to know how their child's activity level compared to the 'normal' level, and whether their child was active enough. Parents also suggested that it would have been useful to have a summary of their child's activity throughout the week, in addition to having an individual day. One parent also said that it would have been useful to know which day the graph showed.

It is recommended that children will continue to receive a feedback certificate. However, the format of this certificate will be revised. It is recommended that the following changes are considered:

1. Getting the certificate templates designed professionally.
2. Showing a line corresponding to the lower threshold of moderate intensity (as established by ALSPAC at 3600 accelerometer counts/min) on the activity graphs so that parents can see how often their child takes part in moderate activity, and therefore whether their child participates in the recommended

government guidelines of at least 60 minutes of moderate physical activity a day.
3. Producing a graph that summarizes the child's activity throughout the week, in addition to the graph summarising one day of activity.
4. Informing parents which day/date the activity graph represents (on the single day graph).

All feedback certificates were sent within four weeks of the activity monitors being returned. It is recommended that all documents inform parents that they will receive their child's feedback certificate within four weeks of returning the activity monitor instead of 4-6 weeks. This will enable a quicker turnover rate.

8.5.8 Information sheet for feedback certificate

The feedback questionnaire did not ask any specific questions about the information sheet. However, one parent did comment that the sheet was very useful in order for their child to understand the graph.

As a result, it is therefore recommended that families still receive information explaining the graphs. However, the appearance of the information sheet was not very professional. It is suggested that a cover letter is sent which incorporates the explanation of the graph. This should be similar to the text sent in the pilot. If a 'moderate activity level' line is added to the graph, this should also be explained in the cover letter.

8.5.9 Feedback questionnaire (feedback certificate mailing)

We have received no negative comments regarding the feedback questionnaire for the feedback certificate mailing. However, the questionnaire was very basic. In addition, there were comments regarding the wording of the first and second questions (i.e. that the certificates weren't useful, but interesting).

As a result, it is recommended that the feedback questionnaire on the feedback certificate is reviewed so that more appropriate and informative questions are asked to the families. Also, as with the feedback questionnaire for the activity monitor mailing an identifier should be added to the feedback certificate mailing questionnaire.

8.5.10 Envelopes

Activity monitor mailing envelope

The physical activity monitor pack was sent out in an A4 windowed envelope. In order to prevent loss of activity monitors 'return to sender' labels were printed and placed on the front of the envelope. It is recommended for aesthetic reasons and to save time that in the main stage the envelopes are pre-printed with 'return to sender' information.

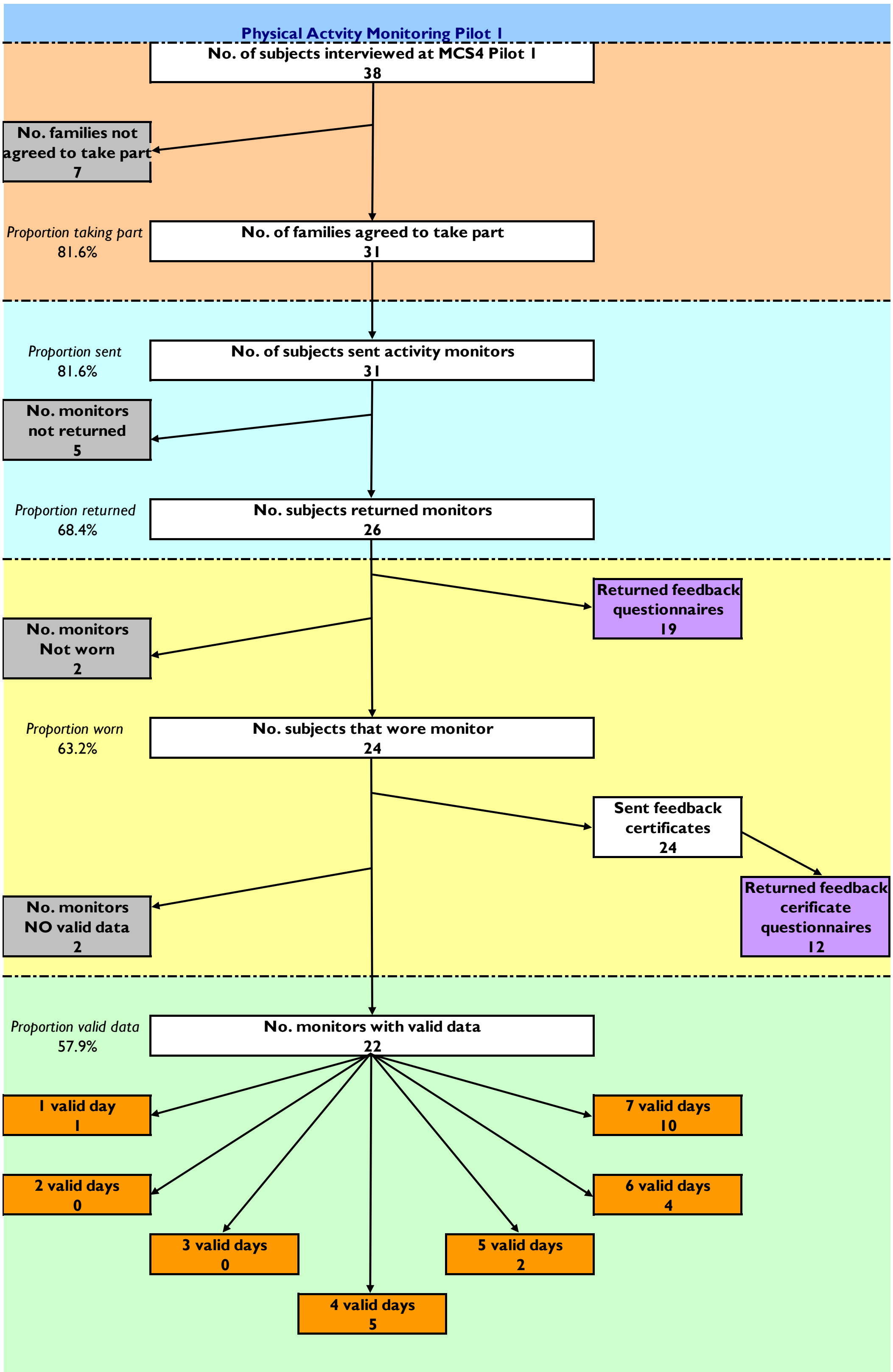
The dress rehearsal activity monitor mailing will be the same as the pilot mailing, with the same enclosures. The contents of this is quite bulky. In the pilot study this made it hard for the mailing envelopes to remain closed. In some, sellotape was used to secure this. It is recommended that for the dress rehearsal all envelopes are closed this way to prevent any loss of monitors in the posting process. Alternatively, if correctly sized 'peel and seal' window envelopes can be purchased these should be used.

Pre-paid envelope for returning activity monitor to ICH

All families returned the activity monitor and belt in the correct pre-paid envelope. The padded material suitably protected the activity monitors, and the size was suitable for returning all documents in addition to the activity monitors. This should therefore remain the same for the dress rehearsal.

Feedback certificate mailing envelope

The feedback certificate mailing was sent out in an A4 envelope. There were no reported problems with this and as a result this will remain the same for the main stage.


Physical Actvity Monitoring Pilot 1
No. of subjects interviewed at MCS4 Pilot 1
38
No. families not agreed to take part
7
Proportion taking part
81.6%
No. of families agreed to take part
31
Proportion sent
81.6%
No. of subjects sent activity monitors
31
No. monitors not returned
5
Proportion returned
68.4%
No. subjects returned monitors
26
Returned feedback questionnaires
19
No. monitors Not worn
2
Proportion worn
63.2%
No. subjects that wore monitor
24
Sent feedback certificates
24
Returned feedback cerificate questionnaires
12
No. monitors NO valid data
2
Proportion valid data
57.9%
No. monitors with valid data
22
1 valid day
1
7 valid days
10
2 valid days
0
6 valid days
4
3 valid days
0
5 valid days
2
4 valid days
5

Appendix 1

Child of the New Century
Age 7 Survey Pilot
Activity Monitor

Summary of key points

Your child should wear the monitor….

- Every day for 7 consecutive days starting day after received
- At all times from first thing in the morning to last thing at night - except when swimming, in shower or bath or playing extremely vigorous sports
- On a belt around the waist
- On top of indoor clothing (or against skin if preferred)
- Above right hip
- Tightly but comfortably against body (not 'flopping around')

You should record on the timesheet (on the back of this form)….

- Dates that the monitor was worn
- Time monitor was put on in the morning and taken off at night
- Any periods spent swimming or cycling (the monitor should still be worn during cycling)
- Any other periods when monitor not worn
- Whether typical week or not

You should also….

- Give the letter about the activity monitor to your child's class teacher
- Return the activity monitor, belt and completed timesheet **as soon as possible** after the 7 day period in the envelope provided

We will….

- Send you a summary of your child's activity 4-6 weeks after the monitor is sent back
- Treat the information recorded on the timesheet in strict confidence in accordance with the Data Protection Act
- Answer any questions you may have. If you have any other questions or any problems with the monitor or timesheet, please call Carly Rich from the Institute of Child Health on 020 7905 2691

Timesheet	Example	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Date	*10/05/07*							
Time put on in morning	*7.45*	:	:	:	:	:	:	:
Time taken off at night	*8.30*	:	:	:	:	:	:	:
How many minutes spent swimming	*0*							
How many minutes spent cycling	*65*							
Did your child take the activity monitor off at all during the day (before they went to bed)?	*Yes*							
If yes: how many minutes did they take it off for?	*15*							

Was this week typical for your child in terms of their usual activity? Yes/ No

IF NO: why not? (e.g. sprained ankle on day 3)..

Appendix B: Dress rehearsal report

Institute of Child Health
University College London

Dress Rehearsal Report of the MCS4 Age 7 Physical Activity Monitor Mailing

Carly Rich, Carol Dezateux, Lisa Calderwood, Lucy Griffiths

October 2007

Executive Summary

- Activity monitoring was piloted in 102 children participating in the MCS4 dress rehearsal.
- the calendar period of the dress rehearsal meant that the period of issue was over the school holidays
- at home interviews 89 / 102 (87%) agreed to take part
- 82 families (91%) were sent monitors within 28 days of the interview. The reasons for sending 8 monitors later than 28 days after the interview were; 5 families had requested a later start date, 2 monitors went missing in the post, and 1 family forgot to start wearing the monitor when first sent
- 74 out of 89 monitors were returned, 58 (78%) within 4 weeks but return was delayed due to the recent postal strike
- all returned monitors and belts were undamaged although USB cover was missing in 6 monitors
- 18 monitors were not worn, largely because the child or family had subsequently changed their mind about taking part
- 56 families returned monitors that had been worn for at least one day
- 62% of these returned the monitor without a reminder, 6 with one reminder, 7 with two reminders, and 5 with three reminders, leaving 15 not returned at all
- valid data (at least 600 minutes per day) was available for at least 4 days (including 2 weekend days) in 38 (69%) of children
- all 56 with data returned completed timesheets
- 46 families completed an evaluation form and analysis of the evaluation forms demonstrated high acceptability from parents and children in relation to the wearing of the physical activity monitor for the purposes of measuring activity levels. There were some minor concerns from parents about attracting attention at school and also some recommendations to not take measurements at the start of the school year

Contents

1. Introduction

As part of the pilot of the Millennium Cohort Study Fourth Sweep (MCS4) researchers at the Institute of Child health (ICH), University College London, took direct measurements of the children's physical activity using an Actigraph activity monitor. All children interviewed for MCS4 dress rehearsal were invited to take part in wearing an activity monitor, and all parents/ guardians were asked for written consent.

Soon after the interviews, participant details were given securely to ICH, and the activity monitors were posted out to the families. Children were instructed to wear the activity monitor at all times for seven consecutive days, except for when sleeping, bathing, showering, swimming, or participating in vigorous activities. The parents/ guardians were also sent a timesheet, and asked to record any periods when their child did not wear the activity monitor. After the seven days, the parents/ guardians were asked to post the monitor and timesheet back to ICH. The data were then downloaded using ActiLife Software, and a feedback certificate with a summary of their child's activity was sent to the family.

2. Timetable

The table below records the relevant dates for the physical activity project:

	Start	End
Interviews	20/07/2007	14/08/2007
Sample Details to ICH	26/07/2007	22/08/2007
Activity monitors sent	28/07/2007	28/08/2007
Activity monitors returned	20/08/2007	16/10/2007
Feedback certificates sent	31/08/2007	08/11/2007

3. Sample

A total of 102 parents/ guardians and their children were interviewed at MCS4 Dress Rehearsal (July/ August 2007).

All children were invited to take part in the activity monitor study, and 89 out of 102 (87%) children agreed and their parents/guardians gave written consent.

4. Fieldwork

Prior to fieldwork the parents/ guardians were sent a short information leaflet explaining when, how, and why the activity monitors were to be worn.

At the interviews the families were shown a 'dummy' activity monitor, which was generally well received by both parents and children. The families were also shown two different sized belts to which the activity monitor could be attached. The majority of the children and parents/ guardians were excited about receiving the monitors and some of the children mentioned they felt quite special at being asked to take part. The parents were particularly interested in the feedback that they would receive.

The parents/ guardians who declined to take part mentioned being concerned about their child being singled out from the rest of their peers and being a potential target for bullying. The children chose not to elaborate on why they did not want to wear the monitor, even when probed by the interviewer.

5. Content

5.1 Activity monitor mailing

Once participant details were given securely to ICH activity monitor packs were sent. These comprised of 7 enclosures:

1. parent cover letter (Appendix 1)
2. information leaflet (Appendix 2)
3. physical activity monitor and belt
4. timesheet for parent and child to complete (Appendix 3)
5. letter for the child's class teacher (Appendix 4)
6. feedback questionnaire for parent and child to tell us their views
7. pre-paid 1st class envelope (padded) for posting back the monitor and completed documents

5.2 Returned enclosures

The parents/ guardians were asked to return the following enclosures in the pre –paid envelope as soon as possible after the seven day monitoring period:

1. physical activity monitor and belt
2. timesheet
3. feedback questionnaire

6. Findings from Dress Rehearsal Mailing (Activity monitor mailing)

Activity monitor related mailing and returns have been securely logged in detail at ICH. The data are stored in a password protected Access database so that named children cannot be matched to descriptive data. The data from the feedback questionnaires have also been entered onto a secure database.

6.1 Sent documents

Parents/ guardians were told that their child's activity monitor would be posted to them within 4 weeks after the interview, unless they requested a later start date, for example, if they were going on holiday.

- *How many children were sent activity monitors?*

All those that gave consent at the interview were sent activity monitors.

- *How long after the interview date were the activity monitors sent?*

The activity monitor sample details were sent to ICH in weekly batches between 26/07/07 and 22/08/2007. The interviews took place between 20/07/2007 and 14/08/2007.

The table below shows how many days after the interviews took place the monitors (n=89) were sent.

Interval from interview by NatCen to sending at ICH (days)	No. of monitors	Percentage (%)	Cumulative percentage (%)
4	1	1	1
5	0	0	1
6	1	1	2
7	2	2	4
8	5	6	10
9	2	2	12
10	4	5	17
11	14	16	33
12	6	7	40
13	5	6	46
14	7	8	54
15	10	11	65
16	5	6	71
17	3	3	74
18	1	1	75
19	2	2	77
20	1	1	78
21	0	0	78
22	6	7	85
23	0	0	85
24	1	1	86
25	2	2	88
26	1	1	89
27	0	0	89
28 (4 weeks after interview)	2	2	91
> 28	8	9	100
Total	*89*	*100*	100

- *What were the reasons for sending the 8 monitors later than 4 weeks after the interview ?*

  - 5 families requested at the interview to be sent later (on holiday).
  - 2 families rang ICH after receiving reminder letters to say that they had not received the monitor at all. Further monitors were sent. It is likely that these went missing in the post.
  - 1 family rang ICH after receiving the monitor explaining that they had forgot to wear the monitor and the light had stopped flashing. As a result monitor was returned and reprogrammed then sent at a later date.

6.2 *Returned documents*

6.2.1 Activity monitor

Parents/ guardians were asked to return the activity monitors and belts as soon as possible after the seven day monitoring period. If the monitors were not returned within 21 days of being sent, a reminder letter was sent. Subsequent reminders were sent 28 days and 35 days after sending the activity monitors.

- *How many parents/ guardians have returned the physical activity monitors?*

At present, 74 out of 89 (83%) activity monitors have been returned. All of these were attached to a belt. There is currently a postal strike taking place that is likely to affect the return of monitors.

- *How many parents/ guardians have received reminder letters?*

At present, 7 families have been sent just one reminder letter, and 6 have since returned their monitor. 9 families have been sent two reminders, and 7 have since returned their monitors. 18 families have been sent all 3 reminder letters, of which 5 family has since returned their monitor.

- *How long did it take the parents/ guardians to return the activity monitors?*

The table below shows how many days it took for the monitors (n = 74) to be returned.

Interval from sending at ICH to receiving back at ICH (days)	No. of monitors	Percentage (%)	Cumulative Percentage (%)
7	1	1	1
8	2	3	5
9	1	1	6
10	5	7	13
11	4	4	17
12	6	8	25
13	6	8	33
14	10	14	47
15	5	7	54
16	3	4	58
17	3	4	62
18	1	1	63
19	1	1	64
20	0	0	64
21 – 27	10	14	78
> 28	16	22	100
Total	*74*	*100 %*	*100%*

- *Was there any damage to the activity monitors?*

No functional damage occurred to the activity monitors during the mail out. However, the USB port protector was missing from six monitors when returned. None of the belts were damaged, and all had remained in good condition.

6.2.2 Timesheets

Parents/ guardians were sent a timesheet and asked to record the dates that the monitor was worn, the times put on in the morning and taken off at night, any periods spent swimming, cycling, or playing vigorous sports, and any additional minutes when the monitor was not worn. They were also asked whether the week was typical for their child in terms of their usual activity. They were asked to return the completed timesheet with the activity monitor as soon as possible after the seven day monitoring period.

- *How many parents/ guardians returned the timesheets?*

A completed timesheet was returned for all of the children that wore the activity monitor.

- *Were the timesheets completed correctly?*

With the exception of one timesheet with dates monitor worn missing, all timesheets were completed correctly.

6.2.3 Feedback questionnaires

Parents/guardians were asked to complete and return the feedback questionnaire in the pre-paid envelope with the activity monitor and completed timesheet.

How many parents/ guardians returned the feedback questionnaire?
At present, 46 feedback questionnaires out of 74 returned activity monitors have been received.

6.3 Evidence from the feedback questionnaires

Responses from 46 feedback questionnaires have been logged, and the answers are shown below.

Q1. On the whole, how did you feel about your child being asked to wear an activity monitor for a week? Do you feel that you understood why and how the activity monitor was worn? Was there anything else you would have liked to have known?

I had no problems and was interested to see the outcome.

Felt ok about it, although I was not expecting to receive it as was told by interviewer that in the pilot would not be using them.

Didn't mind him wearing monitor. Understood all that was asked. Didn't need to know anything else.

Happy for her to wear it as long as she was happy and comfortable. Completely understood reasons.

I was happy for her to wear the activity monitor and fully understood what the research entailed. Good explanation and instructions so no additional questions.

I had no problems and was interested to see the outcome.

Everything was explained very clearly and I had no objections to my child wearing the device

He was alright with it when he had to wear it. I didn't really understand why he had to wear it.

It would be useful to know a little more about how the monitor works and how the information is retrieved from it.

Was ok with the request. Maybe to have seen a dummy model before it was delivered.

I was fine about her wearing the monitor. The only problem we had was that the week it rained most of the time, so a lot of activities we couldn't do.

I understood why but she was reluctant to wear it because she felt different from her friends.

I understand why it was worn and was happy for her to wear it.

OK. Not worried at all. Everything was explained. I was happy that my child was happy to wear it.

All the information was well explained before starting the physical activity monitoring.

Absolutely fine, but a bit of confusion as we were told it was to be when he returned to school.

We were happy for her to wear the monitor and understood why and how it was worn.

Very happy for him to wear monitor. We both are interested in taking part in CNC.

I felt quite confident in my child wearing the monitor. I fully understood why and how the monitor was worn. There is nothing else I would have liked to have known.

She didn't mind wearing the monitor. The information we were given about the monitor told us everything we needed to know.

Ok. She enjoyed it.

Child didn't like wearing the monitor. He said it made him itch, but he understood why I asked him to wear it.

I felt ok having my daughter wear the monitor, and it was explained to me, both by the lady carrying out the survey on your behalf and the literature.

We both felt ok with our child wearing the belt it's a good idea to see how active he is.

I didn't feel any different from other days when my daughter was wearing the activity belt. I understood the reason for my daughter to wear the belt. I regard the exercise as another exercise with my daughter.

No problems. Child was very aware of why she was wearing it.

Interviewer fully explained it all to my son and he was fine with wearing and understanding why.

A bit daunted at first, but everything was quite clear and after day 1 it was fine.

I felt fine about him wearing it. I'm interested to see the results on how active he is.

I felt alright about my son wearing it.

Everything was explained well, quite happy.

I thought it was a fun idea and would produce interesting results.

I am pleased that my daughter wore it as it goes to future research.

We didn't mind her wearing the monitor, and we did understand and no there was nothing else we needed to know. We were happy to help.

Q2. Overall, how easy or difficult did you find it to understand the letter, information leaflet and teacher letter?

Very easy	33	72 %
Easy	12	26 %
Difficult	0	0 %
Very difficult	0	0 %
Missing	1	2 %
Total	*46*	*100%*

Q3. Overall, how easy or difficult did you find it to understand and complete the timesheet?

Very easy	33	72 %
Easy	9	20 %
Difficult	2	4 %
Very difficult	0	0 %
Missing	*2*	*4 %*
Total	*46*	*100%*

Q4. Overall, how confident or unconfident are you that the information on the timesheet is accurate?

Very confident	21	46 %
Confident	22	48 %
Unconfident	1	2 %
Very unconfident	1	2 %
Missing	1	2 %
Total	*46*	*100 %*

Q5. Was your child able to provide the information needed to fill out the timesheet on days when they were at school?

Always	10	22 %
Sometimes	2	4 %
A little	1	2 %
Not at all	1	2 %
N/a	31	67 %
Missing	1	2 %
Total	*46*	*100 %*

Please note that 67% of children were on school holidays during the activity monitoring

Q6. Which of these statements best describes your child's activity during the monitoring week?

My child was much more active than usual	2	4 %
My child was a little more active than usual	4	9 %
My child was as active as usual	26	57 %
My child was a little less active than usual	12	26 %
My child was a lot less active than usual	0	0 %
Missing	2	4 %
Total	*46*	*100 %*

Q7. If your child was more or less active than usual, was this change in activity mainly because their activity was being monitored?

Yes	0	0 %
No	18	39 %
I don't know	0	0 %
N/ a	28	61 %

Total	*46*	*100 %*

Q8. Did your child's teacher allow your child to wear the monitor at school?

Yes	13	28 %
No	0	0 %
I don't know	1	2%
N/a	31	67 %
Missing	*1*	*2 %*
Total	*46*	*100 %*

Q9. Do you have any other comments on the letter, leaflet, time sheet, teacher information letter or teacher involvement?

I had no problems.

School teacher information was a bit confusing as it was school holiday week.

Did not wear the monitor at school because she was on holiday.

Why was this needed?

Child was not at school during the time of being monitored.

School holidays. I was at work so I got my information from my childminder.

The teacher thought it was very exciting.

Part of the time she wore the monitor she was still on school holidays so she was probably a bit more active on these days.

Q10. Were you confused about when you had to start wearing the activity monitor?

Not confused at all	41	89 %
A little confused	3	7 %
Very confused	0	0 %
Missing	2	4 %
Total	*46*	*100 %*

Q11. In relation to returning the activity monitor, were you confused about when and how you were supposed to return it?

Not confused at all	42	92 %
A little confused	1	2 %
Very confused	0	0 %
Missing	3	6 %
Total	*42*	*100 %*

Q12. Did your child wear his/ her activity monitor at all the required times?

Yes	34	74 %

No	10	22 %
I am not sure	2	4 %
Total	*46*	*100 %*

Q13. Did your child find the activity monitor comfortable or uncomfortable to wear?

Very comfortable	15	33 %
Quite comfortable	24	52 %
Quite uncomfortable	6	13 %
Very uncomfortable	1	2 %
Total	*46*	*100 %*

Q14. Did your child find the activity monitor belt too big or too small to wear?

Too big	6	13 %
The right size	38	83 %
Too small	0	0 %
Missing	2	4%
Total	*46*	*100 %*

Q15. Was your child able to put the belt on, and take if off on their own?

Yes	42	91 %
No	3	7 %
Missing	*1*	*2 %*
Total	*46*	*100%*

Q16. Do you have any other comments regarding the comfort, ease and convenience of wearing the activity monitor?

Felt it was a bit bulky as the monitor had to sit on the hip

Excess, dangly strap got in the way sometimes.

Having now used it for a week I would not be happy to let my child wear it to school as it identifies them as being different and other children seem to enjoy fiddling with it.

The strap dangled down and monitor moved off my hip when I exercised.

At the beginning of the week she was more conscious of the monitor.

The black rubber fell off on the first day!

It kept becoming loose and not holding position

Too obvious, it could be seen under her clothes.

She said the black stopper on the side of the red box kept coming out.

First couple of days he fiddled with it as it kept moving around his body, but after a couple of days he did not notice that he had it on. Concerned about little black rubber bit on monitor kept coming off! The monitor was fitted on his vest and covered with baggy T-shirt so it was not noticeable to anyone.

The monitor did not always stay in the right position (on the hip) but moved around slightly if she was being particularly active.

The belt tended to ride up from his hip to his waist.

The monitor was easy to put on and she found it very comfortable.

Because it was school holidays we weren't in a routine so unfortunately it was off or not put on for some of the time.

It didn't tend to stay around the hip area but settled around the waist.

After wearing for just one day she had a bruise on her hip and refused to wear again. Sorry.

We didn't let her take the monitor off or put in on because if she had her way she wouldn't wear it at all.

6.4 Data completeness and quality

Monitors were returned by 18 of 74 (24 %) families unworn. Five had written to say that they did not want their child to start wearing the monitor as it was the start of their school term, so did not think it was the best time for their child to wear it. Two had written to say that their child had refused to wear the monitor. One family had just had a new baby, and felt it was too demanding for their other child at the present time. One activity monitor pack was returned by Royal Mail as the 'addressee had gone away'. The remaining unworn activity monitors were returned without any timesheets or any explanation.

Thus activity monitors were returned by 56 children with at least one valid day of data. The table below summarises the number of valid days (defined as wearing the monitor for a minimum of 600 minutes per day) data for these 56 children.

No. of valid days	No. of monitors	Percentage (%)	Cumulative frequency (%)
7	11	20	20
6	11	20	40
5	7	13	53
4	9	16	69
3	8	14	83
2	5	9	92
1	5	9	99
Total	*56*	*100%*	*100*

38 children provided at least four valid days of data, and all monitors had at least one valid day of data.
Three of the five children with only one valid day of data had worn the monitor for one day only.

Findings from the feedback questionnaire show that the children's behaviour was not altered as a result of them wearing the activity monitors, therefore the data represents the children's 'normal' physical activity. Although, 37 % of children changed their physical activity levels slightly, and 5 % changed their physical activity levels dramatically, these changes were not because they were wearing the monitors. Nearly all parents said this was because their children were on school holidays.

7. Findings from Pilot Mailing (Feedback Certificate mailing)

7.1 Sent documents

Once parents had returned their child's activity monitors to ICH, the activity data were downloaded and feedback certificate packs were sent. Parents/ guardians were told that their child would receive a certificate summarising their activity levels within 4 weeks after sending back the activity monitor. The feedback certificate mailing comprised of the following enclosures:

1. Cover letter to explain the graph on the feedback certificate (Appendix 5)
2. Feedback certificate showing a graph summarising one day of the child's activity levels
3. Feedback questionnaire for the parent and child to tell us their views on the feedback certificate
4. Pre-paid 1st class envelope for posting back the completed feedback questionnaire

The feedback certificates were produced by downloading and saving the activity data from the monitors using ActiLife software. This data is then processed by a macro that was used in the ALSPAC study, which produces a certificate with a personalised graph summarising the child's first day of activity. Parents/ guardians were told which date this graph represented. Each graph also had a red line which corresponds to 3600 counts/minute. It was explained to parents that any activity above this line on the graph shows when their child was moderately intense. Additional information on the current advice from the Department of Health was also given (i.e. that children should exercise at this level or higher for about an hour a day on average).

Any monitors that were worn but did not have enough valid data to produce a summary graph were sent a certificate without a graph on. The corresponding cover letter apologised and explained that unfortunately their child's monitor had problems in correctly identifying their child's activity.

- *How many children have been sent their feedback certificates?*

All 56 children that wore and have returned their activity monitors have been sent their feedback certificates.

- *How long after the activity monitor return date were the feedback certificates sent?*

The table below shows how many days after the activity monitors were returned (n=56) the feedback certificates were sent

Interval between receiving monitor back at ICH to sending feedback certificate (days)	No. of monitors	Percentage (%)
≤7	38	68
8 - 14	18	32
15 - 21	0	0
22 - 28	0	0

≥ 29 (4 weeks)	0	0
Total	*56*	*100*

- *Were there any complications sending the feedback certificates ?*

None.

7.2 Returned documents – feedback questionnaire

Parents/guardians were asked to complete and return the feedback questionnaire on the feedback certificate in the pre-paid envelope supplied.

How many parents/ guardians returned the feedback questionnaire?
At present, 16 out of 49 feedback certificates have been received.

7.3 Evidence from the feedback questionnaires

Responses from 16 feedback questionnaires have been logged into a password protected database, and the answers are shown below.

Q1. How easy or difficult did ***you*** *find it to understand the feedback certificate and the information leaflet?*

Very easy	8	50 %
Easy	4	25 %
Difficult	2	12.5 %
Very difficult	0	0 %
Missing	*2*	*12.5 %*
Total	*16*	*100 %*

Q2. How easy or difficult did ***your child*** *find it to understand the feedback certificate?*

Very easy	3	19 %
Easy	11	69 %
Difficult	0	0 %
Very difficult	1	6 %
Missing	1	6 %
Total	*16*	*100 %*

Q3. How interesting did ***you*** *find the feedback certificate?*

Very interesting	7	44 %
Interesting	7	44 %
Uninteresting	1	6 %
Very uninteresting	0	0 %
Missing	1	6 %
Total	*16*	*100 %*

Q4. How interesting did ***your child*** *find the feedback certificate?*

Very interesting	4	25 %
Interesting	8	50 %
Uninteresting	3	19 %
Very uninteresting	0	0 %
Missing	*1*	*6 %*
Total	*16*	*100 %*

*Q5. Did **you** find the feedback certificate and the information leaflet useful?*

Very useful	11	73 %
A little useful	3	19 %
Not at all useful	1	7 %
Missing	*1*	*6 %*
Total	*16*	*100 %*

Q6. Do you or your child have any other comments on the feedback certificate and the information leaflet?

As the certificate only shows one day activity out of the seven monitored it's hard to get a true figure, as it could be possible that the day covered was the least active of all days monitored.
Just wondered if the day you picked to show on the graph was the average, or the most active
I didn't understand how he was more active at 8pm when there were other times in the day where he was more active. There was no way that was the time when he was most active.
We were hoping for graphs showing all days, not just one. I was also hoping for a more detailed summary / interpretation of the graphs & an example of an average graph with which to compare. I think graphs should not be on the certificates, the dates should be eg from … to … Perhaps instead of a graph something saying you achieved …. counts per minute.
Unfortunately our certificate was unable to indicate how the trial had worked, due to the monitor he wore having problems identifying his activity, although it was nice to have it was of little real interest.
It was interesting to know that my daughter is getting quite a bit of exercise through the day. My daughter was pleased with her certificate.
We really enjoyed doing the whole thing. Thank you!
It would be interesting to see a printout for the activity levels for each of the 7 days instead of just one.

8. Conclusions and Recommendations for Main Stage

8.1 Acceptability

In general, the findings from the dress rehearsal study show a good degree of acceptability from parents and children in relation to the wearing of the physical activity monitor for the purposes of measuring activity levels .

At the interview nearly all parents/ guardians (87%) agreed and gave consent for their children to take part in wearing the activity monitor. Most (81%) children that were sent activity monitors packs took part by wearing the monitor.

The physical activity monitor was well received by most parents and children. Parents were interested in the idea of the physical activity measurement. Respondents and cohort children were very pleased to find this out that they would receive a feedback certificate summarising their child's activity over the week they wore the monitor.

There were mixed reactions to the idea of wearing the monitor from the cohort children. The majority had no problems with wearing it, and some were excited about the idea. Some, however, were worried about being picked on by their friends. The cohort children were more keen than their parents to know why they were wearing the monitor.

8.2 Feasibility

In general, the findings from the pilot study show that direct collection of children's physical activity levels using Actigraph physical activity monitors in cohort members is feasible. Previous studies such as ALSPAC have been based on subjects visiting a clinic where a trained interviewer fits and explains the activity monitor. The current pilot study shows that posting physical activity monitors to subjects can be a reliable and efficient way of obtaining valid data on children's activity levels.
Of the families that gave consent at the interview 69% have returned Actigraphs that satisfied the validity criteria (> 4 days with 10 hours recording). This included 19% that satisfied the validity criteria for seven days. The compliance achieved is comparable, and even higher than some levels reported in previous large fields studies that administer Actigraph's through clinic visits (Van Coevering, 2005).

8.3 Changes to documents

Prior to their interview families were sent a basic information leaflet explaining the physical activity project. At the interview children were asked if they would like to participate in wearing the monitor. Parents/ guardians that did agree to their child wearing the Actigraph were asked to sign a consent form. At the interview families were not given any documents, but were told that detailed information would be sent. Initial feedback from the interviewers was positive, but they suggested that they could be given copies to show parents in case they were interested. It is recommended that in the main stage interviewers are given laminated copies of the information leaflet, timesheet and the teacher letter.

8.3.1 Parent cover letter

In general, the parent cover letter was well received and all parents/ guardians said that they found the letter 'very easy' or 'easy' to understand.

The only suggested change to the cover letter for the main stage is that any information regarding the feedback questionnaire should be removed. In addition, it should be made clear that parents/ guardians will not be charged if they lose or damage the monitor, but that they should still ring ICH to let them know of the situation.

8.3.2 Information leaflet

The information leaflet was also positively received and all parents/ guardians found it 'easy' or 'very easy' to understand.

In addition, nearly all parents/ guardians were 'not confused at all' about when they had to start wearing the monitor, suggesting that the information sheet served its purpose. Only 7% of parents/ guardians said they were a 'little confused' as to when they should start wearing the monitor. Furthermore, nearly all were 'not confused at all' about when and how they were supposed to return the monitor.

There a few recommended changes to the information leaflet. Firstly, we suggest that any information regarding removing the activity monitor during vigorous activities should be removed as parents may interpret this in variable way and there is not objective reason for this. This would affect data validity dramatically, and the aim of the study is to monitor all physical activity, particularly vigorous activity. It is also recommended that any information regarding the flashing light being present when the monitor is on should be omitted from the information leaflet. This is because we now plan to disable the flashing light on the activity monitor for two reasons. Firstly, we would like to sample data at a higher frequency using 10 second epochs which is now recommended for children of this age so that sporadic bursts of activity can be captured. This shorter epoch requires more battery and is possible for the full 7 days with these latest models of accelerometers if the 'flashing light' setting is disabled. Secondly, it eradicates the problem of parents calling, and often worrying when monitors have unknowingly been sent without the flashing mode being enabled. The only function of the flashing mode is to show that the activity monitor is on, but by turning this off data collection is not affected. The final recommended change to the information leaflet is that it is made more personal by replacing 'the child' to 'your child' throughout.

8.3.3 Physical activity monitor and belt

Belt

Children were allocated different sized belts according to their waist measurement. Any children with a waist measurement of under 52cm were sent a small (24"/ 61cm) belt, and any children with a waist measurement of 52cm or over were sent a larger belt (32"/ 81.3cm). 18% of children had a waist measurement of less than 52cm, and 82% of children had a waist circumference of 52cm or larger.

Information received from the feedback questionnaire regarding the comfort, size and ease of wearing the activity monitor was conflicting. Most children found the activity monitor 'quite comfortable' to wear and 'the right size'. Furthermore, nearly all parents/ guardians stated that their child was able to put the belt on and take it off on their own. There were also several comments mentioning how happy their child was to wear the monitor, and that they had encountered no problems.

However, there were some negative findings regarding the belts. The main concern from the feedback questionnaires was that 14% of children of children found their activity monitor belt too big. All six children that did find their belt too big had been sent larger belts. However, their waist sizes ranged from 54cm – 64cm. A few families also commented that the strap dangled down and got in the way a bit, as well as saying that the monitor moved around quite frequently because the belt was too big.

To help make the belts more comfortable to wear, and to resolve any problems with the sizes of the belts it is recommended that the waist boundaries for the allocation of belt sizes be amended. The smaller belts should possibly be given to children with a waist measurement under 62cm, and children with a waist measurement of 62cm or larger should be given the larger sized belt.

Activity Monitor

An additional unanticipated issue with the activity monitor was regarding the USB port protectors. In six of the returned monitors the USB port protectors were missing. Three parents/ guardians also commented that the USB protector kept coming out. This is of particular concern because the protectors are needed in order to prevent any damage to data collection and download. It is recommended that spare protectors are purchased from Actigraph.

Another problem that occurred with the activity monitors was regarding the stickers that were put on the back of the monitors. Each monitor had an activity monitor ID number and a number to call if the monitor was found by anyone. Some families had tried to remove the stickers, despite being asked not to. It is suggested that the same information is put on anti- tamper labels which cannot be removed.

8.3.4 Timesheet and summary

Feedback regarding the timesheet from the initial interviews was positive, with parents understanding the importance of accurately recording the activities of the child. Although interviewers expressed doubts over whether parents would remember to fill the sheets in, all families returned their completed timesheets and nearly all families correctly filled in the timesheets.

Findings from the feedback questionnaire found that nearly all parents/ guardians found the timesheet 'very easy' or 'easy' to understand and complete, although two families did say that it was 'difficult' to understand and complete. Also, nearly all were either 'very confident' or 'confident' that the information on the timesheet was accurate. Furthermore, for those children that were at school during the monitoring period nearly all parents/ guardians felt that their child was able to provide the information needed to fill out the timesheet on days when they were at school.

Only two parents/ guardians felt 'unconfident' that the information on the timesheet was accurate, and two families stated that their children could provide only 'a little' or 'no' information to fill out the timesheet on days when they were at school. There were no further written comments regarding the timesheet.

The only recommended change to the timesheet is that the 'time spent in vigorous activities' column should be removed because it is now recommended that the monitor is worn during vigorous activities.

8.3.5 Letter for child's class teacher.

In general, the letter for child's class teacher was well received and all parents/ guardians said they found it 'easy' or 'very easy' to understand.

At the interviews there was some concern that the child wearing the activity monitor in class would pose an unwelcome burden for their teacher. However, the feedback questionnaire revealed that all of the teachers of children who wore the monitor during term time did allow them to wear the monitor. One family even commented that their child's teacher thought it was very exciting.

The majority of children who took part in the activity monitoring were on school holidays. As a result a few parents commented that the teacher letter was not necessary, and one parent even said that this confused her. It would, however, be extremely difficult to know when children are on holidays as term time varies by country as well as by school! It is recommended that all families continue to be sent the teacher letter, but it should be stressed on the information leaflet and also by interviewers that this letter is only needed during school term time.

No other recommended changes to the letter for the child's class teacher are to be made for the main stage.

8.3.6 Feedback questionnaire (activity monitor mailing)

We have received no negative comments regarding the feedback questionnaire. However, no feedback questionnaire will be sent during the main stage as we will no longer need information to aid the main stage design.

8.3.7 Feedback certificate

There were mixed responses from the feedback questionnaire regarding the feedback certificate.

Nearly all parents/ guardians (86%) and their children (93%) found the feedback certificate 'very easy' or 'easy' to understand. In addition, nearly all parents/ guardians (93%) and their children (80 %) found the feedback certificate 'very interesting' or 'interesting'. Furthermore, nearly all parents/

guardians (73%) found the feedback certificate and the information leaflet very useful.

Half of all parents that returned feedback forms recommended changes that would make the feedback certificate more useful. A few parents suggested that it would have been useful to see graphs for all the days that their child wore the monitor, because it could be possible that the day covered was the least active of all the days monitored. One parent recommended that the graphs should not be on the certificate as their child was not really interested in this.

It is recommended that children will continue to receive a feedback certificate. However, the format of this certificate will be revised. It is recommended that the following changes are considered:

1. Getting the certificate templates designed professionally.
2. Printing graphs on a separate page to the certificate.
3. Either; 1) producing a graph that summarizes the child's activity throughout the week, in addition to the graph summarising one day of activity, or 2) producing graphs for all days that the physical activity monitor was worn.

8.3.8 Cover letter to explain the feedback certificate

The feedback questionnaire revealed that nearly all parents/ guardians (73%) found the information leaflet useful.

As a result, it is therefore recommended that families still receive the cover letter which thanked participants for taking part in the activity monitoring and also explained the graphs. However, the appearance of the cover letter was not very professional. It is recommended that the cover letter is designed and printed professionally. Depending on the decision of which changes are to be made to the feedback certificate the content of the cover letter will need to be revised.

8.3.9 Feedback questionnaire (feedback certificate mailing)

We have received no negative comments regarding the feedback questionnaire for the feedback certificate mailing. However, no feedback questionnaire will be sent during the main stage as we will no longer need information to aid the main stage design.

8.3.10 Envelopes

Activity monitor mailing envelope

The physical activity monitor pack was sent out in an A4 windowed envelope. In order to prevent loss of activity monitors 'return to sender' information was pre-printed on the front of the envelope. It is recommended for practical reasons and to save time that in the main stage the envelopes will continue to be pre-printed with 'return to sender' information. A reasonable quote for the main stage envelopes has already been obtained from a printer.

The main stage activity monitor mailing will include the same enclosures as the dress rehearsal except for the feedback certificate. As the contents were quite bulky 'peel and seal' window envelopes were used to prevent any envelopes opening unnecessarily. These proved to be effective in preventing this, and therefore it is recommended that the same envelopes will be used in the main stage.

One unanticipated practical issue with the envelopes was the time consuming process of writing the department cost code and '1st class' on each envelope. It is therefore recommended that this information is pre-printed on the envelopes in addition to the 'return to sender' information. Alternatively, if this is not cost effective suitable self inking 'stampers' could be purchased.

Pre-paid envelope for returning activity monitor to ICH

All families returned the activity monitor and belt in the correct pre-paid envelope. The padded material suitably protected the activity monitors, and the size was suitable for returning all documents in addition to the activity monitors. This should therefore remain the same for the main stage.

Feedback certificate mailing envelope

The feedback certificate mailing was sent out in an A4 envelope. There were no reported problems with this and as a result this will remain the same for the main stage. It is recommended that a self inking 2nd class 'stamper' be purchased, in addition to a number 'stamper' for the department code to help save time on mailing procedures.

9. Conclusion

The dress rehearsal has shown a good degree of acceptability from parents and children in relation to wearing the physical activity monitor for the purposes of measuring activity levels. The current study also shows that posting physical activity monitors to subjects is a feasible way of obtaining valid data on children's activity levels. The lose rate of 17% of monitors with each issue is comparable with other studies. The data quality seems good by comparison with studies using fitting of monitors by trained staff. Given the importance of obtaining objective measurements of physical activity this seems a reasonable loss as alternative self report measures of activity are known to be unreliable. The current work provides sufficient confidence to recommend inclusion of accelerometers in main fieldwork pending funding.

APPENDICES

Appendix 1

The child first and always

Our Ref: «Serial_No»/ «Child_No»

«Main_title» «Main_forename» «Main_surname» and «Partner_title»
«Partner_forename» «Partner_surname»
«Address_line_1»
«Address_line_2»
«Address_line_3»
«Address_line_4» «Address_line_5»
«Postcode»

15 October 2012

Dear «Main_forename» and «Partner_forename»,

Child of the New Century - Age 7 Survey Pilot
Physical Activity Monitoring

Thank you very much for your help with this important part of the study.

Please find enclosed your physical activity monitor pack containing:

1. **information leaflet** - please take some time to read through this
2. **physical activity monitor and belt**
3. **timesheet** for you and your child to complete
4. **teacher letter** for you to fill in and give to your child's class teacher
5. **feedback questionnaire** for you and your child to tell us your views
6. **pre-paid envelope** for posting back the monitor and completed documents

Your child should start wearing the activity monitor tomorrow morning, and continue to wear it every day for 7 days.

Please return the activity monitor, belt, completed timesheet, and completed feedback questionnaire back to us in the pre-paid envelope as soon as possible after the 7 days. We will then send your child a certificate summarising their activity levels.

If you or your child no longer wish to take part in the activity monitoring, please return the monitor and belt in the pre-paid envelope provided. If the monitor is lost or damaged, please call Carly Rich on 020 7905 2691.

If you have any other questions or would like further information about this part of the study please call Carly Rich on 020 7905 2691.

Yours sincerely,

Heather Joshi

Professor Heather Joshi OBE
Study Director

Professor Carol Dezateux
Institute of Child Health

Carly Rich
Institute of Child Health

Appendix 2

enclosed feedback questionnaire. This is helpful for the design of the main stage of the survey.

When should I return the activity monitor and completed documents?
The activity monitors, belts, completed timesheet, and completed feedback form must be returned as soon as possible after the 7-day monitoring period is over. Enclosed is a pre-paid envelope to send them back in. You do not need a stamp. It is very important that the activity monitor is returned promptly. This is because we only have a limited number and the monitor will be sent to another family.

Please try not to lose or damage the activity monitor. However, if you do lose or damage the monitor, please call Carly Rich on 020 905 2691. We will not charge you to replace or repair it. We would still like you to return the monitor even if it is damaged.

What will happen to the information collected on the activity monitor?
The information will be treated in strict confidence in accordance with the Data Protection Act. The information you provide will be used solely to help with the design of the main survey.

Will I get any feedback about my child's activity levels?
Your child will receive a feedback certificate summarising their activity levels within 4 weeks of sending back the activity monitor.

How do I find out more about this part of the study?
This part of the study in being carried out in collaboration with the researchers at the Institute of Child Health, University College London. They are responsible for sending out the activity monitors and sending you feedback after the monitor has been returned to them. **If you have any other questions or would like further information about this part of the study, please call Carly Rich on 020 7905 2691.**

Thank you for your help

Child of the New Century
Age 7 Survey Pilot
Physical Activity Monitoring

We would like to measure your child's physical activity using an activity monitor. This leaflet explains more about the activity monitor and activity monitor documents.

What is the Actigraph activity monitor?
The activity monitor is a small, lightweight device that is worn around the waist on a belt. It is designed to measure physical activity by measuring and recording all your child's movements.

The activity monitor contains a spring which moves up and down when your child moves around. The movements of the spring are recorded onto a micro-chip inside the activity monitor. There is a flashing light on the activity monitor which indicates that it is on. You might have an on/off button on the activity monitor but these have been disabled. Nothing will happen if it is pressed.

On the back of your child's activity monitor is a number. This will be the same number that is on your child's timesheet. It would be helpful if you and your child could remember their activity monitor number. This is because another family member or friend might also be wearing a monitor and we do not want them to get mixed up. Please do not take the sticker off the monitor when you return it.

How should the activity monitor be worn?
The activity monitor is worn on a belt around the waist. The activity monitor should be positioned on the side of the hip (on top of the 'bony' part of the hip). The activity monitor should be fitted tightly but comfortably to your child's body. The belt can be adjusted to the correct fit. In order to accurately record you child's movement, it is important that the activity monitor only moves when your child's body moves. For this reason, it is essential that the activity monitor

should be fitted snugly against the child's body and not have any 'free movement' i.e. it should not be allowed to 'flop around'.

It should usually be worn on top of indoor clothing. If your child prefers he or she can also wear it against the skin underneath their clothing, though they may find that the belt rubs slightly on their skin or that the monitor feels cold. It should not be worn on top of outdoor clothing like coats. Finally, it doesn't really matter which way up the monitor goes.

When should my child start wearing the activity monitor?

Your child should start wearing the activity monitor on the morning after you receive it. It doesn't matter which day of the week your child starts on. The activity monitor is pre-programmed to turn on automatically at 5am in the morning of the second day after it is posted out. Unless the monitor has been delayed in the post, this should be the morning of the day after you receive it. When the monitor is turned on, a flashing light is visible on the monitor. **If this flashing light is not visible on the morning after you receive it, the monitor should not be worn and you should contact Carly Rich on 020 7905 2691.**

If the monitor has been delayed in the post, you may find that the monitor is already on when you receive it i.e. the flashing light is visible. That's fine. Your child should still start to wear it on the morning after it is received as normal. We will know from the timesheet when your child actually started wearing it. The monitor is not programmed to turn off on a particular date so it should remain on for seven days (even if there is a delay receiving it).

At what times should my child wear the activity monitor?

The activity monitor should be worn every day for 7 continuous days, and should be put on first thing in the morning as soon as the child gets up and worn until the child goes to bed. The activity monitor should not be worn during swimming or when the child is having a bath or shower. However, the monitors are shower proof so it doesn't matter if they get a little bit wet in the rain. In addition, if the child is taking part in extremely vigorous sports e.g. rugby where there is a danger that the monitor might injure someone or get damaged, they should take it off. We would like your child to behave just as they would normally.

What is the timesheet for?

You will be sent a timesheet and asked to keep a record of the dates that the activity monitor is worn, the time the activity monitor is put on in the morning and taken off at night and any periods that the monitor was not worn for any reason. In addition, any periods spent swimming, cycling, or playing vigorous sports should be recorded on the timesheet.

We want to record the time the child has spent swimming and playing vigorous sports as these are the only kinds of physical activity for which the monitor cannot be worn. We want to record the time the child has spent cycling because this kind of activity cannot be measured very accurately by the monitor (though it should still be worn during cycling). We would also like you to indicate whether or not the week that the child wore the activity monitor was a typical week in terms of their physical activity.

What about when my child is at school?

If your child receives their activity monitor during term time please encourage your child to wear it at school. We hope that most teachers will be happy for children to wear the monitors at school. A letter is enclosed for your child's class teacher which explains to them why your child is wearing the monitor. You should fill in the relevant details on the letter, including your child's activity monitor number which you can find on the back of the activity monitor or on the timesheet. We understand that you may not always know if the child has taken the activity monitor off when they are at school. If possible, it would be helpful if you could ask your child if they took the activity monitor off at school for any reason, and record this on the timesheet.

What is the feedback questionnaire for?

We would be very grateful if you could complete and return the

Appendix 3

Child of the New Century
Age 7 Survey Pilot
Physical Activity Monitoring

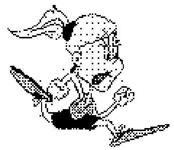
Child of the new Century

The child first and always

Summary of key points

Your child should wear the monitor...

- Every day for 7 continuous days starting the morning after received
- At all times from first thing in the morning to last thing at night - except when swimming, in shower or bath, or playing extremely vigorous sports
- On a belt around the waist
- On the right hip (on the 'bony' part of the hip)
- On top of indoor clothing (or against skin if preferred)
- Tightly but comfortably against body (not 'flopping around')



You should record on the timesheet (on the back of this form)...

- Dates that the monitor was worn
- Times monitor was put on in the morning and taken off at night
- Any periods spent swimming, cycling (the monitor should still be worn during cycling), or playing vigorous sports
- Any other periods when monitor not worn
- Whether typical week or not

You should also...

- Fill in and give the letter about the activity monitor to your child's class teacher
- Fill in the feedback questionnaire
- Return the activity monitor, belt, completed timesheet and completed feedback questionnaire **as soon as possible** after the 7 day period in the pre-paid envelope provided

We will...

- Send you a summary of your child's activity within 4 weeks after the monitor is sent back
- Treat the information recorded on the timesheet in strict confidence in accordance with the Data Protection Act.
- Answer any questions you may have. If you have any questions or problems with the monitor or timesheet, please call Carly Rich from the Institute of Child Health on 020 7905 2691.

Appendix 4

Child of the New Century
Age 7 Survey Pilot

Physical Activity Monitoring
Letter for Class Teacher

Dear ……………………………………………….

My child: ……………………………..……………

is taking part in the pilot study for the Age 7 Survey of the Child of the New Century study.

This is an important national survey which is exploring what it is like to grow up in the 21st Century by following around 19,000 children born in the UK in 2000/2001. The study is run by the Centre for Longitudinal Studies, a research centre in the Institute of Education, based at the University of London. The interviews are being carried out by the National Centre for Social Research (NatCen), an independent research organisation. Child of the New Century is paid for the ESRC (the government's Economic and Social Research Council) and other government departments from all countries of the UK.

We have already taken part in the pilot interviews for this study. The study also involves collecting information about my child's physical activity over a period of 7 days using an activity monitor. The activity monitor is a small, lightweight device that is worn around the waist on a belt. This part of the study is being carried out in collaboration with researchers at the Institute of Child Health (ICH), University College London.

I am writing to let you know that my child is wearing an activity monitor for 7 days for this research project. It is important that the monitor is worn at all times, including when he or she is at school. The only exceptions are during activities such as swimming, bathing or showering when the monitor will get wet and during extremely vigorous contact sports such as rugby where there is a danger that the monitor might injure someone or get damaged.

Thank you for your co-operation

My child's activity monitor number is………….

Name ……………………………………………………………………………………

Signed…………………………………………….. ***Date***………………………………………..

If you would like to know more about the Child of the New Century study, please contact the Centre for Longitudinal Studies on 0800 092 1250, or if you have any queries on the physical activity monitor please contact Carly Rich at the Institute of Child Health on 020 7905 2691.

Appendix 5

The child first and always

Child of the New Century – Age 7 Survey Activity Monitor Certificate

Thank you and your child very much for your help with this important part of the study. As a way of us saying thank you please find enclosed an activity certificate for your child. Please take some time to read through this leaflet as it will help you to understand the activity graph on your child's certificate, and also help you to explain the graph to your child.

Your Child's Activity Graphs

For You

- The graph on your child's certificate shows how active your child was from 5 o'clock in the morning until midnight, on one day of the week that they were wearing the activity monitor.
- The bars on the graph shows how active your child was at any particular time.
- When the bars are higher this shows when you child was more active, and when the bars are lower this shows when you child was less active.
- If there are no bars on the graph at certain times this is when they were not wearing the monitor (e.g. when they were asleep or when they forgot to wear the monitor).
- Any bars above the red line at 3600 counts/min show when you child's activity was moderately intense.
- Current advice from the Department of Health is that children should exercise at this level or higher for about an hour a day on average.

For You To Explain To Your Child

- See if your child can see when they first put the monitor on (the first time when the bars appear on the graph), and probably when they first got up.
- Ask your child to spot some points when the bars are higher (when they were most active).
- Your child might be able to pick out when they went to school or when they first went out (particularly if they walked), and also when they took part in any sports activities or had a PE lesson.
- They might also be able to see when they took part in anything else active such as playing with friends, taking the dog for a walk, or going shopping.
- Try to see if your child can spot some times when the bars on the graph are lower (when [they were doing inactive things).
- Your child might be able to spot times when they were sitting down (in class or at home), watching TV, having something to eat, or playing a computer game.

We would be very grateful if you could complete and return the enclosed feedback questionnaire in the pre-paid envelope. This is very helpful for the design of the feedback certificates in the main stage of the survey.
If you have any other questions or would like further information about this part of the study please call Carly Rich on 020 7905 2691.

Appendix 6

Timetable and Sample

Fieldwork (NatCen/ IOE)
It is anticipated that the timetable and sample characteristics for the main stage activity monitoring fieldwork will be as follows:

Wave	**Country**	**Estimated Dates of birth**	**Fieldwork period**	**Estimated Number of Issued Families**	**Estimated Number of Interviewed Families**	**Estimated Number of Children agreeing to Activity Monitor (assume 85% consent rate and apply multiplication factor of 1.014 for multiple births)**
E1	England	Sept 1 2000-February 28th 2001	January 21st 2008-June 6th 2008 (20 weeks)	5725	4725	4070
W1	Wales	Sept 1 2000-February 28th 2001	January 21st 2008-June 6th 2008 (20 weeks)	1275	1050	905
E2	England	March 1st 2001-January 11th 2002	March 31st 2008-September 12th 2008 (24 weeks)	5725	4725	4070
W2	Wales	March 1st 2001-January 11th 2002	March 31st 2008-September 12th 2008 (24 weeks)	1275	1050	905
S1	Scotland	Nov 24th 2000-Feb 28th 2001 (if started school in August 2005)	February 25th 2008-August 29th 2008 (26 weeks)	400	350	300
N1	Northern Ireland	Nov 24th 2000-July 1st 2001	February 25th 2008-August 29th 2008 (26 weeks)	900	755	650
S2	Scotland	March 1st 2001-January 11th 2002 (+any earlier births started school August 2006)	August 1st 2008-December 31st 2008 (22 weeks)	1700	1420	1225
N2	Northern Ireland	July 2nd 2001-Jan 11th 2002	September 1st 2008-December 31st 2008 (18 weeks)	900	755	650
TOTAL				17, 900	14,830	12,775

Laboratory Work (ICH)
However, the table below shows an estimated timetable with the aim of delivering activity monitors within 6 weeks of interviews.

Wave	Interviews	ICH Receives samples (+28 days)	ICH sends monitors (+7 days)	Monitors Returned (4 week cycle)	Feedback Certificate Sent (within 4 weeks)
E1	January 21st 2008- June 6th 2008 (20 weeks)	February 18th 2008 – July 4th 2008	February 25th 2008 – July 11th 2008	March 24th 2008 – August 8th 2008	April 21st 2008 – September 5th 2008
W1	January 21st 2008- June 6th 2008 (20 weeks)	February 18th 2008 – July 4th 2008	February 25th 2008 – July 11th 2008	March 24th 2008 – August 8th 2008	April 21st 2008 – September 5th 2008
E2	March 31st 2008- September 12th 2008 (24 weeks)	April 28th 2008- October 10th 2008	May 5th 2008 – October 17th 2008	June 2nd 2008 – November 14th 2008	June 30th 2008 – December 12th 2008
W2	March 31st 2008- September 12th 2008 (24 weeks)	April 28th 2008- October 10th 2008	May 5th 2008 – October 17th 2008	June 2nd 2008 – November 14th 2008	June 30th 2008 – December 12th 2008
S1	February 25th 2008-August 29th 2008 (26 weeks)	March 24th 2008 -September 26th 2008	March 31st 2008 – October 3rd 2008	April 28th 2008 - October 31st 2008	May 26th 2008 – November 28th 2008
N1	February 25th 2008-August 29th 2008 (26 weeks)	March 24th 2008 -September 26th 2008	March 31st 2008 – October 3rd 2008	April 28th 2008 - October 31st 2008	May 26th 2008 – November 28th 2008
S2	August 1st 2008- December 31st 2008 (22 weeks)	August 29th 2008-January 28th 2009	September 5th 2008 – February 4th 2009	October 3rd 2008 – March 4th 2009	October 31st 2008 – April 1st 2009
N2	September 1st 2008- December 31st 2008 (18 weeks)	September 29th 2008- January 28th 2009	October 6th 2008 – February 4th 2009	November 3rd 2008 – March 4th 2009	December 1st 2008 – April 1 2009

Appendix C: Published manuscript (seasonal review)

Seasonal variation in accelerometer-determined sedentary behaviour and physical activity in children: a review

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Abstract

Aim

To undertake a review of the methods and findings of published research evaluating the influence of season on accelerometer-determined sedentary behaviour (SB) and physical activity (PA) in children.

Methods

A literature search was carried out using PubMed, Embase, Medline and Web of Science up to, and including, June 2011. The search strategy focused on four key elements: children, SB or PA, season and accelerometer. Articles were eligible for inclusion if they were published in English, included healthy study participants aged ≤ 18 years, reported at least one outcome variable derived from accelerometer-determined measurements, and compared SB or PA between two or more seasons, or controlled for season of measurement. Eligible papers were reviewed and evidence tables compiled reporting on publication year, country studied, study recruitment, consent rate, sample descriptives, study design, accelerometer protocol, valid accelerometer data receipt, season definition, statistical methods and key findings.

Results

Sixteen of 819 articles were eligible for inclusion: children aged two to five years, six to twelve, or six to 18 years were included in five, six and five articles respectively. Six articles were from the UK, six from other European countries, three from the USA and one from New Zealand. Study sample sizes ranged from 64 to 5595. PA was reported in all articles but SB in only three. Only four studies were longitudinal and none of these reported SB. Seasonal variation in PA was reported in all UK studies, being highest in summer and lowest in winter. In four non-UK studies seasonal variation in PA was not found. Findings were inconclusive for SB.

Conclusion

There is sufficient evidence to support public health interventions aimed at increasing PA during winter in UK children. No conclusions can be drawn regarding the effect of season on children's SB reflecting few studies of small sample size, lack of repeat measures, incomparable definitions of season and inconsistent accelerometer protocols. Future research should determine factors that drive seasonal patterns in PA and SB in children such as age, sex, and geographic and climatic setting to inform interventions and target populations.

Keywords

Accelerometer, Season, Child, Physical activity, Sedentary Behaviour, Review

Introduction

Accelerometer-based measures of physical activity (PA) and sedentary behaviour (SB) are being increasingly obtained in large-scale studies to determine the level and pattern of children's PA and SB, their determinants and relation to health outcomes. Such studies can help to identify optimal patterns of activity associated with future health and well-being and inform interventions to help populations meet these optimal patterns. This is essential as there is increasing evidence that PA patterns are established in childhood [1], that maintenance of an active lifestyle in adult life is protective against many chronic diseases [2-4], and that - in children as well as in adults - levels of PA have declined with successive generations in developed countries and those in economic transition [5].

A season is a division of the year marked by changes in weather, ecology and hours of daylight which have the potential to influence PA and SB. Periods of low temperatures, high rain fall, strong winds and snow may reduce the likelihood of children being physically active. Although the meteorological factors associated with seasons cannot be changed, the ability to identify specific seasons that are characterised by low PA levels and/or high periods of SB is important for the design of future public health interventions aimed at promoting PA and reducing SB.

It is also important to account for seasonal influence on PA and SB as large-scale cross-sectional studies rely on measurements made in different individuals and in different seasons, potentially introducing bias in between-subject differences in the assessment of habitual activity levels.

While the influence of season on PA levels has been reviewed by others these have, for the most part, focussed on adults [6-8] rather than children, and the extent to which findings can be reliably extrapolated to children is uncertain. Furthermore, the only review to concentrate on children [9] did not focus on accelerometer-determined activity.

In recent years accelerometers have been regarded as the 'gold standard' method to examine PA in childhood populations [10,11], as reliance on self or parent proxy reports may overestimate PA levels [12]. Carson *et al.* [9], summarising data from 35 studies in children, reported that in the majority (83%) a seasonal variation in children's PA was found. However, studies based on accelerometer-determined activity were not reported separately, a number of major studies [13-19] published on this topic were omitted and the influence of seasonality on SB was not examined. As SB is not simply the absence of PA, but involves purposeful engagement in activities that involve minimal movement and low energy expenditure [20], seasonality may exert a different influence on SB than on PA in children.

We aimed to update and extend the review published by Carson *et al.* [9] by reviewing the influence of season on accelerometer-determined measures of PA and SB in children including studies published up to and including June 2011. The main purpose is to describe the current studies and their population coverage, critically appraise the study design and analytic methods used, and identify any significant gaps in evidence to inform public health guidelines and policy on optimal PA and SB levels in children.

Methods

Search strategy

We searched Embase, Medline, PubMed, and the Web of Science electronic databases (see search strategy illustrated in additional file 1). This search strategy focused on four key elements: children, PA or SB, season, and accelerometer. Further studies were identified by hand-searching the bibliographies of published reviews and all included studies.

Inclusion criteria

Studies were included if a full article was available, published in English, and included in the database from the year of inception up to and including June 2011 when the final searches were run. Any study or methodological design was included provided at least one outcome variable of PA or SB derived from accelerometer-determined measurements was reported, PA or SB were compared between at least two seasons, or adjustment was made for season of measurement. Articles were included if study participants, or a clearly defined subgroup, comprised children aged two to 18 years that were not selected on the basis of having a specific disease or health problem. Articles were not restricted according to study sample size or country of origin.

Data extraction and analysis

Eligible papers were reviewed and evidence tables compiled reporting on year of publication, country studied, recruitment procedure, consent rate, sample size, age range, sex distribution, study design (cross sectional vs. longitudinal), valid accelerometer data receipt (children providing accelerometer data meeting individual study definition of 'valid data'), definition of season employed, accelerometer protocol and outcome variables reported, statistical methods and key findings. The NHS Centre for Reviews and Dissemination [21] proposes a simple assessment to guarantee a minimum level of quality based on study design. However, a preliminary review of abstracts suggested that nearly all of the studies included in this review were observational studies and therefore poorly differentiated by this study hierarchy. Nevertheless, information relevant to the methodological quality of each article including the recruitment and sampling procedures, bias in consent and valid accelerometer data receipt are reported. The results of the review are presented as a qualitative review; no attempt has been made to synthesise statistical outcomes as the lack of uniformity across research methodology was too great to permit this.

Searches and abstract review

A total of 819 abstracts were identified by the final electronic searches (219 in PubMed, 157 in Embase, 134 in Medline and 309 in Web of Science), of which 585 were duplicates, leaving 234 unique articles (Figure 1). Of these, 158 were not relevant to the research objective and 46 did not meet inclusion criteria, leaving 14 review and 16 original research articles. No further articles were identified by hand-searching of bibliographies, leaving 16 articles to be included in the review. Of these 11 were found in three databases, two in two and three in one only. No articles were identified through Embase (Figure 1).

Figure 1 Flowchart of articles (*n* = 16) included in review. Flowchart reporting the total number of abstracts identified by the final electronic searches, and the number of these that were duplicates, did not meet the inclusion criteria, or were not relevant to the research objective. The number of reviews identified by the electronic searches and the final number of articles included in the review are also reported

Figure 2 Articles (*n* = 16) included in the review identified by each electronic database. Venn diagram showing the derivation of articles included in the review

Results

Overview of studies

Sixteen articles (Table 1) were identified that reported 13 different studies assessing seasonal variation in accelerometer-determined PA in children, and in three this included SB. The dates of publication ranged from 2002 [22] to 2010 [14] and date of data collection from 1997 [16,23] to 2007 [14,18,24,25]. Twelve authors reported studies from Europe [13-18,23,24,26-29] (including six from the UK), three from the USA [19,22,30], and one from New Zealand [25]. In 12 studies between-subject seasonal differences in PA were assessed [14-16,18,19,22,23,25,26,28-30], and in the remaining four within-subject differences were evaluated through repeated accelerometer measurements in the same individuals (referred to here as longitudinal studies) [13,17,24,27].

Table 1 Articles ($n = 16$) evaluating the influence of season on accelerometer-determined PA and SB in children

Authors: study name (if applicable)	Year; country, region	Method of recruitment	Study consent rate (%)	Sample [Size; gender; mean age (±SD)]	Period of data collection	Description of study	Accelerometer protocol (model; no. days wear; epoch; valid data; intensity cut points)	Valid accelerometer data receipt (%)	Season definition	Statistical methods	Main PA results	Main SB results	Finding of seasonal variation in PA	Finding of seasonal variation in SB
Bringolf-Isler *et al* [13]; The Swiss surveillance program on childhood allergy and respiratory symptoms	2009: Switzerland, Bern, Biel-Bienne and Payerne	Study	80.0	n=189: 81m, 88f; 6-7y, 9-10y & 13-14y (range)	Win 2004 & Spr/ Sum 2005	Within subject repeat measures in 2 seasons	Actigraph 7164; 7d wear; 60 sec epoch; Valid data:≥1d, ≥480min/d	86.0	Win: NS; Sum: NS	Mixed linear regression	No difference in PA(cpm) between win & sum (638 vs. 670 cpm; p>0.05)	NS	No	NS
Burdette *et al* [30]	2004: US, Ohio	Advertising	NS	*Total* n=214: *Spring sample*: n=28. *Summer sample*: n=39. *Autumn sample*: n=89. *Winter sample*: n=58; 122m, 92f; 44 (range 29-52)mth	Jul 2000-Jun 2001	Between subject measures in 4 seasons	Tritac R3D: 3d wear (inc. 2w/d & 1dw/e); 60 sec epoch; Valid data:NS	NS	Spr: Mar-May; Sum: Jun-Aug; Aut: Sep-Nov; Win: Dec-Feb	NS	No difference in PA (cpm) across 4 seasons (p>0.05): win PA tend to be lower (p=0.05)	NS	No	NS
Finn *et al* [22]	2002: USA, South Dakota	Childcare centre	NS	n=214; 106m. 108f; 3.93 (0.06)y	NS	Between subject measures in 2 seasons	Actiwatch AW16; 2d wear; 60 sec epoch; Valid data:NS; Vigorous:1000cpm	90.0	Sum: NS; Aut: NS	Forward-backward stepwise regression	No difference in total daily counts (p=0.28) or % time spent in vigorous PA (p=0.35) between sum & aut; higher PA in aut compared sum between 09:00 and 19:00 (159.9 vs. 131.2 cpm; p<0.05)	NS	Yes	NS
Fisher *et al* [26]; Study of Preschool Activity,	2005: Scotland. Glasgow	Study	NS	*Total* n=209; 101m. 108f; *Spring sample*: n=70: 40m, 30f;	Feb 2001-Jul 2002	Between subject measures in 4 seasons	Actigraph 7164; 3d wear (younger children), 7d wear (older	97.0	Spr: Feb-Apr; Sum: May-Jul; Aut: Aug-	ANOVA	*Total PA*: Lower PA in spr than sum (mean diff −125 cpm; p<0.001), aut (mean diff=118 cpm;	Seasonal differences in % time spent SB (p<0.001); Higher (p<0.05)	Yes	Yes

Lifestyle and Energetics				*Summer sample:* n=52; 24m, 28f; *Autumn sample:* n=41; 13m, 28f; *Winter sample:* n=46; 25m, 21f; 4.8 (1.2)y			children); Epoch: NS; Valid day: 360min/d; SB:<1100cpm, light:1100-3200cpm. MVPA: >3200cpm		Oct; Win: Nov-Jan		p<0.01), & win (mean diff=77 cpm; p<0.05), *Light PA:* Lower light PA (p<0.05) in spr than sum (mean diff=4.3% of monitored time) or aut (mean diff=2.8 % of monitored time) *MVPA:* Lower MVPA (p>0.05) in spr than sum (mean diff=4.3% of monitored time) & aut (mean diff=1.0% of monitored time)	in spr than sum (mean diff=4.8% of monitored time) or aut (mean diff=2.9% of monitored time)		
King *et al* [14]; Gateshead Millennium Study	2010: England, Tyne and Wear	Study	83.5	n=480; 244m; 236f; 7y	2006-2007	Between subject measures in 4 seasons	Actigraph 7164 & GT1M; 7d wear: 15 sec epoch; Valid number days:≥2d & 1d w/e: SB:<1100cpm, MVPA:≥3200cpm	94.7	Spr/ Aut: Mar- Oct; Sum: May-Aug; Win: Jan-Dec	Linear regression	PA (cpm) lower in win, & spr/aut than sum (β coefficient: 0.0033 to 0.058; p<0.001); MVPA lower in spr/ aut than sum (β coefficient: 0.087 to 0.208; p<0.001)	SB higher in spr/ aut & win than summer (-2.907 to -1.684; p<0.001).	Yes	Yes
Kolle *et al* [15]	2009: Norway, all regions	School	NS	*Total n*=1824: 940m, 884f; *Age 9y sample:* n=1127; 602m, 525f; *Age 15y sample:* n=697; 338m, 359f	Mar 2005-Oct 2006	Between subject measures in 3 seasons	Actigraph 7164; 4d wear (inc. 1d w/e); 10 sec epoch; Valid data:≥2d, ≥480min/d	79.0	Spr: 1 Mar-15 June; Aut: 1 Sep-30 Nov; Win: 1 Dec- 28 Feb	Linear regression	*Age 9y:* Higher in spr than win (diff girls: 188 cpm; CI: 112 to 265; p<0.001: diff boys: 121 cpm; 41 to 201; p=0.001) & aut (girls diff: 112 cpm; CI: 57 to 167; p<0.001: boys diff: 113 cpm; CI: 53 to 172; p<0.001) *Age 15y:* No differences in cpm between seasons (p>0.05)	NS	*Age 9y:* Yes; *Age 15y:* No	NS
Kristensen *et al* [23]; European Youth Heart Study	2008: Denmark, Odense	Study	*1997 sample Children:* 76.0; Adolescents: 65.0	*1997 sample Children:* n=377; 177m, 200f; 9.7 (0.4)y; Adolescents: n=232;	1997 & 2003	Between subject comparisons in 4 seasons in 2 groups of children (1997 &	Actigraph 7164; 5d wear; Epoch:NS; Valid data:≥3d, ≥600min/d	69.3	Spr: Mar-May; Sum: Jun-Aug; Aut: Sep-Nov; Win: Dec-	Linear regression	*Age 8-10y:* Highest PA (cpm) in spr than win & aut months in 1997 & 2003 (p<0.0001) *Age 14-16y:* No diff in PA(cpm)	NS	*Age 8-10y:* Yes; *Age 14-16y:* No	NS

			2003 sample Children: 57.6; Adolescents: 65.0	102m, 130f; 15.5 (0.5)y; *2003 sample: Children:* *n*=416; 179m, 237f; 9.8 (0.4)y; Adolescents: *n*=305; 134m, 171f; 15.8 (0.4)y;		2003)			Feb		between months in 1997 & 2003 (p=0.06)			
Mattocks *et al* [27]; Avon Longitudinal Study of Parents and Children	2007: England, Avon	Study	64.0	*n*=315; 148m, 167f; 11.65 (0.19)y	NS	Within subject repeat measures in 4 seasons	Actigraph 7164; 7d wear; 60 sec epoch; Valid data:≥3d, ≥600min/d;	*Season 1:* 90.0; *Season 2:* 86.0; *Season 3:* 81.0; *Season 4:* 78.0; *All 4 seasons:* 70.0	Spr: Feb-Apr; Sum: May-Jul; Aut: Aug-Oct; Win: Nov-Jan	ICC values	PA (cpm) highest sum & lowest win (diff: 93 cpm; p: NS)	NS	Yes	NS
Nilsson *et al* [16]; European Youth Heart Study	2009: Denmark (Odense), Portugal (Madeira) , Estonia (Tartu) & Norway (Oslo)	Study	NS	*n*=1954; 918m, 1037f; 9.7 (0.4)y & 15.5 (0.5)y	1997 & 2003	Between subject comparisons in 3 seasons in 2 groups of children (1997 & 2003)	Actigraph 7164; 4d wear (inc. 2 w/e); 60 sec epoch; Valid data:≥3d (inc. 1 w/d), ≥600min/d; SB:<100cpm, MVPA:≥2000cpm	NS	Spr: NS; Aut: NS; Win: NS	Repeat measures ANOVA (adjusted for season)	Adjusting for the season of measurement did not change PA (cpm & MVPA)	Adjusting for season of measurement did not change SB	No	No
Nyberg *et al* [17]; Stockholm Obesity Prevention Project	2007: Sweden, Stockholm	School	NS	*n*=97; 41m, 56f; *Baseline age:* 7.5 (0.92)y; *Follow-up age:* 9 (0.92)y	2002- 2005	Within subject repeat measures in 2 periods between 2002 - 2005	Actiwatch-4; 7d wear; 60 sec epoch; Valid data:≥4d , ≥600min/d	92.0	Dark: Oct-Mar; Light: Apr-Sept	Linear regression	Difference in PA (cpm) higher in dark followed by light measurements & light followed by light measurements than light followed by dark measurements (p=0.001& p=0.024, respectively)	NS	Yes	NS
Owen *et al* [18]; Child Heart and Health Study	2009: England, London, Birmingham and Leicester	Study	69.0	*n*=2144; 1029m, 1115f; 9.9 (range 9.2-10.7)y	Jan 2006-Feb 2007	Between subject comparisons across 4 seasons	Actigraph GT1M; 7d wear; 5 sec epoch; Valid data:≥1d, ≥600min/d	60.0	Monthly	Multilevel linear regression	PA (mean activity counts & cpm) higher in sum months than win months	NS	Yes	NS
Riddoch *et*	2007:	Study	93.0	*n*=5595;	Jan 2003-	Between	Actigraph 7164;	78.2	Spr: 1 Mar-	ANOVA	PA (cpm & MVPA)	NS	Yes	NS

al [28]; Avon Longitudin al Study of Parents and Children	England, Avon			2262m; 2933f 11.79 (SD 0.24)y	Jan 2005	subject comparisons across 4 seasons	7d wear; 60 sec epoch; Valid data:≥3d, ≥600min/d; MVPA: ≥3600cpm		31 May; Sum: 1 Jun-31 Aug; Aut: 1 Sep–30 Nov; Win: 1 Dec- 28 Feb		were highest in sum & lowest in win (p<0.001)			
Rowlands *et al* [24]	2009: England, southwest	School	NS	n=64; 32m, 32f; 9.9 (0.3)y	Jan/ Feb 2007 & Jun/ Jul 2007	Within subject repeat measures in 2 seasons	Actigraph GT1M; 6d wear; 2 sec epoch; Valid data:≥3d (w/d), ≥600min & ≥1d (w/d); ≥ 480min; Moderate & vigorous:Trost *et al* [32]	76.2	Sum: Jun-Jul; Win: Jan-Feb	Repeated measure ANOVA; ICC values	*Total PA:* PA (cpm & moderate PA) higher in sum than win for boys on w/e & w/d & higher for girls on w/e (p<0.05); PA (vigorous PA) higher in sum than win for boys on w/d (p<0.05) *PA bouts:* PA bout duration (light, moderate & vigorous) higher in sum than win (p<0.05) in boys; PA bout frequency & intensity (vigorous) higher in sum than win (p<0.05) in girls *Consistency of PA:* PA less seasonal variation in girls than boys when including w/d & w/e (girls ICC: 0.72- 0.90; boys ICC: 0.63- 0.68; all p<0.01)	NS	Yes	NS
Rundle *et al* [19]; New York City Head Start	2009: USA, New York	Study	NS	n=437; 213m, 224f; 50.7 (8.0)m	Jun 2003- Jan 2006	Between subject comparisons in 2 seasons	Actiwatch; 6d wear; 60 sec epoch; Valid data:NS	84.6	Sum: May-Sep; Win: Oct-Apr	Linear regression	PA (cpm) higher in sum than win (β coefficient: 87.04; p<0.001)	NS	Yes	NS
Taylor *et al* [25]; Family Lifestyle, Activity,	2008: New Zealand, Dunedin	Study	59.0	*Total n*=574; 319m, 255f; *Age 3y sample:* n=208;	2004- 2007	Longitudinal between subject measures between 3	Mini Mitter Actical; 5d wear; Epoch: NS; Valid data:≥3d,	*Age 3y sample:* 93.0; *Age 4y sample:* 86.0; *Age 5y sample:*	Spr: Sep-Oct; Sum: Nov-Feb; Aut: Mar-	Linear regression	*Age 3y:* PA (cpm) lower in spr than sum or win (p<0.001) *Age 4 & 5y:*	NS	*Age 3y:* Yes; *Age 4 & 5y:* No	NS

Movement and Eating Study				113m, 95f; *Age 4y sample:* n=180; 101m, 79f. *Age 5y sample:* n=186; 105m, 81f.		seasons at 3 different ages	length of day calculated from parental report;	96.0	May; Win: Jun-Aug		No difference in PA (cpm) across 3 seasons at 4y & 5y (p=0.974 & p=0.383, respectively)			
Wennlöf *et al* [29]; European Youth Heart Study	2005; Sweden, Örebro	Study	50.0	*Total n*=969; 471m, 498f; *Age 9y sample:* 9.5 (range 8.5- 10.3)y; *Age 15y sample:* 15.6 (range 14.7- 16.4)y	Spr 1999	Between subject comparisons in 3 seasons	Actigraph 7164; 3-4d wear; Epoch:NS; Valid data:≥1d; ≥600min/d;	69.0	Spr: Mar-May; Aut: Sep-Nov; Win: Dec-Feb	Three way ANOVA (age, sex, season)	PA (cpm) highest during Apr & May; Significant effect from month of measurement in cpm (p<0.001)	NS	Yes	NS

Abbreviations: n = sample size; m = males; f = females; y = years; mth = months; spr = spring; sum = summer; aut = autumn; win = winter; NS = not specified; Jan = January; Feb = February; Mar = March; Apr = April; Jun = June; Jul = July; Aug = August; Sep = September; Oct = October; Nov = November; Dec = December; d = days; min = min; sec = seconds; cpm = counts per min; SB = sedentary behaviour; MVPA = moderate and vigorous PA; w/d = weekday; w/e = weekend; PA = PA; RSK = rural Saskatchewan; OOM = Old Order Mennonite

Sample characteristics

The sample sizes for studies that used a repeated measures design ranged between 64 [24] and 315 [27], and between 209 [26] and 5595 [28] for studies examining seasonal differences between subjects. Children aged two to five years, six to 12 years, or six to 18 years were included in five [19,22,25,26,30], six [14,17,18,24,27,28] and five [13,15,16,23,29] studies respectively. In 13 articles a measure of weight status was reported [14-17,19,22-29] while in only four was ethnicity [18,19,22,30] or socioeconomic status [13,14,22,23] of the sample reported.

Accelerometer measurement protocol

The Actigraph was the most commonly used accelerometer by studies included within this review and there is extensive literature on its use to measure PA in children supporting its reproducibility, validity and feasibility in large samples of children [31]. In nine studies [13-16,23,26-29] the Actigraph 7164 were used, in two the Actigraph GT1M [18,24], in three the Actiwatch [17,19,22], with one study each for the Tritac R3D accelerometer [30] and the mini Mitter Actical accelerometer [25].

In thirteen (81%) articles authors reported the epoch selected; this was usually 60 seconds [13,16,17,19,22,27,28,30] with individual studies using shorter epochs, namely two [24], five [18], 10 [15], and 15 [14] seconds. Subjects were asked to wear the accelerometer for between two [22] to seven days [13,14,17,18,27,28], with most requesting seven days wear. The criteria used to determine number of days of accelerometer data per child required to characterise habitual activity were specified in 13 articles [13-18,23-25,27-29]: these ranged from one [13,18,29] to four days [17]. In five at least one weekend day was stipulated [14-16,24,30]. In eleven articles duration of wear in any single day was specified [13,15-18,23,24,26-29]: these ranged from at least 360 minutes (six hours) [26] to at least 600 minutes (ten hours) [16-18,23,27-29]. Moderate to vigorous PA (MVPA) was defined using a range of count values varying from 2000 [16] to 3600 [28] cpm. Vigorous PA was defined using Trost *et al.* [32] and a threshold of 1000 [22] cpm.

Main findings

A seasonal variation in PA levels was reported in all of the UK studies [14,18,24,26-28]. Mattocks *et al.* [27] evaluated seasonal and intra-individual variation of PA in 315 11 year old UK children by obtaining four repeat accelerometer measurements over a full calendar year and calculated intraclass correlation coefficient (ICC) values to determine the extent to which activities in different seasons vary. ICC values for variation in activity (cpm) over the course of the year increased from 0.49 to 0.53 after adjusting for month of measurement, indicating an effect of month. PA levels were higher in summer than winter [27]. Using a cross-sectional study design, Owen *et al.* [18] examined ethnic differences in mean daily PA (cpm) in a cross-sectional study of 144 11 year old UK children, adjusting for month of measurement: PA was higher in summer than winter and did not vary by sex [18]. Riddoch *et al.* [28] compared PA across all four seasons in 5595 11 year old UK children: PA levels (cpm and MVPA) were lowest in winter compared to summer ($n = 5595$).

Wennlöf *et al.* [29] compared the PA levels (cpm) of 969 nine and 15 year old Swedish children who were measured once only in spring, autumn, or winter and found that children were most active during April and May with a significant effect of month of measurement in total PA being observed. Rundle *et al.* [19] compared the activity levels of 437 four year old US children measured either during summer or winter and found season of measurement to be the strongest predictor of mean activity counts with children more active during summer than winter.

By contrast, no variation according to the season of measurement was found in four studies, none of these were carried out in the UK [13,16,22,30], and only one of which compared PA levels (cpm) across all four seasons [30] in 219 US children measured once throughout the year. Bringolf-Isler *et al.* [13] examined the association between PA (cpm) and socio-demographic and environmental characteristics, including season in a longitudinal study of 189 six to 14 year old Swiss children who were measured once in either winter or summer. Nilsson *et al.* [16] determined between- and within- day differences in total PA (cpm), and the daily time spent in MVPA in 1954 nine and 15 year old children from four European countries. They found that adjustment for season of PA measurement (autumn, winter and spring) did not alter their main findings. Finn *et al.* [22] also found no differences between summer and autumn total PA (cpm) and vigorous activity in 214 three to five year old US children.

In only three articles [14,16,26] was seasonal variation in children's SB evaluated: two from the UK [14,26], and all cross-sectional. Fisher *et al.* [26] compared total PA (cpm) and percentage time spent in SB, light PA, and MVPA across all four seasons in 209 Scottish children (mean age 4.8 years): children were more sedentary in spring than summer. King *et al.* [14] explored 22 potential correlates including season of total PA (cpm), MVPA and SB in 480 seven year old UK children and found that SB was higher in spring, autumn and winter compared to summer. In contrast, Nilsson *et al.* [16] reported that levels of SB in nine and 15 year old European children were not influenced by season of measurement (including only spring, autumn, and winter).

In three articles seasonal PA data were analysed separately for different age groups [15,23,25]. Kristensen *et al.* [23] compared PA levels (cpm) across all four seasons and reported an effect of age: season had less influence on 14 to 16 year olds than in eight to 10 year olds. Overall, European children were more physically active in the spring than in winter or autumn, with the exception of adolescents. Kolle *et al.* [15] compared PA levels (cpm) across spring, autumn, and winter, and found that season had less influence on PA in Norwegian 15 year olds than in Norwegian nine year olds: younger children were more active during spring than during winter and autumn, but the PA levels of 15 year olds did not vary by season. Taylor *et al.* [25] compared total PA (cpm) across all four seasons in New Zealand children at age three, four and five years. Seasonal variation in PA differed by age group: children were less active during spring than during summer or winter at three years, but these differences were not observed at four and five years.

Rowlands *et al.* [24] are the only authors to have considered the influence of gender on seasonal variation of PA. In a longitudinal study of only 64 nine to 11 year old UK children measured in only one of two seasons (summer and winter). Total PA (cpm) and moderate activity were higher during summer than winter for boys on weekend and weekdays, and higher for girls on weekend days. For boys, vigorous activity was higher during summer than winter on weekdays, while weekday activity was higher in summer than winter; for girls, weekend activity was higher in summer than winter. Rowlands *et al.* [24] are also the only authors to have assessed seasonal variation in PA patterns according to the frequency, intensity and duration of PA bouts (lasting greater than four seconds) of light, moderate, and vigorous intensity activity. They found that the mean duration of all intensity PA bouts was greater during summer than winter in boys, and the frequency and intensity of vigorous intensity PA bouts was greater during summer than winter in girls [24]. There are no reports of variation in PA or SB by ethnicity, socioeconomic status, weight status or region of residence.

Discussion

Key findings

In summary, seasonal variation in PA was reported in the majority of studies, particularly in children living in the UK, and in younger rather than older children. These seasonal differences were reported in all UK studies ($n = 6$), being highest during summer and lowest during winter. Findings from non-UK studies were inconsistent: seasonal variation in PA was reported in seven studies, but not in four. Findings from non-UK studies that were based in the same country were also inconsistent. For example, one US study reported higher levels of PA in summer than winter [19]; however, a different US study reported higher levels of PA in autumn than summer [22], and one found no association between season and PA levels [30]. Findings were inconclusive for SB and vigorous PA.

Strengths and limitations of review

This review identified a large number of potential studies obtained from a systematic literature search conducted in a range of databases. The broad definition of search terms and systematic search strategy should have enabled this review to detect as many potential studies as possible. Only studies with accelerometer-determined measurements of activity were included as they are currently regarded as the optimal method for measurement of PA and SB in population studies [33], providing greater accuracy and reliability than self-report methods [34]. This review provides the best summary to date of the evidence evaluating seasonal variation in accelerometer-determined PA and SB in children.

The heterogeneity in study samples, design, accelerometer protocols, statistical methods and outcome measures included in this review limited interpretation and meant that it was not possible to meta-analyse the results. The semi-quantitative reporting in this review provides only a somewhat arbitrary classification of seasonal variation with the focus on specifying seasons characterised by low or high activity rather than the strength of variation. Only one reviewer undertook the reviewing process and no robust indicator of methodological quality was provided due to the lack of uniformity across research methodology. A number of the articles have drawn data from the same cohort studies, for example the Avon Longitudinal Study of Parents and Children [27,28] and the European Youth Heart Study [16,23,29], which may introduce bias into the analysis sample. As this review was restricted to published studies only, publication bias may be present.

Strengths and limitations of studies

Limitations across the studies included small sample sizes, inconsistent study designs and accelerometer protocols, and the use of varied seasonal definitions and statistical methods. There were also few studies that employed a repeat measures study design, the most appropriate design allowing differentiation between seasons and between subjects. The studies included in the current review comprised geographically clustered samples, limiting the representativeness of their findings. Few studies evaluated seasonal variation in SB or in vigorous PA independently of total PA. There were also limited and conflicting evidence regarding sex and age effects on seasonal variation in PA therefore no conclusions can be reached on this.

However, there were a sufficient amount of UK studies conducted in a range of settings that reported consistent findings. In addition, only studies using accelerometers were included in this review because they provide more accurate estimates of volumes and intensities of PA than self-report measures [35]. However, there are limitations associated with the use of accelerometers including underreporting levels of cycling, and their inability to accurately measure swimming or load bearing activity. Despite recent advances in accelerometer design allowing researchers to select shorter epochs whilst still being able to measure for a sufficient number of days, a 60 second epoch was used in half the studies included in this review. Due to the sporadic nature of children's PA, longer epochs may be inappropriate when measuring PA and may underestimate levels of MVPA [36]. It has also been widely documented that the use of different thresholds to define activity intensities limits the ability for researchers to make reliable comparisons of MVPA levels between studies, and at present there is still no consensus on the best threshold to use [37].

Further research needed

Future studies of seasonal activity in children need to use large samples, employ a repeat measures study design, use comparable definitions of season, and use a consistent standardised approach to accelerometer measurement. This should include the use of a short epoch, presenting count data as well as minutes of MVPA, and also take into account activities that cannot be measured accurately by accelerometers.

Further research is also needed to understand seasonal variation in children's SB and vigorous PA independently of total PA so that public health interventions aimed at reducing SB and increasing vigorous PA can be targeted at specific times of the year. Recent evidence suggests that SB in children is associated with an elevated metabolic risk profile [38,39], elevated blood pressure [40], and increased body weight [41-46], independent of PA. Furthermore, participation in vigorous intensity PA appears more consistently associated with lower adiposity [47-49] than total PA [47,50], and this may even be independent of time spent in SB [43].

Seasonal variation in PA appears to be location specific; therefore additional research is needed in different countries and within different regions of larger countries. Characteristics that define seasons including the weather, ecology, and hours of daylight vary according to country, and even within different regions of large individual countries. For example, winter in the UK is different to winter in Norway in terms of weather and also available sunlight, and the weather in the US state of New York (Rundle *et al.* [19]) is characterised by cold, snowy winters and usually warm summers, whereas South Dakota (Finn *et al.* [22]) usually experiences cold winters and hot summers that can bring thunderstorms with high winds, thunder and hail.

Regional differences in seasonal variation may reflect variations in climate. As the meteorological factors associated with seasons in a specific region cannot be altered, there may be a role for future research to study other factors associated with variation of PA and

SB throughout the seasons. This will enable us to understand what encourages a child to be more or less physically active in specific seasons. For example, previous research [51] evaluating regional differences in pedometer-determined PA between urban and rural primary children living in Cyprus found an interaction between season and rural/urban regions: rural children were more active in summer, and urban children were more active in winter. To our knowledge, the only study evaluating seasonal differences in accelerometer-determined PA in rural and urban children is reported in a published abstract by Tremblay *et al.* [52]. The authors found that rural children were more active during summer and urban children more active in the winter.

Additional research is needed that examines possible interactions of season with other factors known to influence PA and SB such as sex, age, ethnic group, weight status and geographic location [53-56]. In contrast to Carson *et al.* [9], we found some evidence to suggest that season influenced children but not adolescents. This may be because adolescents have less free time to play outdoors than children; therefore, their PA is less influenced by fluctuations in daylight and weather. Adolescents are also more likely to participate in organised PA that takes place all year around [57]. Sex differences in PA across season may relate to the type of playground activities typically undertaken by boys and girls at school [24]. Boys undertake more vigorous activity during play time at school than girls and therefore warm summer weather may have more impact in the amount of PA that they undertake [57].

In the majority of studies identified for this review, authors reported a measurement of weight and several reported the ethnic composition of their sample; however, none determined whether seasonal variation in activity were associated with weight status', or ethnic group. Overweight children are less likely to be active than underweight children [58,59], and British South Asian children are less likely to be active than European whites and black African-Caribbeans [18,60-63]. It is possible that the influence of season on PA and SB may be enhanced in specific ethnic groups, or in overweight children compared to underweight children. It is important to identify factors that may cause or interact with seasonal effects in PA and SB, so that interventions can target certain groups of children.

Conclusion

From our review we suggest there is sufficient evidence to develop public health interventions to increase PA during winter in UK children. There is insufficient high quality evidence to suggest this for children living in other countries and this may reflect regional variations in climate as well as varying definitions of season. No conclusions can be drawn regarding the effect of season on children's SB or vigorous PA reflecting few studies of small sample size, lack of repeat measures, incomparable definitions of season and inconsistent accelerometer protocols. More research is needed to determine whether levels and patterns of vigorous PA and SB vary according to season utilizing a consistent standardised approach to accelerometer measurement, a repeated measures study design and in large geographically dispersed samples. Future research should be aimed at addressing the gaps in evidence identified in this review namely seasonal effects on SB and vigorous PA, and the determinants of seasonal patterns in PA such as age, sex, and geographic and climatic setting so that interventions can be season-specific and target inactive children.

Competing interests

The authors declared that they have no competing interest.

Authors' contributions

CR was responsible for the conception and design of the review, the literature search, critical appraisal of the included papers, and also drafted the manuscript. LJG and CD made substantial contributions towards the conception and design of the review and revising the manuscript. All authors read and approved the final manuscript.

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Additional files

Additional file_1_as DOC
Additional file 1: Literature search strategy. Literature search strategy used in electronic databases

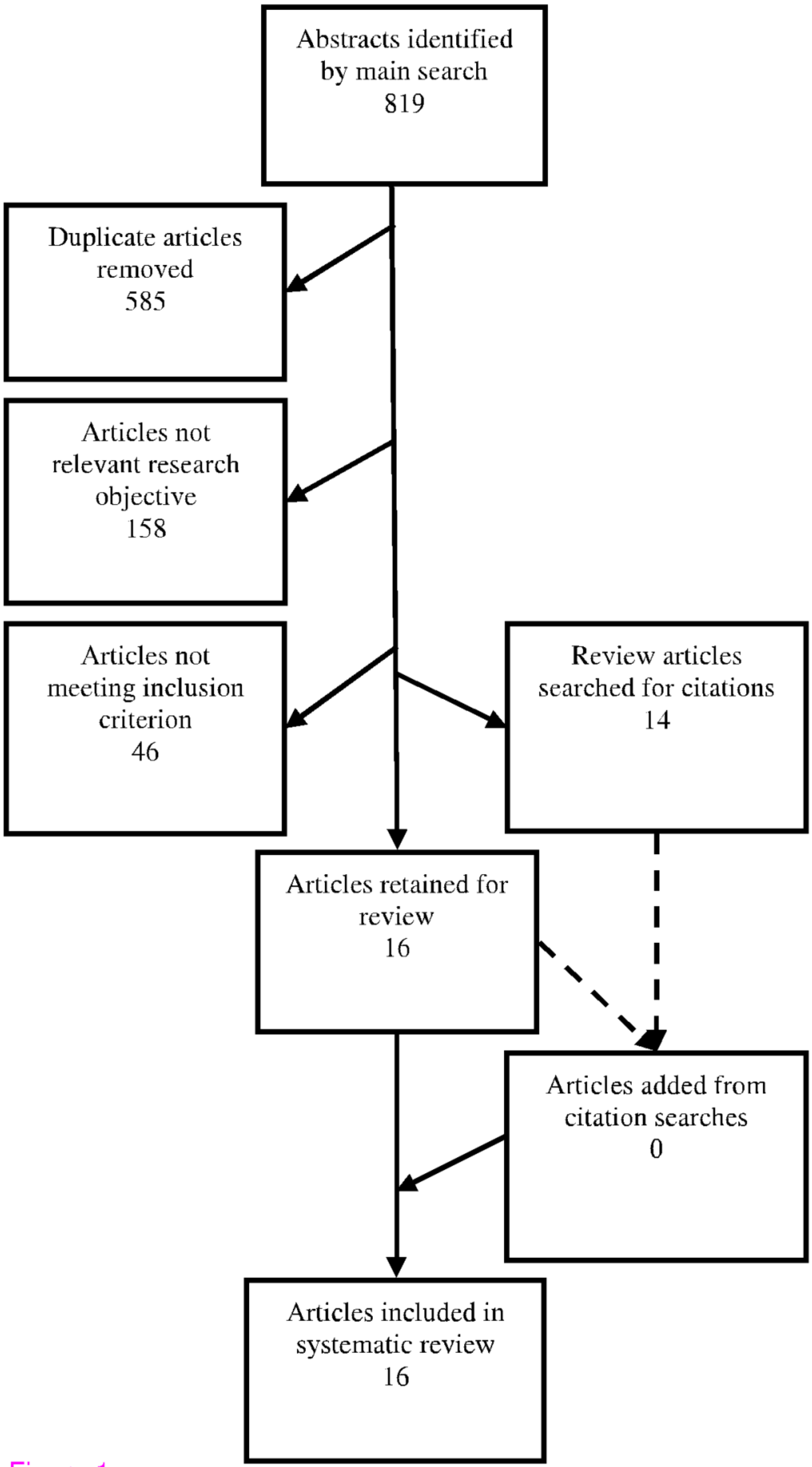
Abstracts identified by main search 819
Duplicate articles removed 585
Articles not relevant research objective 158
Articles not meeting inclusion criterion 46
Review articles searched for citations 14
Articles retained for review 16
Articles added from citation searches 0
Articles included in systematic review 16

Figure 1

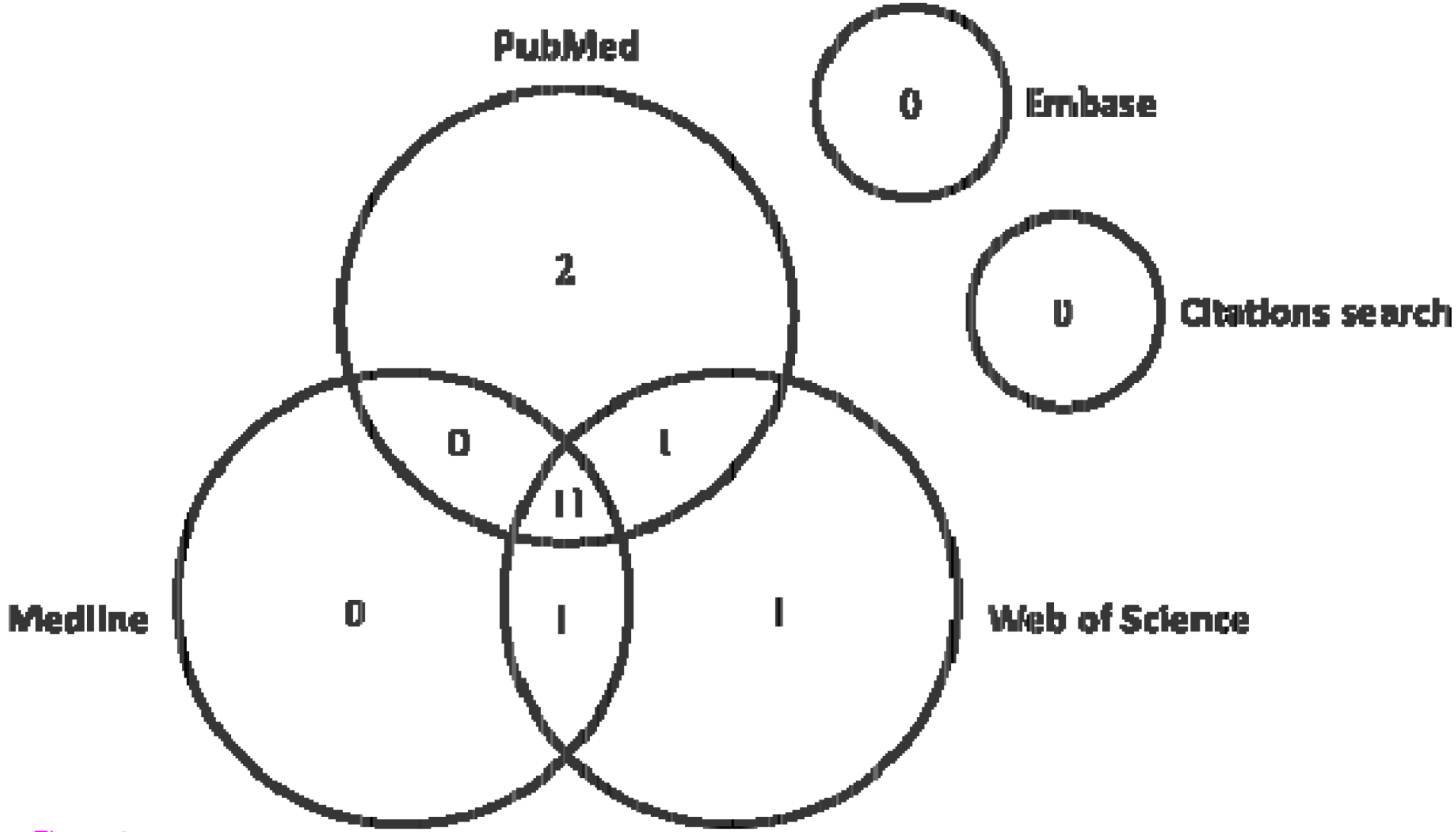
PubMed
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Figure 2

Appendix D: Published manuscript (predictors of non-response)

Open Access Research

BMJ open accessible medical research

Predictors of non-response in a UK-wide cohort study of children's accelerometer-determined physical activity using postal methods

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ABSTRACT

Objectives: To investigate the biological, social, behavioural and environmental factors associated with non-consent, and non-return of reliable accelerometer data (≥2 days lasting ≥10 h/day), in a UK-wide postal study of children's activity.

Design: Nationally representative prospective cohort study.

Setting: Children born across the UK, between 2000 and 2002.

Participants: 13 681 7 to 8-year-old singleton children who were invited to wear an accelerometer on their right hip for 7 consecutive days. Consenting families were posted an Actigraph GT1M accelerometer and asked to return it by post.

Primary outcome measures: Study consent and reliable accelerometer data acquisition.

Results: Consent was obtained for 12 872 (94.5%) interviewed singletons, of whom 6497 (50.5%) returned reliable accelerometer data. Consent was less likely for children with a limiting illness or disability, children who did not have people smoking near them, children who had access to a garden, and those who lived in Northern Ireland. From those who consented, reliable accelerometer data were less likely to be acquired from children who: were boys; overweight/obese; of white, mixed or 'other' ethnicity; had an illness or disability limiting daily activity; whose mothers did not have a degree; who lived in rented accommodation; who exercised once a week or less; who had been breastfed; were from disadvantaged wards; had younger mothers or lone mothers; or were from households with just one, or more than three children.

Conclusions: Studies need to encourage consent and reliable data return in the wide range of groups we have identified to improve response and reduce non-response bias. Additional efforts targeted at such children should increase study consent and data acquisition while also reducing non-response bias. Adjustment must be made for missing data that account for missing data as a non-random event.

ARTICLE SUMMARY

Article focus

- This paper investigates the biological, social, behavioural and environmental factors associated with non-consent and non-return of reliable accelerometer data (≥2 days lasting ≥10 h/day) in a UK-wide postal study of children's activity.

Key messages

- Consent was less likely for children with a limiting illness or disability, children who did not have people smoking near them or had access to a garden and children who lived in Northern Ireland.
- From those who consented, reliable data were less likely to be returned by boys, overweight/obese children, those who were not white, mixed or 'other' ethnicity, younger mothers, mothers without a degree, families with only one parent, households with just 1 or more than 3 children, children who lived in rented accommodation, had been breastfed or had a limiting illness or disability and children from disadvantaged wards.
- Children who exercised less than twice a week, according to the parent-proxy report of physical activity, were less likely to return reliable accelerometer data.

Strengths and limitations of this study

- This is the first large-scale accelerometer study using a postal distribution methodology to investigate the predictors of non-response associated with study non-consent and non-receipt of reliable data.
- A wide range of biological, social, behavioural and environmental factors are investigated as potential predictors of non-response. But our findings may not be directly applicable to different ages.

BACKGROUND

The development of accelerometers enables the frequency, intensity and duration of free-living activity to be measured objectively in large-scale population studies. The majority of previous large scale accelerometer studies have demonstrated the use of the activity monitor to participants and distributed them in the context of a face-to-face meeting within a clinic[1–3] or school setting.[4–17] Although effective, the cost and time constraints of this data collection method can be substantial, particularly in large studies where subjects are geographically dispersed. The use of postal methods to distribute and return accelerometers can achieve higher population coverage than face-to-face administering and return, while also potentially reducing time and financial costs. Despite this, there are no large-scale accelerometer studies in UK children that have used this method.

Although non-response is a problem for nearly all large-scale studies, the use of a postal methodology may increase data loss and potentially introduce bias into study findings. Lack of face-to-face contact with researchers may reduce motivation for participation, or involve uncertainty for participants relating to the accelerometer wear or return protocol. There is also a dependence on external factors such as an efficient postal service and relying on subjects to return their accelerometers.

Few studies have examined predictors of consent in large-scale accelerometer studies in children. In those available, only the effects of gender[17] and ethnicity[5] have been investigated. No large-scale accelerometer studies using postal distribution methods have evaluated predictors of consent, and only one has evaluated differences between children who did and did not return reliable data.[18] Gender, age and ethnic differences between children who did and did not provide reliable accelerometer data are well investigated in studies using face-to-face distribution methods,[3 5 10 13 16 18–22] but the findings are inconsistent, possibly due to differences in study design, accelerometer protocol or study populations. Further research is needed to determine the factors associated with non-response in large-scale studies using a novel postal distribution methodology. This would enable researchers to minimise non-response, and also reduce the effect of bias through modification of analytical methods (eg, weighting analyses to account for non-response). Therefore, the aim of this study was to investigate the biological, social, behavioural and environmental predictors of non-response resulting from study non-consent and non-return of reliable accelerometer data in a UK-wide postal study of children's activity.

METHODS

Study population

The Millennium Cohort Study (MCS) is a UK-wide prospective study of the social, economic and health-related circumstances of British children born in the new century.[23] All families who were claiming Child Benefit (all UK residents qualify for Child Benefit if they have children under 16 years) when their children were aged 9 months were eligible for sampling. A stratified clustered sampling design was employed to ensure an adequate representation of all four UK countries, disadvantaged areas and areas with high minority ethnic populations in England. The original cohort (MCS1) comprised 18 818 children (18 295 singletons; response rate 72%) whose parents were first interviewed at home when their child was aged 9 months.[24] Three further home interviews have been completed, at ages 3, 5 and 7 years. At age 7, accelerometers were used to measure children's activity. All children were invited to wear an accelerometer and written consent was obtained from the parents/guardians of those agreeing. Parents/guardians who gave consent were given an explanation on how their child should wear the accelerometer and were asked to demonstrate correctly putting a 'dummy' activity monitor on their child. Interviewers also explained how and when they should expect to receive their child's activity monitor, and how and when they should return the monitor.

Accelerometer protocol

Levels and patterns of physical activity (PA) were measured using the Actigraph GT1M uni-axial accelerometer (Actigraph, Pensacola, Florida). The Actigraph has been extensively validated in children against observational techniques,[25] heart rate telemetry,[26] indirect calorimetry[27] and energy expenditure measured by doubly labelled water.[28] A 15 s sampling epoch was selected in order to optimise the ability to capture the sporadic nature of children's activity.[29] Accelerometers were programmed using ActiLife Lifestyle Monitoring System software (V.3.2.11) to start collecting data at 05:00 2 days after posting. Accelerometers (attached to an elasticated belt) were posted together with a parent cover letter, an information leaflet, a timesheet, a letter for the child's class teacher and a prepaid envelope (for returning the accelerometer) to families via UK Royal Mail first class delivery. Families were asked to complete a timesheet to encourage accelerometer wear, recording the time the accelerometer was first put on in the morning and taken off at night, and any periods during the day when the accelerometer was not worn (including time spent swimming). Distribution occurred between May 2008 and August 2009. A free-phone telephone number was provided for families to call if they had any further questions. Families were sent translated versions of the documents if requested at the MCS home interview. Children were asked to start wearing their accelerometer the morning after they received it on their right hip for seven consecutive days during all waking hours, but were asked to remove it during all aquatic activities as these monitors are not waterproof. If children were unable to wear their accelerometer on the week requested, they were asked to return it so that it could be recharged and reprogrammed for a more convenient date.

Parents/guardians were asked to return the accelerometer and completed timesheet as soon as possible after the monitoring period in the prepaid envelope. On return of the accelerometer, families were sent a certificate and a set of graphs summarising their child's weekly activity, together with a letter thanking them for their involvement. Three postal reminder letters were sent at weekly intervals to those not returning their accelerometer within 3 weeks after issue. The third reminder letter included an additional prepaid envelope. Further weekly reminders were issued by text, email or phone call depending on the contact details held. A final reminder letter offered families a £10 incentive gift voucher for the return of their accelerometer.

Accelerometer data processing

Accelerometer data were processed using the package pawacc[30] developed in the R software environment for statistical computing (V.2.15.0).[31] Accelerometer non-wear was defined as any time period of consecutive zero-counts for a minimum of 20 min[5] and counts ≥11 715 counts/min were excluded as these values were regarded as extreme.[32] Children with a wear time period of ≥2 days lasting ≥10 h/day were considered to provide reliable data.[33] Full details on data processing are given in Geraci *et al*[34]

Statistical methods

All analyses were conducted in STATA/SE V.11.0 (Stata Corporation, Texas, USA) and weighted using MCS survey and non-response weights to account for attrition between contacts and adjusted to allow for the clustered sample design. All singleton children that took part in the fourth sweep of the MCS (MCS4) interviews were included in the analyses (n=13 681). Twins and triplets were not included in the analyses because data were unintentionally not coded to allow the interview and accelerometer data for twins (n=332) and triplets (n=30) to be accurately linked. Sample sizes and weighted percentages were calculated for the total sample, and stratified for consenting and non-consenting children, and for children who did and did not return reliable accelerometer data, according to the potential predictor variables. Potential predictor variables are reported in table 1, and were chosen based on prior research investigating non-response in previous large-scale accelerometer studies and the MCS4 interviews[35 36] so that we could determine if the sample was biased according to factors typically associated with PA in children.[24–26]

All potential predictor variables were entered into unadjusted logistic regression models. p Values were obtained from adjusted Wald tests. Multicollinearity was investigated to determine which variables were to be included in the adjusted logistic regression models because several of the variables reported similar concepts. This was achieved by examining the bivariate correlations between all potential predictor variables, and calculating the variance inflation factors (VIF). The VIF is an index that measures how much the variance of an estimated regression coefficient is increased because of collinearity.[38] VIF values were calculated using the formula $1/(1–R^2)$ after regressing each potential predictor variable against all other variables (where R is the correlation coefficient between two variables); VIF values greater than 2.5 are often considered a matter of concern.[38] Multicollinearity was evident between 'maternal occupation' (VIF=2.83) and 'whether the mother was in work or not' (VIF=2.54; correlation coefficient=0.78), and between 'government office region' (VIF=2.49) and 'country' (VIF=2.53; correlation coefficient=0.77). In each case, one of the pair of variables was removed from the model, one at a time, and the VIFs recalculated. The removal of 'mother in work or not' and 'government office region' reduced any signs of multicollinearity (ie, all variables had VIF<2.5).

All the remaining variables were entered into two separate adjusted logistic regression models to determine the predictors of data loss resulting from study non-consent and non-return of reliable data. p Values were obtained from adjusted Wald tests to determine differences between the regression coefficients.

RESULTS

Sample

A total of 14 043 children (13 681 singletons) took part in the fourth sweep of the MCS interviews (figure 1). Parents of 13 219 (94.1%) children (12 872 singletons) gave consent for their child to wear an accelerometer Accelerometers were sent to 12 625 (95.5%) consenting children (12 303 singletons); 29 (0.2%) children were not sent an accelerometer because the fieldwork team were unable to send it during the requested time period, and full contact details of the remaining 565 (4.3%) children were unavailable. We obtained reliable data (≥2 days lasting ≥10 h/day) from 6675 (50.5%) consenting children (6497 singletons). A total of 7004, 6326, 5910, 5153, 4002 and 2244 consenting children had ≥1, ≥3, ≥4, ≥5, ≥6 and ≥7 reliable days of data lasting at least 10 h/day.

CONSENT

Unadjusted analyses

Biological, social, behavioural and environmental factors were all associated with study consent (table 2). Pakistani/Bangladeshi children were almost half as likely to consent compared with white children. Several social factors were associated with non-consent including mothers not working, mothers without a degree (with the exception of those with no qualifications), households with only one child or an income of £10 400 or less, households that spoke another language apart from English, and children who did not have people smoking near them. Children with a limiting illness or disability were half as likely to provide study consent compared with those without a limiting illness or disability.

Table 1 Potential predictor variables used in analyses

Factor	Approximate age of MCS child at data collection	Level for analysis
Biological		
Child's gender	7 years	Male; female
Child's ethnicity*	7 years	White; mixed; Indian; Pakistani/Bangladeshi; black or black British; other
Child's body mass index (BMI) †	7 years	Underweight/ normal weight; overweight/ obese
Social		
Mother's age at birth (years)	9 months	14–19; 20–29; 30–39; ≥40
Maternal current occupation‡	7 years	Managerial & professional; intermediate; small employers & own account workers; lower supervisory & technical; semi- routine & routine; non-employed
Maternal highest academic qualification	7 years	Degree(s)/ post graduate diplomas; higher education/ teaching qualifications/ diplomas; A/ AS/ S-levels; O-levels/ GCSE grades A-C; GCSE grades D-G; other academic qualifications; none of these
Lone parent status	7 years	Non-lone parent; lone parent
Number of children in the household (including the cohort child)	7 years	1; 2–3; ≥4
Main household language	7 years	English only; English and other language; non-English speaking
Whether anyone smokes near the child	7 years	Yes; no
Whether the mother is in work or not	7 years	In work or on leave; not in work or leave
Main housing tenure	7 years	Own outright, own mortgage/loan, part own/mortgage; rent from local authority or housing association; rent privately; other
Type of accommodation	7 years	House or bungalow; flat or maisonette; studio, room, bedsit, other
Household income	7 years	<£10400; £10400–20800; £20800–31200; £31200–52000; >£52000
Behavioural		
Whether the child has any illnesses or disabilities that limits activity	7 years	Yes; no
Number of days a week the child participates in sport or exercise: parent report	7 years	≥3 days/week; 2 days/week; 1 day/week; less often/not at all
Number of hours the child watches TV on weekdays	7 years	Less than an hour/not at all; 1–3 h; 3–5 h; >5 h
Whether the child was ever breastfed	9 months	Yes; no
Environmental		
Access to garden	7 years	Yes; no
Ward type (at time of sampling) §	9 months	Advantaged; disadvantaged; ethnic
Government office region	7 years	North East; North West; Yorkshire and the Humberside; East Midlands; West Midlands; East of England; London; South East; South West; Wales; Scotland; Northern Ireland; Isle of Man/ Channel Islands
UK country	7 years	England; Wales; Scotland; Northern Ireland

*Categorised according to guidelines from the Office for National Statistics.[32]
† Defined using the International Obesity Task Force cut-off for BMI.[31]
‡Classified according to the National Statistics Socio-economic Classification.[33]
§Wards classified as ethnic if at least 30% of residents were from an ethnic minority group (in the 1991 census), disadvantaged if above the upper quartile of the Child Poverty Index[37] and the remaining were advantaged (no ethnic stratum in Wales, Scotland and Northern Ireland[24]).

Children who exercised less than once a week or had never been breastfed were also less likely to provide consent. Consent was also less likely for children from ethnic wards, or those who lived in Yorkshire and Humberside, London or Northern Ireland.

Adjusted analyses

After controlling for other predictor variables, consent remained significantly less likely for children who did not have people smoking near them and children with an illness or disability that limited daily activity (table 2).

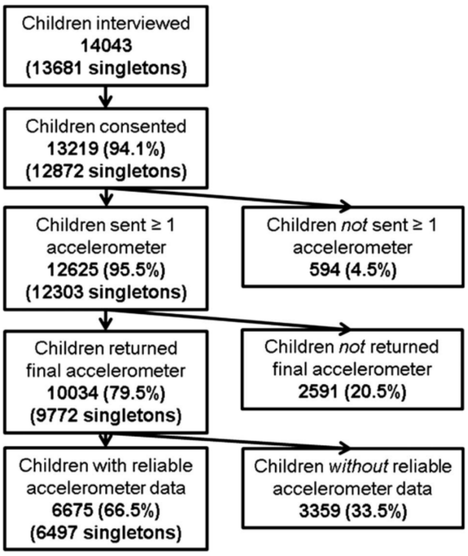

Figure 1 Summary of children in the Millennium Cohort accelerometer study.

Consent was also less likely for children who had access to a garden, and those who lived in Northern Ireland.

RELIABLE DATA ACQUISITION

Unadjusted analyses

All variables in the unadjusted models were associated with reliable data acquisition except residential country (table 3). Within the sample who consented and were sent accelerometers, we were less likely to receive reliable data from boys, overweight/obese children and those who were not white or 'other' ethnicity. The social factors associated with non-return of reliable data included younger mothers (<30 at birth of cohort child), mothers not in managerial, professional, lower supervisory or technical occupations, or not educated to degree level, households with just one, or four or more children, or who spoke English and another language, children who had people smoking near them, or who lived in a flat or maisonette, and families who did not own their own home or had a household income of less than £31 200. Lone parents were half as likely to return reliable accelerometer data compared with two parent families. We were also less likely to acquire reliable accelerometer data from children with a limiting illness or disability, those who exercised 1 day a week or less, or watched TV for 3–5 h on weekdays or who had been breastfed. We were also less likely to acquire reliable data from children without access to a garden, children from disadvantaged or ethnic wards, and those who lived in North East or North West England, Yorkshire and Humberside, West Midlands, London, Wales, Scotland or Northern Ireland.

Adjusted analyses

After controlling for other predictor variables, reliable accelerometer data acquisition was significantly less likely from boys, overweight/obese children and those who were not white, mixed or 'other' ethnicity (table 3). More social factors remained significantly associated with non-return of reliable data than with consent including younger mothers (<30 at birth of cohort child), mothers without a degree (excluding those with 'other' qualifications), lone parent families, households with just one, or four or more children and children that lived in any type of rented accommodation. We were also less likely to acquire reliable data from children with a limiting illness or disability, children who exercised once a week or less or had been breastfed and children from disadvantaged wards.

DISCUSSION

Summary of findings

In this nationally representative cohort of UK children, a high proportion of families (94.1% of children interviewed; n=13 219) agreed to take part in a study that used postal methods to distribute and return accelerometers in order to measure children's PA. The use of a postal methodology enabled the MCS to acquire a large volume of reliable accelerometer data (n=6675; 51% of consenting children).

A number of different factors were associated with study non-consent and non-return of reliable accelerometer data in a nationally representative cohort of UK children (table 4). More differences were observed for the return of reliable data than in the consent to participate, quite likely to be due to the very high consent rate. In particular, a number of biological and social factors were related to non-return of reliable data that were not associated with non-consent. Social disadvantage was more apparent in children who did not return reliable data than in non-consenting children.

Comparisons with existing research

Few accelerometer-based studies of children's PA have investigated correlates of consent.[5,17] Van Sluijs *et al*[17] and Owen *et al*[5] investigated gender differences between children who consented to wearing an accelerometer in two large-scale studies. In contrast to our study, girls were more likely to consent than boys in the Sport, Physical activity and Eating behaviour: environmental Determinants in Young people (SPEEDY)[17] study, whereas Owen *et al*[5] found no ethnic differences between consenting and non-consenting children participating in the Child Heart Health Study in England.

Only one large-scale study using postal methods to distribute and return accelerometers has investigated predictors of reliable data acquisition.[18] Janz *et al*[18] found

Table 2 Weighted percentages and sample sizes for total singletons interviewed (n=13 681), consenting (n=12 872) and non-consenting singletons (n=809), adjusted and unadjusted ORs (95% CI) and p values for predictors of consent

	Weighted % (n)			Unadjusted regressions		Adjusted regression	
	Interviewed	Consenting	Non-consenting	OR (95% CI)	p Value	OR (95% CI)	p Value
All	100.0 (13681)	94.5 (12872)	5.5 (809)				
Biological							
Child's gender							
Male	51.4 (6950)	94.7 (6541)	5.3 (409)	1.07 (0.90 to 1.28)	0.442	1.10 (0.91 to 1.32)	0.318
Female	48.6 (6731)	94.4 (6331)	5.6 (400)	1		1	
Child's ethnicity							
White	85.5 (11373)	95.1 (10745)	4.9 (628)	1		1	
Mixed	3.2 (367)	91.9 (345)	8.1 (22)	0.59 (0.32 to 1.08)		0.57 (0.30 to 1.10)	0.093
Indian	1.9 (339)	91.8 (316)	8.2 (23)	0.58 (0.35 to 0.96)	0.089	0.91 (0.45 to 1.84)	0.793
Pakistani/Bangladeshi	4.7 (869)	92.1 (794)	7.9 (75)	0.61 (0.45 to 0.82)	0.001	1.06 (0.67 to 1.70)	0.779
Black or Black British	3.2 (446)	92.8 (411)	7.2 (35)	0.67 (0.41 to 1.09)	0.103	0.64 (0.36 to 1.14)	0.126
Other	1.4 (186)	92.4 (173)	7.6 (13)	0.63 (0.32 to 1.26)	0.190	1.06 (0.49 to 2.26)	0.884
Child's BMI							
Under/normal weight	79.9 (10582)	94.9 (10011)	5.1 (571)	1	0.313	1	0.802
Overweight/obese	20.1 (2759)	94.4 (2583)	5.6 (176)	0.90 (0.74 to 1.10)		0.97 (0.79 to 1.20)	
Social							
Mother's age at birth (years)							
14–19	8.5 (1005)	93.9 (940)	6.1 (65)	0.87 (0.61 to 1.26)	0.468	1.01 (0.69 to 1.48)	0.962
20–29	45.4 (6103)	94.7 (5752)	5.3 (351)	1.02 (0.87 to 1.19)	0.844	1.14 (0.95 to 1.36)	0.159
30–39	43.4 (6184)	94.6 (5817)	5.4 (367)	1	0.215	1	0.983
≥40	2.7 (389)	93.0 (363)	7.0 (26)	0.75 (0.48, 1.18)		1.01 (0.59 to 1.73)	
Maternal occupation							
Managerial and professional	22.5 (3173)	95.4 (3018)	4.6 (155)	1		1	
Intermediate	12.9 (1746)	95.7 (1666)	4.3 (80)	1.08 (0.73 to 1.58)	0.707	1.21 (0.80 to 1.85)	0.371
Small employers and own account workers	5.8 (751)	95.5 (716)	4.5 (35)	1.03 (0.68 to 1.55)	0.885	1.15 (0.74 to 1.77)	0.533
Lower supervisory and technical	2.7 (345)	95.7 (328)	4.3 (17)	1.08 (0.62 to to 1.88)	0.797	1.26 (0.67 to to 2.38)	0.467
Semiroutine and routine	18.1 (2385)	94.8 (2248)	5.2 (137)	0.88 (0.64 to 1.21)	0.433	1.03 (0.73 to 1.46)	0.847
Non-employed	37.9 (4993)	93.3 (4628)	6.7 (365)	0.68 (0.53 to 0.88)	0.003	0.79 (0.60 to 1.07)	0.119
Maternal academic qualification							
Degree(s)/postgraduate diplomas	18.6 (2756)	95.5 (2623)	4.5 (133)	1		1	
Higher education/teaching qualifications/diplomas	11.4 (1592)	94.9 (1512)	5.1 (80)	0.88 (0.63 to 1.22)	0.441	0.81 (0.56 to 1.17)	0.265
A/AS/S-levels	9.2 (1299)	94.9 (1231)	5.1 (68)	0.88 (0.61 to 1.25)	0.467	0.84 (0.56 to 1.26)	0.390
O-levels/GCSE grades A-C	32.0 (4219)	94.6 (3958)	5.4 (261)	0.83 (0.63 to 1.10)	0.191	0.81 (0.57 to 1.13)	0.217
GCSE grades D-G	11.0 (1396)	94.2 (1308)	5.8 (88)	0.77 (0.52 to 1.13)	0.182	0.72 (0.47 to 1.10)	0.129
Other academic qualifications	2.5 (358)	93.3 (335)	6.7 (23)	0.66 (0.39 to 1.10)	0.109	0.73 (0.43 to 1.24)	0.247
None of these	15.3 (2057)	93.3 (1902)	6.7 (155)	0.66 (0.48 to 0.91)	0.012	0.91 (0.61 to 1.35)	0.632
Lone parent status							
Non-lone parent	77.3 (10785)	94.7 (10157)	5.3 (628)	1		1	
Lone parent	22.7 (2896)	94.0 (2715)	6.0 (181)	0.87 (0.72 to 1.05)	0.151	1.01 (0.78 to 1.29)	0.916

Continued

Table 2 Continued

	Weighted % (n)			Unadjusted regressions		Adjusted regression	
	Interviewed	**Consenting**	**Non-consenting**	**OR (95% CI)**	**p Value**	**OR (95% CI)**	**p Value**
Number of children in the household							
1	13.3 (1771)	92.9 (1649)	7.1 (122)	0.73 (0.59 to 0.90)	0.004	0.82 (0.64 to 1.05)	0.110
2–3	72.9 (9886)	94.8 (9325)	5.3 (561)	1		1	
≥4	13.8 (2024)	95.0 (1898)	5.0 (126)	1.05 (0.82 to 1.35)	0.695	1.30 (0.99 to 1.71)	0.062
Household language							
English only	89.8 (11786)	94.9 (11127)	5.1 (659)	1		1	
English and other	9.6 (1796)	91.3 (1656)	8.7 (140)	0.56 (0.43 to 0.72)	0.000	0.68 (0.46 to 1.00)	0.052
Non-English speaking	0.5 (99)	86.7 (89)	13.3 (10)	0.35 (0.14 to 0.89)	0.027	0.45 (0.16 to 1.31)	0.145
Whether anyone smokes near the child							
No	86.4 (11837)	94.4 (11126)	5.6 (711)	1		1	
Yes	13.6 (1759)	95.8 (1672)	4.2 (87)	1.37 (1.03 to 1.82)	0.031	1.37 (1.02 to 1.84)	0.037
Whether mother is in work or not						NA	NA
In work or leave	61.6 (8511)	95.2 (8077)	4.8 (434)	1	0.000		
Not in work or leave	38.4 (5170)	93.4 (4795)	6.6 (375)	0.71 (0.60 to 0.84)			
Main housing tenure							
Own outright to full or part loan/mortgage	63.1 (8996)	94.6 (8475)	5.4 (521)	1	0.577	1	0.197
Rent from local authority or housing association	24.9 (3092)	94.3 (2900)	5.8 (192)	0.93 (0.72 to 1.20)		1.23 (0.90 to 1.70)	
Rent privately	9.8 (1177)	95.8 (1118)	4.2 (59)	1.30 (0.94 to 1.80)	0.111	1.49 (1.01 to 2.20)	0.045
Other	2.2 (277)	92.3 (258)	7.7 (19)	0.68 (0.38 to 1.21)	0.188	1.07 (0.59 to 1.94)	0.836
Type of accommodation							
House or bungalow	89.9 (12436)	94.6 (11708)	5.4 (728)	1		1	
Flat or maisonette	9.7 (1175)	94.5 (1101)	5.5 (74)	0.99 (0.70 to 1.41)	0.952	1.05 (0.65 to 1.68)	0.853
Studio, room, bedsit, other	0.4 (49)	99.7 (48)	0.3 (1)	17.2 (2.78 to 106.5)	0.002	NA	NA
Household income							
<£10400	13.1 (1733)	92.6 (1603)	7.5 (130)	0.56 (0.39 to 0.80)	0.001	0.73 (0.46 to 1.16)	0.185
£10400–£20800	26.8 (3794)	94.6 (3561)	5.4 (233)	0.78 (0.58 to 1.06)	0.113	1.02 (0.71 to 1.49)	0.896
£20800–£31200	23.1 (3234)	94.4 (3035)	5.6 (199)	0.76 (0.57 to 1.00)	0.052	0.99 (0.72 to 1.37)	0.929
£31200–£52000	24.9 (3359)	95.2 (3183)	4.8 (176)	0.88 (0.64 to 1.22)	0.451	1.00 (0.71 to 1.42)	0.996
>£52000	12.2 (1541)	95.7 (1474)	4.3 (67)	1			
Behavioural							
Disability or illness that limits activity							
No	93. 2 (12783)	94.8 (12066)	5.2 (717)	1		1	
Yes	6.8 (898)	90.8 (806)	9.2 (92)	0.54 (0.41 to 0.71)	0.000	0.65 (0.47 to 0.90)	0.010
Frequency of sport or exercise							
3 or more days/week	19.9 (2705)	95.7 (2575)	4.4 (130)	1		1	
2 days/week	20.8 (2829)	95.7 (2693)	4.3 (136)	1.02 (0.76 to 1.38)	0.899	1.12 (0.82 to 1.52)	0.486
1 day/week	26.1 (3592)	94.7 (3383)	5.4 (209)	0.80 (0.61 to 1.07)	0.132	0.87 (0.65 to 1.19)	0.387
Less often or not at all	33.2 (4485)	93.1 (4161)	6.9 (324)	0.62 (0.46 to 0.82)	0.001	0.77 (0.55 to 1.06)	0.110
Hours per weekday child watches TV							
Less than an hour/not at all	19.3 (2684)	94.8 (2524)	5.2 (160)	1		1	
1–3 h	64.8 (8748)	94.3 (8227)	5.7 (521)	0.91 (0.72 to 1.14)	0.415	0.90 (0.70 to 1.16)	0.425

Continued

Table 2 Continued

	Weighted % (n)			Unadjusted regressions		Adjusted regression	
	Interviewed	**Consenting**	**Non-consenting**	**OR (95% CI)**	**p Value**	**OR (95% CI)**	**p Value**
3–5 hours	11.1 (1462)	95.9 (1388)	4.1 (74)	1.30 (0.92 to 1.83)	0.136	1.37 (0.97 to 1.93)	0.073
>5 h	4.8 (711)	94.9 (669)	5.1 (42)	1.02 (0.66 to 1.56)	0.932	1.14 (0.72 to 1.81)	0.581
Child ever breastfed							
No	33.6 (4394)	93.6 (4075)	6.4 (319)	0.77 (0.64 to 0.93)	0.006	0.88 (0.72 to 1.09)	0.236
Yes	66.5 (9287)	95.0 (8797)	5.0 (490)	1		1	
Environmental							
Access to garden							
No	7.4 (905)	95.6 (857)	4.4 (48)	1.27 (0.90 to 1.81)	0.178	1.70 (1.01 to 2.85)	0.045
Yes	92.6 (12755)	94.5 (12000)	5.5 (755)	1		1	
Ward type							
Advantaged	56.7 (5693)	95.1 (5408)	4.9 (285)	1		1	
Disadvantaged	37.0 (6326)	94.0 (5924)	6.0 (402)	0.80 (0.62 to 1.05)	0.103	0.89 (0.66 to 1.21)	0.466
Ethnic	6.3 (1662)	92.2 (1540)	7.8 (122)	0.60 (0.46 to 0.80)	0.000	0.75 (0.48 to 1.17)	0.211
Government office region							
North East	3.6 (395)	93.4 (368)	6.6 (27)	0.42 (0.16 to 1.06)	0.065	NA	NA
North West	10.8 (1125)	94.8 (1063)	5.2 (62)	0.54 (0.28 to 1.03)	0.062		
Yorkshire and the Humberside	8.9 (1013)	92.5 (938)	7.5 (75)	0.36 (0.18 to 0.73)	0.005		
East Midlands	7.3 (734)	95.3 (705)	4.7 (29)	0.60 (0.27 to 1.37)	0.226		
West Midlands	8.0 (1009)	95.7 (958)	4.3 (51)	0.66 (0.32 to 1.34)	0.245		
East of England	9.3 (971)	96.7 (935)	3.3 (36)	0.86 (0.41 to 1.77)	0.674		
London	11.1 (1403)	93.7 (1315)	6.3 (88)	0.44 (0.23 to 0.85)	0.015		
South East	14.5 (1360)	94.6 (1288)	5.4 (72)	0.52 (0.26 to 1.03)	0.060		
South West	8.2 (766)	97.1 (745)	2.9 (21)	1	0.024		
Wales	5.1 (1951)	94.3 (1844)	5.7 (107)	0.49 (0.26 to 0.91)	0.019		
Scotland	9.3 (1598)	94.0 (1499)	6.0 (99)	0.46 (0.24 to 0.88)	0.000		
Northern Ireland	4.0 (1354)	89.3 (1212)	10.7 (142)	0.25 (0.13 to 0.46)			
Isle of Man/Channel Islands	0.02 (2)	100 (2)	0 (0)	NA	NA		
Country							
England	64.2 (8786)	95.0 (8326)	5.1 (460)	1		1	
Wales	14.2 (1945)	94.2 (1838)	5.8 (107)	0.87 (0.65 to 1.15)	0.313	0.97 (0.71 to 1.33)	0.859
Scotland	11.6 (1599)	94.0 (1500)	6.0 (99)	0.83 (0.60 to 1.17)	0.287	0.73 (0.51 to 1.03)	0.077
Northern Ireland	9.9 (1351)	89.1 (1208)	10.9 (143)	0.43 (0.32 to 0.59)	0.000	0.46 (0.32 to 0.65)	0.000

Frequencies of missing data: ethnicity (101); BMI (340); occupation (288); academic (4); smoking (85); housing tenure (139), accommodation (21); income (20); sport (70); TV (76); garden (21).
BMI, body mass index.

Table 3 Weighted percentages and sample sizes for all singletons sent an accelerometer (n=12303), singletons whom we did (n=6497) and did not (n=5806) acquire reliable accelerometer data, adjusted and unadjusted ORs (95% CI) and p values for predictors of reliable data acquisition

	Weighted % (n)			Unadjusted regression		Adjusted regression	
	Sent	Reliable data acquired	Reliable data not acquired	OR (95% CI)	p Value	OR (95% CI)	p Value
All	100.0 (12303)	52.7 (6497)	47.3 (5806)				
Biological							
Child's gender							
Male	51.2 (6233)	50.8 (3176)	49.2 (3057)	0.86 (0.78 to 0.95)	0.002	0.81 (0.74 to 0.90)	0.000
Female	48.8 (6070)	54.6 (3321)	45.4 (2749)	1		1	
Child's ethnicity							
White	86.2 (10 310)	54.8 (5685)	45.2 (4625)	1		1	0.206
Mixed	3.1 (329)	47.7 (167)	52.3 (162)	0.75 (0.57 to 0.99)	0.045	0.84 (0.63 to 1.10)	0.004
Indian	1.9 (305)	42.7 (139)	57.4 (166)	0.61 (0.44 to 0.85)	0.003	0.50 (0.31 to 1.10)	0.001
Pakistani/Bangladeshi	4.4 (726)	32.2 (243)	67.8 (483)	0.39 (0.31 to 0.49)	0.000	0.50 (0.34 to 0.70)	0.002
Black or Black British	3.1 (386)	36.6 (151)	63.5 (235)	0.47 (0.34 to 0.65)	0.000	0.58 (0.41 to 0.83)	0.838
Other	1.4 (165)	53.1 (80)	36.6 (85)	0.93 (0.66 to 1.29)	0.688	0.95 (0.59 to 1.36)	
Child's BMI							
Under/normal weight	80.1 (9671)	54.5 (5315)	45.5 (4356)	1		1	
Overweight/obese	19.9 (2483)	45.5 (1114)	54.6 (1369)	0.69 (0.63 to 0.77)	0.000	0.73 (0.66 to 0.82)	0.000
Social							
Mothers age at birth (years)							
14–19	8.4 (895)	31.8 (283)	68.2 (612)	0.30 (0.25 to 0.36)	0.000	0.52 (0.42 to 0.64)	0.000
20–29	45.3 (5486)	48.5 (2660)	51.5 (2826)	0.61 (0.56 to 0.68)	0.000	0.78 (0.71 to 0.85)	0.000
30–39	43.7 (5578)	60.6 (3346)	39.4 (2232)	1		1	
>40	2.6 (344)	59.3 (208)	40.7 (136)	0.95 (0.74 to 1.21)	0.654	1.21 (0.92 to 1.60)	0.171
Maternal occupation							
Managerial and professional	22.9 (2907)	62.5 (1806)	37.5 (1101)	1		1	
Intermediate	13.3 (1621)	56.4 (922)	43.6 (699)	0.78 (0.67 to 0.90)	0.001	0.97 (0.83 to 1.14)	0.728
Small employers and own account workers	6.0 (695)	55.9 (387)	44.1 (308)	0.76 (0.64 to 0.91)	0.002	0.89 (0.74. 1.08)	0.236
Lower supervisory and Technical	2.8 (318)	54.3 (177)	45.7 (141)	0.71 (0.54 to 0.94)	0.015	1.13 (0.84 to 1.52)	0.413
Semiroutine and routine	18.1 (2140)	51.2 (1104)	48.8 (1036)	0.63 (0.56 to 0.71)	0.000	1.01 (0.88 to 1.17)	0.838
Non-employed	37.0 (4377)	45.6 (1978)	54.4 (2299)	0.50 (0.45 to 0.56)	0.000	1.03 (0.90 to 1.18)	0.691
Maternal academic qualification							
Degree(s)/postgraduate diplomas	19.0 (2525)	67.1 (1661)	32.9 (864)	1		1	
Higher education/teaching qualifications/diplomas	11.7 (1473)	58.4 (854)	41.6 (619)	0.69 (0.59 to 0.80)	0.000	0.82 (0.69 to 0.96)	0.015
A/AS/S-levels	9.4 (1187)	56.8 (682)	43.2 (505)	0.64 (0.54 to 0.77)	0.000	0.78 (0.65 to 0.93)	0.007
O-levels/GCSE grades A-C	32.1 (3787)	51.4 (1940)	48.6 (1847)	0.52 (0.46 to 0.59)	0.000	0.70 (0.61 to 0.82)	0.000
GCSE grades D-G	10.8 (1242)	46.4 (571)	53.6 (671)	0.42 (0.36 to 0.50)	0.000	0.71 (0.58 to 0.86)	0.000
Other academic qualifications	2.3 (311)	44.7 (132)	55.3 (179)	0.40 (0.29 to 0.54)	0.000	0.76 (0.54 to 1.06)	0.102
None of these	14.8 (1776)	35.7 (657)	64.3 (1119)	0.27 (0.23 to 0.32)	0.000	0.56 (0.47 to 0.67)	0.000

Continued

Table 3 Continued

	Weighted % (n)			Unadjusted regression		Adjusted regression	
	Sent	Reliable data acquired	Reliable data not acquired	OR (95% CI)	p Value	OR (95% CI)	p Value
Lone parent status							
Non-lone parent	77.8 (9749)	56.4 (5498)	43.6 (4251)	1		1	
Lone parent	22.2 (2554)	39.5 (999)	60.5 (1555)	0.50 (0.45 to 0.56)	0.000	0.75 (0.65 to 0.86)	0.000
Number of children in the household							
1	12.8 (1558)	46.4 (726)	53.7 (832)	0.70 (0.61 to 0.79)	0.000	0.83 (0.71 to 0.96)	0.012
2–3	73.2 (8926)	55.4 (4957)	44.6 (3969)	1		1	
≥4	14.0 (1819)	44.1 (814)	55.9 (1005)	0.64 (0.55 to 0.73)	0.000	0.82 (0.71 to 0.95)	0.009
Household language							
English only	90.5 (10 688)	53.9 (5795)	46.1 (4893)	1		1	
English and other	9.0 (1536)	40.6 (666)	59.4 (870)	0.58 (0.50 to 0.68)	0.000	0.94 (0.74 to 1.19)	0.616
Non-English speaking	0.5 (79)	42.8 (36)	57.2 (43)	0.64 (0.37 to 1.10)	0.106	1.15 (0.60 to 2.21)	0.681
Whether anyone smokes near the child							
No	86.1 (10 640)	54.5 (5787)	45.5 (4853)	1	0.000	1	
Yes	13.9 (1617)	42.1 (701)	57.9 (916)	0.61 (0.56 to 0.74)		0.90 (0.78 to 1.05)	0.194
Whether mother is in work or not							
In work or leave	62.4 (7768)	57.0 (4443)	43.1 (3325)	1		NA	NA
Not in work or leave	37.6 (4535)	45.6 (2054)	54.4 (2481)	0.63 (0.59 to 0.72)	0.000		
Main housing tenure							
Own outright, full or part mortgage/loan	63.7 (8174)	60.2 (4873)	39.8 (3301)	1		1	
Rent for local authority or housing association	24.3 (2733)	38.5 (1047)	61.5 (1686)	0.41 (0.40 to 0.46)	0.000	0.79 (0.68 to 0.92)	0.002
Rent privately	9.8 (1075)	42.5 (447)	57.5 (628)	0.49 (0.42 to 0.57)	0.000	0.78 (0.66 to 0.92)	0.003
Other	2.1 (238)	41.6 (97)	58.4 (141)	0.47 (0.36 to 0.62)	0.000	0.87 (0.63 to 1.19)	0.382
Type of accommodation							
House or bungalow	90.1 (11 210)	54.3 (6054)	45.7 (5156)	1		1	
Flat or maisonette	9.5 (1033)	38.3 (416)	61.7 (617)	0.52 (0.45 to 0.61)	0.000	0.87 (0.72 to 1.05)	0.141
Studio, room, bedsit, other	0.4 (46)	47.4 (24)	52.6 (22)	0.76 (0.38 to 1.52)	0.433	0.81 (0.40 to 1.67)	0.572
Household income							
<£10 400	12.5 (1503)	36.7 (552)	63.3 (951)	0.33 (0.28 to 0.39)	0.000	1.20 (0.95 to 1.50)	0.121
£10 400–£20 800	26.6 (3381)	43.4 (1485)	56.6 (1896)	0.43 (0.37. 0.50)	0.000	1.17 (0.97 to 1.42)	0.105
£20 800–£31 200	23.1 (2915)	56.4 (1651)	43.6 (1264)	0.73 (0.63 to 0.84)	0.000	1.28 (1.08 to 1.52)	0.004
£31 200–£52 000	25.2 (3065)	61.5 (1895)	38.5 (1170)	0.90 (0.79 to 1.03)	0.115	1.17 (1.01 to 1.35)	0.035
>£52 000	12.5 (1428)	64.0 (913)	36.0 (515)	1		1	
Behavioural							
Disability or illness that limits activity							
No	93.7 (11 555)	53.6 (6192)	46.4 (5363)	1		1	
Yes	6.3 (748)	39.5 (305)	60.5 (443)	0.57 (0.48 to 0.67)	0.000	0.68 (0.56 to 0.82)	0.000
Frequency of sport or exercise							
3 or more days/week	20.3 (2483)	62.6 (1544)	37.4 (939)	1		1	
2 days/week	21.3 (2602)	61.4 (1576)	38.6 (1026)	0.95 (0.82 to 1.09)	0.457	1.03 (0.89 to 1.18)	0.701

Continued

Table 3 Continued

	Weighted % (n)			Unadjusted regression		Adjusted regression	
	Sent	Reliable data acquired	Reliable data not acquired	OR (95% CI)	p Value	OR (95% CI)	p Value
1 day/week	26.0 (3227)	51.5 (1662)	48.5 (1565)	0.63 (0.56 to 0.72)	0.000	0.80 (0.70 to 0.91)	0.001
Less often or not at all	32.4 (3955)	41.9 (1708)	58.1 (2247)	0.43 (0.38 to 0.49)	0.000	0.73 (0.64 to 0.83)	0.000
Hours per weekday that child spends watching TV							
Less than an hour/not at all	19.2 (2411)	54.8 (1337)	45.2 (1074)	1		1	
1–3 h	64.8 (7891)	53.3 (4205)	46.7 (3686)	0.94 (0.84 to 1.06)	0.316	1.09 (0.96 to 1.24)	0.170
3–5 h	11.3 (1330)	47.3 (640)	52.7 (690)	0.74 (0.62 to 0.88)	0.001	1.07 (0.89 to 1.28)	0.490
>5 h	4.8 (632)	49.5 (308)	50.5 (324)	0.81 (0.64 to 1.02)	0.078	1.19 (0.93 to 1.52)	0.168
Child ever breastfed							
Yes	66.9 (8425)	43.5 (1691)	56.5 (2187)	0.58 (0.52 to 0.64)	0.000	0.81 (0.74 to 0.91)	0.000
No	33.1 (3878)	57.2 (4806)	42.8 (3619)	1		1	
Environmental							
Access to garden							
No	7.4 (803)	37.7 (315)	62.3 (488)	0.52 (0.42 to 0.63)	0.000	1.00 (0.75 to 1.22)	0.982
Yes	92.6 (11 486)	53.9 (6179)	46.1 (5307)	1		1	
Ward type							
Advantaged	57.7 (5237)	58.8 (3193)	41.2 (2044)	1		1	
Disadvantaged	36.4 (5622)	45.1 (2705)	54.9 (2917)	0.58 (0.52 to 0.65)	0.000	0.84 (0.75 to 0.95)	0.006
Ethnic	6.0 (1444)	39.8 (599)	60.3 (845)	0.46 (0.40 to 0.54)	0.000	1.05 (0.83 to 1.33)	0.668
Regions in England							
North East	3.5 (339)	50.6 (173)	49.4 (166)	0.55 (0.37 to 0.82)	0.004	NA	NA
North West	10.9 (1025)	48.7 (466)	51.3 (559)	0.48 (0.36 to 0.66)	0.000		
Yorkshire and the Humberside	8.6 (892)	54.0 (438)	46.0 (454)	0.60 (0.43 to 0.84)	0.003		
East midlands	7.4 (682)	61.3 (400)	38.7 (282)	0.84 (0.60 to 1.19)	0.338		
West Midlands	8.2 (913)	53.5 (451)	46.5 (462)	0.60 (0.43 to 0.83)	0.002		
East of England	9.6 (901)	62.3 (534)	37.7 (367)	0.87 (0.66. 1.16)	0.346		
London	10.8 (1230)	48.7 (577)	51.3 (653)	0.52 (0.38 to 0.70)	0.000		
South East	14.6 (1233)	58.9 (713)	41.1 (520)	0.78 (0.59 to 1.02)	0.068		
South West	8.3 (709)	64.4 (448)	35.6 (261)	1			
Wales	5.0 (1755)	56.0 (899)	44.0 (856)	0.65 (0.50 to 0.85)	0.002		
Scotland	9.1 (1421)	54.8 (761)	45.2 (660)	0.64 (0.48 to 0.86)	0.003		
Northern Ireland	4.0 (1201)	54.9 (636)	45.1 (565)	0.68 (0.52 to 0.91)	0.010		
Isle of Man/Channel Islands	0.02 (2)	61.4 (1)	38.6 (1)	0.96 (0.06 to 15.02)	0.978		
Country							
England	64.7 (7936)	53.0 (4204)	47.1 (3732)	1		1	
Wales	14.1 (1748)	51.2 (898)	48.8 (850)	0.93 (0.81 to 1.07)	0.304	0.96 (0.84 to 1.09)	0.521
Scotland	11.5 (1422)	51.5 (761)	48.5 (661)	0.94 (0.79 to 1.12)	0.520	0.94 (0.78 to 1.14)	0.520
Northern Ireland	9.8 (1197)	52.6 (634)	47.4 (563)	0.99 (0.83 to 1.17)	0.869	0.99 (0.81 to 1.21)	0.895

Frequencies of missing data: ethnicity (82); BMI (149); occupation (245); academic (2); smoking (46); housing tenure (83), accommodation (14); income (11); sport (36); TV (39); garden (14).
BMI, body mass index.

Table 4 Predictors of study non-consent and non-receipt of reliable accelerometer data in the Millennium Cohort accelerometer Study

Study non-consent	Non-return of reliable accelerometer data
	Biological
	▶ Boys
	▶ Non-white, mixed or 'other' ethnicity children
	▶ Overweight or obese children
	Social
	▶ Younger mothers (<30 at birth of cohort child)
	▶ Mothers without a degree
	▶ Lone parents
	▶ Households with 1 or ≥4 children
	▶ Children who lived in rented accommodation
Behavioural	*Behavioural*
▶ Children with a limiting illness or disability	▶ Children with a limiting illness or disability
▶ Children who did not have people smoking near them	▶ Children who exercised once a week or less
	▶ Children who had been breastfed
Environmental	*Environmental*
▶ Children who had access to a garden	▶ Children from disadvantaged wards
▶ Children who lived in Northern Ireland	

no differences between boys and girls according to the number of days of reliable data they provided. Other large-scale studies using face-to-face distribution methods have investigated potential predictors of reliable data acquisition using a range of factors, but the findings are inconsistent. In four studies, younger children were more likely to provide reliable accelerometer data than older children,[3 20–22] whereas another three found no age differences.[10 16 19] In agreement with our study, boys were less likely to provide reliable data than girls in the Avon Longitudinal Study of Parents and Children (ALSPAC)[20] and the UK Children's Health and Activity Monitoring Program.[13] In contrast, the National Health and Nutrition Examination Survey[3] and the SPEEDY study[17] reported that girls were less likely to return reliable data than boys: no gender differences in reliable data acquisition were reported in several other studies.[10 19 21] In contrast to our study, no ethnic differences according to reliable data acquisition were reported by previous studies.[5 13 19 21] The majority of previous studies report that weight status was not related to reliable data acquisition.[10 13 16 39] However, in agreement with our study, overweight children were less likely to return reliable data than non-overweight children in the ALSPAC,[20] whereas overweight children were more likely to provide reliable data than non-overweight children in Project EAST[19]

Few studies have investigated behavioural predictors of reliable data acquisition.[10 16 21] No previous studies have reliably investigated whether PA predicts non-response. However, the Physical Exercise and Appetite in Children Study reported that they were more likely to acquire reliable data from physically active children than those who were less active.[10] In contrast, Sirard *et al*[21] reported that PA levels did not predict whether children returned reliable accelerometer data. Both studies compared the PA levels of children who did and did not return reliable data; however, PA is not reliably estimated in children without reliable data. Only studies with an alternative measure of activity can accurately estimate PA differences in non-response. Few studies have investigated social and environmental factors as potential predictors of reliable data acquisition, although studies have looked at socioeconomic status,[10] child deprivation,[13] local and area independent mobility,[16] child[19] and parental[17] education and free school meal status.[22]

Strengths and limitations

The MCS4 is the first large-scale longitudinal cohort study to objectively measure PA in a socially and ethnically diverse population of children from all four UK countries. This is also the first large-scale accelerometer study using a postal distribution methodology to investigate the predictors of non-response associated with study non-consent and non-return of reliable data. The MCS provided a range of biological, social, behavioural and environmental information on children, their families and their environment, which enabled us to simultaneously examine a broad range of potential predictors. As this is a contemporary cohort, the findings of this study are applicable to the lives of young children now. Furthermore, we have used a robust accelerometer wear time threshold to define children with reliable data.[33]

However, our findings may not be applicable to different ages. PA levels vary according to age, and children's PA is very different from adult's PA in many respects;[3] it is therefore unlikely that without further research the findings of this study can be applied to adult populations. Age has also been shown to be related to the return of reliable accelerometer data in several studies.[3 20–22] In addition, although the UK country of residence did not predict non-response in our study, our findings may differ in other studies involving samples of children living in non-UK countries.

Many of the predictor variables in this study were based on parent-report measures, and therefore recall bias may have influenced the information collected. For example, maternal reports of smoking near the child at the age 7 sweep may have been underreported, although any underestimate in this is likely to lead to an underestimate of the effect.[40] However, the information collected within the MCS using parent-report methods has been shown to be valid and reliable.[41 42] Non-consent for children who did not have people smoking near them may reflect highly protective parents. A small number of the MCS children had missing data for the predictor variables. Since the MCS has a large sample size, imputing data for these missing variables would only increase the sample size by a small proportion. Several factors that were not investigated within this study may also influence non-response, for example, who the cohort children were interviewed by, whether they were sent, or tried to return an accelerometer during a postal strike, or which reminder methods were sent to the family to encourage return of the accelerometer.

Recommendations for study practice and further research

This study has reported the biological, social, behavioural and environmental factors associated with non-response in a PA study using postal methods to distribute and return accelerometers. Researchers should be aware of these factors and recognise potential bias occurring as a result of this methodology so that future studies can implement strategies to reduce the threat of data loss. For example, we found that the language spoken by the cohort families at MCS4 did not influence consent. This may be because non-English speaking families were offered translated versions of all study documents, and a translator was made available at the study interview. However, consent was less likely from children living in Northern Ireland; this may be because a different fieldwork agency conducted the home interviews in Northern Ireland than in England, Wales and Scotland. Considerable efforts are required by researchers and parents to encourage boys, non-white and overweight/obese children to wear and return their accelerometer as requested so that we can acquire reliable data from these populations. Lone parents and families with a large number of children may not have returned their child's accelerometer because they forgot, or did not have the time to do so. Therefore, it is crucial that studies issue timely reminders throughout fieldwork, and in particular, to these populations. Caution should also be taken if sampling children with an illness or disability that limits daily activity as non-response was very high among these children and may therefore bias study findings.

Further research should be aimed at investigating whether the predictors of non-response identified in this study also predict non-response in other large-scale accelerometer studies across different age groups and countries, and in studies using different accelerometer distribution and return methods. If studies are unable to increase response in the populations identified in our study, then researchers need to be aware of their influence on the validity of findings, and control for these factors in associated analyses. An important finding was that children who were reported to exercise once a week or less were less likely to return reliable data. As a result, study findings may be biased as inferences about the PA levels of the population that are based on the observed sample may not be the same as those based on the target sample. However, the PA predictor variable was based on the parent-proxy report of their child's usual weekly frequency of sport or any other PA. The limitations associated with parent-proxy reports of children's PA have been well defined.[43] Although it is beyond the scope of the study, several statistical methods to deal with missing data have been developed and their performance in reducing estimation bias depends on the quality of the models that underpin them.[44] Current work is being undertaken to develop response propensity weighting adjustments in the MCS4 accelerometer study.

CONCLUSION

Researchers should be aware of factors associated with non-response in a large-scale accelerometer study that uses postal distribution and return methods so that future studies can implement strategies to reduce the threat of data loss. Accelerometer studies in children who use our postal methodology need to encourage data return from boys, overweight/obese and non-white children, mothers who are young or who have few qualifications, families with only one parent or a large number of children, children who exercise less than twice a week and children living in various forms of disadvantaged circumstances. If studies are unable to increase response in these sections of the population, then researchers should weight analyses to account for non-response.

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Contributors CR, LJG, MCB and CD were responsible for the conception and design of the study. CR carried out the statistical analyses and drafted the manuscript. MG generated and produced the accelerometer data processing software. MCB, FS and CR also made substantial contributions towards accelerometer data processing. HJ, as director of the MCS, worked with CD to raise the funding from the Wellcome Trust, and oversaw the CLS collaboration in the project. LC made substantial contributions towards the accelerometer fieldwork protocol. All authors contributed towards revising the manuscript and have approved the final manuscript.

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Competing interests None.

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Data sharing statement The MCS data for surveys 1–4 are currently available via the Economic and Social Data Service; the MCS accelerometer data will be available at the beginning of 2013.

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Appendix E: Published manuscript (calibration)

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PLoS one

Actigraph Accelerometer-Defined Boundaries for Sedentary Behaviour and Physical Activity Intensities in 7 Year Old Children

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Abstract

Background: Accurate objective assessment of sedentary and physical activity behaviours during childhood is integral to the understanding of their relation to later health outcomes, as well as to documenting the frequency and distribution of physical activity within a population.

Purpose: To calibrate the Actigraph GT1M accelerometer, using energy expenditure (EE) as the criterion measure, to define thresholds for sedentary behaviour and physical activity categories suitable for use in a large scale epidemiological study in young children.

Methods: Accelerometer-based assessments of physical activity (counts per minute) were calibrated against EE measures (kcal.kg^{-1}.hr^{-1}) obtained over a range of exercise intensities using a COSMED K4b^2 portable metabolic unit in 53 seven-year-old children. Children performed seven activities: lying down viewing television, sitting upright playing a computer game, slow walking, brisk walking, jogging, hopscotch and basketball. Threshold count values were established to identify sedentary behaviour and light, moderate and vigorous physical activity using linear discriminant analysis (LDA) and evaluated using receiver operating characteristic (ROC) curve analysis.

Results: EE was significantly associated with counts for all non-sedentary activities with the exception of jogging. Threshold values for accelerometer counts (counts.minute^{-1}) were $<$100 for sedentary behaviour and $\leq$2240, $\leq$3840 and $\geq$3841 for light, moderate and vigorous physical activity respectively. The area under the ROC curves for discrimination of sedentary behaviour and vigorous activity were 0.98. Boundaries for light and moderate physical activity were less well defined (0.61 and 0.60 respectively). Sensitivity and specificity were higher for sedentary (99% and 97%) and vigorous (95% and 91%) than for light (60% and 83%) and moderate (61% and 76%) thresholds.

Conclusion: The accelerometer cut points established in this study can be used to classify sedentary behaviour and to distinguish between light, moderate and vigorous physical activity in children of this age.

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Introduction

The importance of physical activity for healthy child development is well established. There is evidence that sedentary behaviour and low levels of physical activity in childhood are associated with an increased risk of childhood obesity as well as with a range of chronic adult disease risk factors including hypertension, insulin resistance and dyslipidaemia [1]. Accurate and valid assessment of sedentary behaviour and physical activity levels during childhood is therefore integral to the understanding of their relation to later health outcomes, as well as to documenting their frequency and distribution within a population.

The development of accelerometer technology has provided a robust alternative to the methods of physical activity assessment based on self report traditionally employed in large scale epidemiological studies. Cost, practicality, and a high subject burden prevent direct observation of physical activity being feasible in population based physical activity research. Self report measures of physical activity in children are of limited validity [2] and proxy report by parents can be unreliable, especially in school-aged children.

Accelerometry is an attractive option as it provides an objective measure of activity frequency, intensity and duration. It also eliminates recall and social desirability bias and may overcome the challenges posed by difficulties in language and literacy [3]. Continuing technological development with subsequent increases in battery life and decreases in unit cost have allowed accelerometers to become feasible in large scale population based physical activity studies.

The Actigraph accelerometer (Actigraph, Pensacola, Florida) has been extensively and successfully used to assess physical activity in children in both small [4,5,6,7,8,9] and large scale [10,11] epidemiological studies. Accelerometers provide dimensionless physical activity scores in 'counts' which are summarised over a user specified time period or epoch. By calibrating accelerometer counts with an objective 'gold standard' measure of energy expenditure (EE) such as oxygen consumption over a range of exercise intensities, threshold values for accelerometer data can be established to delineate categories of physical activity intensity. Accelerometer-based data can then be summarised according to these threshold values to determine whether, at a population level, physical activity meets current public health guidelines, which are conventionally expressed in terms of the minutes spent each day in moderate to vigorous physical activity (MVPA).

While accelerometer counts have been calibrated with respect to EE data in a number of studies of different age groups using either structured [9,12] or free living activities [13] these studies have differed widely in design, methods and statistical approaches to data reduction and analysis, resulting in considerable variation in the threshold values published in the literature. The majority of calibration studies have focused on discriminating between differing intensities of physical activity (light, moderate, vigorous). However, accelerometers are also able to identify sedentary behaviour which is not simply the absence of physical activity. It has been suggested that sedentary behaviour comprises the majority of young children's time [14] and it is increasingly considered as an independent risk factor for a number of metabolic disorders [15] with its own patterns and determinants rather than simply one extreme of the physical activity continuum. Few studies have objectively assessed free-living sedentary behaviours in children, and those that have, have included considerably different age groups [5,8].

The Millennium Cohort Study (MCS) is a nationally representative, UK-wide, cohort study of 12768 children born in the new century (between September 2000 and January 2002). A range of social, economic and health-related information has been collected from cohort members at home interviews held at ages nine months and three, five and seven years. At the age seven year interview, these data were enhanced by measures of physical activity obtained by accelerometer. The present study aimed to calibrate accelerometer counts against measured EE ($kcal.kg^{-1}.hr^{-1}$) in a sample of children of similar age to those participating in the MCS in order to establish thresholds which define sedentary behaviour and light, moderate and vigorous activity based on accelerometer counts, and to do this using entirely self-paced rather than structured activities since the former are more representative of free living activities of children at this age. The overall aim is to use these thresholds to summarise the physical activity data collected from the MCS, and other large epidemiological studies.

Methods

Participants

The study sample consisted of children aged between 7 and 8 years attending a North London primary school. Information letters were sent to the parents of all 83 children in the relevant year group inviting them to participate in this study. Written consent was obtained from the parent/guardian of 55 children prior to participation in study. This study was approved by the University College London Research Ethics Committee (reference 1325/001).

Anthropometry

Height was measured using Leicester Height Measure Stadiometers (Seca Ltd, Birmingham, UK), recorded to the nearest 0.1 cm. Weight (to the nearest 0.1 kg), and body fat percentage (to the nearest 0.1%) were measured using an electronic body composition scale (Tanita BF 522W, Middlesex, UK). Waist circumference was measured (to the nearest 0.1 cm) using a SECA tape (SECA, Hamburg, Germany), midway between the costal margin and the iliac crest. Two measurements were taken and their mean was recorded.

Accelerometry

Measurements were made using the Actigraph GT1M uni-axial accelerometer (Actigraph, Pensacola, Florida). This uses a piezoelectric lever to detect accelerations in the vertical plane in the range of 0.05–2 g. This range is consistent with normal human movement and allows the rejection of high intensity vibrations. Flexion of this lever caused by movement generates a signal proportional to the amount of acceleration. This signal is then summed over a user defined time period (epoch) which may range from 1–240 seconds. It is small (38 mm×37 mm×18 mm), lightweight (925 g) and has been demonstrated to measure physical activity in children reliably when compared with heart rate monitoring [16] indirect [9] and room [4] calorimetry, and doubly labelled water [17] techniques.

While a number of previous studies have used one minute [4,9] or 30 second epochs [8] it has been suggested that the sporadic nature of children's movements when compared to adults requires more frequent assessment [18]. In view of this, in the current study we used 15 second epochs. Participants wore the accelerometer on a flexible elastic belt worn round the waist, in the right midaxillary line and level with the iliac crest. Data were downloaded immediately following completion of the protocol using the Actigraph software version 3.8.3 (Actigraph, Pensacola, Florida).

Indirect Calorimetry

Oxygen consumption (VO_2) and heart rate were measured using a portable breath by breath metabolic unit developed by COSMED (Model K4b$_2$, Rome). This is a small (70 mm×50 mm×100 mm), lightweight (475 g) indirect calorimetry system that is worn in a chest harness. It is ideally suited to the determination of EE in non laboratory settings, and has been demonstrated to be a valid measure of oxygen uptake in both adults [19] and children [20]. All expired gases pass through a face mask connected to a bidirectional flowmeter to O_2 and CO_2 analysers via a sample line, allowing air flow volumes and fractions of expired oxygen ($FE.O_2$) and carbon dioxide ($FE.CO_2$) to be measured. On each day of testing the unit was warmed up for 30 minutes and a delay calibration (to account for the delay between expiration and gas analysis) was carried out according to the manufacturer's guidelines. Prior to each test the unit was calibrated using a reference gas of known volume (5.2% CO_2, 16.0% O_2, 78.8% N).

Protocol

All activities were performed indoors in the school's own gymnasium. Three children took part each test day, two in the morning and one in the afternoon session. The study protocol and equipment were explained to each child, anthropometric measurements obtained and the accelerometer and COSMED devices positioned. The COSMED and accelerometers were then synchronised and the test initiated. Each participant was required to perform seven activities of increasing intensity. These activities were selected to provide a full range of physical activity intensities, from sedentary to vigorous, which also reflected free living activities typical of children of this age. The activities were as follows:

1. Lying Down – subjects lay down for 30 minutes while watching a DVD.
2. Sitting – subjects sat upright on a bench while playing a computer game for 5 minutes.
3. Slow walking – subjects were instructed top 'walk slowly' round a marked track for 5 minutes.
4. Brisk walking – subjects were instructed to 'walk quickly' round a marked track for 5 minutes.
5. Jogging – subjects were instructed to 'jog' round a marked track for 5 minutes.
6. Hopscotch –subjects played hopscotch at their own pace for 5 minutes.
7. Basketball – subjects performed a basketball drill involving, dribbling, running and shooting for 5 minutes.

All activities were self paced. The walking and jogging activities took place around a marked 10 m×4 m track. There was a brief interval (<2 mins) between each activity to allow for movement of equipment, although activities 2, 3 and 4 (slow walking to jogging) were performed continuously. All activities were 5 minutes in duration with the exception of the first activity (lying down) which lasted 30 minutes in order to achieve EE values close to those of resting metabolism (note these values were used to represent sedentary behaviour and not to establish basal metabolic rate). Oxygen consumption and accelerometer counts were recorded throughout.

Data reduction

The COSMED and accelerometer data were exported and aligned using a specially designed Microsoft Access macro, and a two minute sample from each activity period selected for analysis. For all activities, lying down excepted, data were sampled between minutes 2.5 and 4.5 to ensure that participants had achieved steady state EE [21] in each activity and to minimise the effect on VO_2 of the anticipation of the end of each task. Data were taken between minutes 22.5–24.5 for the lying down period. VO_2 was converted to units of EE ($kcal.kg^{-1}.hr^{-1}$) using the constant 1 L O_2 = 4.825 kcal [22]. O_2 data were then converted into METs. The standard definition of 1 MET as being equal to a VO_2 value of 3.5 $ml.kg^{-1}.min^{-1}$ is inappropriate for use with children as VO_2 can decline from ~6 $ml.kg^{-1}.min^{-1}$ at age 5 to 3.5 $ml.kg^{-1}.min^{-1}$ at age 18 [23]. Since participants were measured in a school environment and were realistically not able to attend the testing sessions in a fasted state we considered it was not feasible to attempt accurate measurement of basal metabolic rate (BMR) in this setting. Furthermore, existing published equations have been well validated. In view of this we predicted BMR in kilocalories for each child using Schofield's gender specific equations based on age, height and weight [23]. MET values for each activity were then calculated as total EE divided by individual BMR. Accelerometer counts in 15 second intervals, were summed for the first and second minutes of the sample period (i.e. using 8 observations). One mean value in counts per minute was then compared to corresponding MET values across each 2 minute sample.

Statistical Methods

All statistical analyses were performed using R version 2.12.1 [24]. Intraclass correlations coefficients (ICC) for EE in METs and accelerometer counts per minute for each activity were calculated across the 2-minute sample period for each child, thus eight individual measurements contributed to the ICC's. Functions in the R library (psychometric) [25] were used to obtain confidence intervals for the ICC estimates and if they were not significantly different from zero it was assumed that the accelerometer counts were stable during this interval, in which case mean values were used in subsequent analyses.

The Shapiro-Wilk test was used to assess normality [26]. Pearson or Spearman correlation coefficients were used to test the association between METs and accelerometer counts, depending on whether the distribution of the corresponding activity was considered Normal. Grubbs tests [27] as implemented in the R library (outliers) [28] were used to identify and remove outliers on a one at a time basis. For skewed distributions outliers were defined using the method by Huber and Vendervieren [29]. Paired *t*-tests with Welch's correction to account for unequal variances were used to compare gender subgroups. Wilcoxon-Mann-Whitney tests were used to assess differences in the energy expenditures of each activity by time of day in which the child was assessed (morning or afternoon). Regression modelling was used to assess the proportion of the variance in accelerometer counts that could be attributed to the height of the participant.

Three cut points were established, assuming a normal distribution for counts in each activity using accelerometer data for sitting, slow walking, brisk walking and jogging only. These three cut points represent the boundaries between sedentary behaviour, light activity, moderate activity and vigorous activity. We used linear discriminant analysis (LDA) as implemented in R library (MASS) [30] to determine the two optimal bounds separating the three non-sedentary activity groups. LDA produces, for each observation, a vector of posterior probabilities belonging to each level of the known activities being performed. Ideally these individual probabilities would be very close to 1 for one particular group and close to 0 for the other possible groups. We obtained the boundaries as the count values at which the posterior probability functions for each activity intersect.

Receiver Operating Characteristic (ROC) curves, as implemented in R Library (ROCR) [31] were used to assess the discriminatory power of the cut points proposed by LDA via their sensitivity and specificity. ROC curves were calculated for values across the range of observed accelerometer counts. Values of 1-specificity and sensitivity corresponding to the cut point values on the ROC curves were plotted and compared with the optimal sensitivity and specificity achievable with a particular ROC curve. This optimal value is the point minimising the distance between the calculated ROC curve and the point representing perfect classification, i.e. complete specificity and complete sensitivity. We also obtained the area under the ROC curve (AUC) which condenses the shape of the ROC curve into one number. If AUC = ½ then the model's predictions are equivalent to a random allocation meaning that the model does not discriminate between pre-defined groups, whilst AUC = 1 implies perfect classification. For each of the activities considered we tested the null hypothesis that the AUC is ½ against the composite alternative AUC>½.using the procedure based on the Wilcoxon-Mann-Whitney U statistic described in Mason & Graham [32].

The performance of the cut points was also evaluated by examining the misclassification rate obtained by predicting the corresponding physical activity intensity using the fitted linear discriminant model and comparing these predictions with the observed physical activity groupings.

We used the running lines smoother implemented in the supsmu function [33] in R library(stats). This is a running lines smoother that represents the data structure in a scatterplot. The smoothness of the fitted line, expressed as the width of the window around each point considered is decided in an adaptive manner depending on the local variation of the scatterplot.

Results

Of the 55 children who consented to take part, 53 (29 male) completed the study and were included in the analysis; of these, 39 were assessed in the morning and 14 in the afternoon. The mean sample values for height (132.9±6.5 cm), weight (31.3±6.8 kg), body mass index (17.6 kg/m^2±2.7 kg/m^2) and waist circumference (61.1 cm±8.2 cm) did not differ significantly by gender. Mean predicted BMR for the sample was 1.58±0.18 kcal.kg^{-1}.hr^{-1} or 5.46 mlO$_2$.kg^{-1}.min^{-1} which is equivalent to the lower EE values recorded during the sedentary activities. ICC estimates, calculated with eight consecutive measurements obtained over the 2 minutes of observations showed no significant variation within individuals across any of the seven sample periods; they were all considerably large, ranging from 0.77 to 0.90, and in all cases the standard errors yielded tight confidence intervals; as they were all smaller than 12% of the estimated ICC. This indicates that accelerometer counts were stable and that steady state activity was achieved for all activities. Data were therefore summarised as a mean for the 2 minute sample period from each activity and used in subsequent analyses. The means of each physical activity for all subjects were therefore included in the analysis. There were no significant differences in the energy expended for a given activity by the time of day in which the child completed the protocol (Wilcoxon-Mann-Whitney tests, $p>0.01$)

As expected, accelerometer counts for the sedentary activities were not normally distributed due to the high proportion of zero counts. In 35 (66%) of children the mean accelerometer count value for the sitting activity was 0; there were three outliers (251.0, 292.5, 483.0) confirmed by the method described in Hubert and Vandervieren [29] and the rest of the values were 1.5, 3.0, 3.0, 3.0, 4.5, 5.5, 5.5, 6.0, 10.5, 11.0, 11.0, 71.5, 94.5, and 96.5. thus we decided to establish a cut-point of 100 cpm to separate sedentary from non-sedentary behaviour. The distributions of accelerometer counts for slow walking and jogging did not deviate significantly from normality ($p = 0.53$ and $p = 0.44$). However, accelerometer data for brisk walking were not normally distributed ($p<0.001$) due to two outlying values (mean values of 6459 counts.min^{-1} and 6684 counts.min^{-1} compared to the sample mean of 2879). Grubbs' test identified these as the only outliers ($p = 0.002$ in both cases) in the dataset. Therefore for the purposes of the LDA the distribution of accelerometer counts for brisk walking was considered normal; the only consequence of deviating from this assumption regarding the LDA would be a slight increase in the misclassification rate caused by these two outliers.

There was a significant relationship between METs and counts for all of the non-sedentary activities ($p<0.001$) with the exception of jogging (Figure 1). The mean EE (kcal.kg^{-1}.hr^{-1} and in METs) and corresponding accelerometer counts (per minute) for each of the seven activities are summarised in Table 1. The accelerometer counts for the two sedentary activities are not reported in the Table because 62% and 66% of the values for lying and sitting respectively were zero.

The variance in accelerometer counts was not significantly attributable to the height of the participants in six of the seven activities. The only exception was the slow walking activity where height accounted for a relatively small proportion (just over 5%) of the variance ($p = 0.04$). The lowest values for counts and EE were observed during the lying and sitting activities. These activities also provided the smallest variation in METs and counts. The jogging activity yielded the highest accelerometer count values. Mean EE was highest during basketball although the mean accelerometer count value for this activity was significantly lower than those recorded for both jogging and hopscotch. This may be indicative of the inability of waist mounted accelerometers to accurately assess the upper body movements involved in this activity. The hopscotch activity yielded high count values but EE values were far lower than expected. This may be attributed to fatigue (observed in almost all subjects at this point) caused by the continuous and progressive nature of the three preceding activities (slow walking, fast walking and jogging) affecting the intensity at which this activity was performed. Due to these measurement issues and the hopscotch and basketball activities were excluded from further analyses. The relationship between EE during activity and accelerometer counts is illustrated in Figure 1. The linear model represented there was fitted using a linear mixed effects procedure with a random effect on the intercept to account for the repeated observations from each child. The dotted line corresponds to the locally adaptive super smoother function [33].

Mean (± standard deviation) distances covered during the slow walk, brisk walk and jogging activities were 278±50 m, 387±57 m and 532±85 m respectively. These distances did not differ by gender for brisk walking and jogging although boys on average walked significantly ($p<0.001$) faster and covered more distance during the slow walk task.

Figure 2 shows the posterior probability vectors for each activity and the cut points characterised as the intersections of these curves. These cut points for sedentary behaviour and for light, moderate and vigorous intensity exercise defined by the linear discriminant analysis were 100, 2240 and 3840 counts per minute and are shown in Table 2 along with the corresponding sensitivity and specificity values and the AUC obtained from the ROC curve analysis. Table 2 also describes the ROC curves which are illustrated in Figure 3. These cut points provided excellent discrimination of both sedentary behaviour and vigorous physical activity as demonstrated by AUC values of 0.98 for both activities, in contrast to light and moderate activities which were not so not as well defined by the cut points (AUC 0.61 and 0.62 respectively). The overall misclassification rate for these four cut points, calculated as the total number of correctly predicted classifications divided by n (53)×4, was 22.2%. The null hypothesis that all four ROC curves constructed did not predict intensity of physical activity accurately was significantly rejected ($p \leq 0.003$).

Discussion

Summary

We have demonstrated a strong association between accelerometer counts and EE measured in a sample of seven year old children over a range of free-living activities. Using these data we have, for the first time established cut points (counts.min^{-1}) to identify sedentary behaviour (≤100) and to differentiate between light (≤2240), moderate (≤3840) and vigorous (≥3841) physical activity in UK 7 year olds. Using ROC curve analysis we have demonstrated that these cut points provide good discrimination

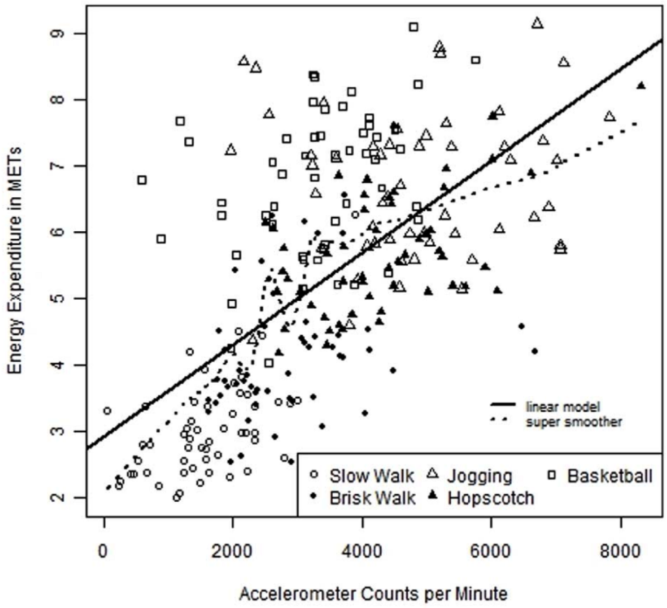

Figure 1. Relationship between accelerometer counts per minute and energy expenditure in METs. Data included for five of the seven activities (data for lying and sitting excluded due to the high number of zero values).
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between physical activity intensity categories, especially for sedentary behaviour and vigorous physical activity, with an overall low misclassification rate and are therefore a useful tool in analysing population physical activity data for this age group.

Comparisons with existing research

Comparison of our findings with those reported from other published calibration studies are complicated due to variation in sample age, criterion measure, accelerometers used and calibration activities employed. However the cut points defined in the current study are very similar to those previously observed by Evenson *et al.* [3] in a similar age group (sedentary $\leq$100 counts.min^{-1}, light $\leq$2292 counts.min^{-1}, moderate $\leq$4008 counts.min^{-1}, vigorous $\geq$4009 counts.min^{-1}). In Evenson *et al.*'s study two accelerometers including the Actigraph were calibrated against the COSMED K4b^2 over 10 activities covering a range of intensities. The cut points obtained for the Actigraph were similar to those obtained in our study. AUCs reported by Evenson *et al.* were also similar to those reported in our study for sedentary behaviour (0.98), lower for vigorous physical activity (0.86), and higher for moderate physical activity (0.85). The better discrimination between moderate and light physical activity in Evenson *et al.*'s study may be due to the more structured nature of the activities used in their protocol which were in addition all performed at a predetermined pace. Locomotor activities such as walking and running were performed on a treadmill at a specified speed, while activities such as stair climbing and 'jumping jacks' were performed in time with a metronome. A number of studies have used similar pacing techniques [4,12,34,35]. This uniformity of activity would ensure significantly reduced inter individual variation in EE and accelerometer counts when compared to the current study in which all activities were entirely self paced. The focus in the current study was to calibrate the accelerometer for use in the measurement of free-living activities. It could be argued that controlling the pace and intensity of activities, such as walking and running, does not accurately reflect natural activity for all individuals. However, Pate *et al.* [12] cross

Table 1. Energy expenditure (EE) in kcal.kg^{-1}.hr^{-1} and METs, and accelerometer counts (per minute) for each activity.

	Activity	EE (kcal.kg^{-1}.hr^{-1})	EE (METs)	Counts.min^{-1}
Sedentary	Lying	2.01 (0.54)	1.26 (0.26)	62%*
	Sitting	2.25 (0.74)	1.42 (0.45)	66%*
Light	Slow walking	4.74 (1.06)	3.02 (0.75)	1592 (783)
Moderate	Brisk walking	6.50 (1.51)	4.15 (1.08)	2879 (1042)
Vigorous	Jogging	10.59 (1.58)	6.77 (1.30)	4835 (1424)
	Hopscotch	8.96 (1.31)	5.74 (1.13)	4299 (1162)
	Basketball	10.67 (1.98)	6.83 (1.51)	3301 (1079)

EE = Energy expenditure calculated from VO_2 measures as $1LO_2$ = 4.825 kcal.
METs calculated as activity EE (kcal.kg^{-1}.hr^{-1})/individual BMR.
Values expressed as mean (standard deviation).
* = % of zero counts.
doi:10.1371/journal.pone.0021822.t001

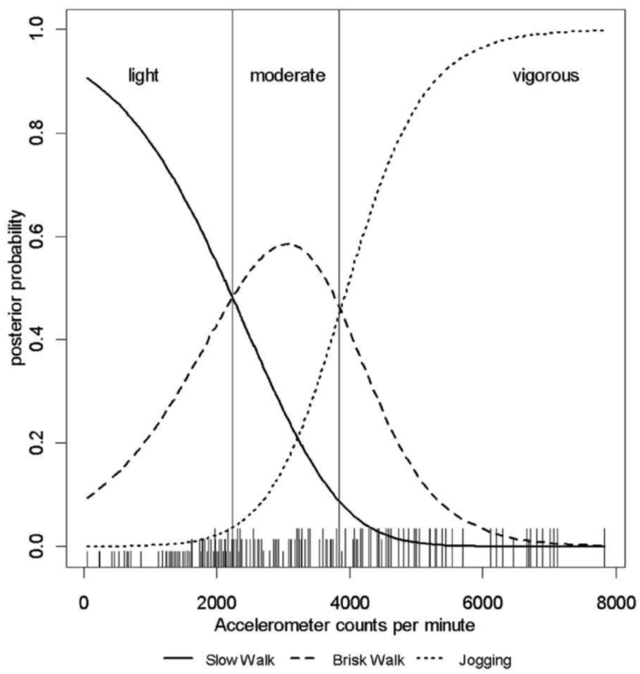

Figure 2. Posterior probability vectors for light, moderate and vigorous activity. Posterior probability vectors for light, moderate and vigorous activity and the cut points which occur at the points of intersection. Activities corresponding to the observed counts are indicated by the height of the ticks on the *x*-axis: the shortest ticks represent slow walking and the tallest represent jogging.
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validated Actigraph cut points established for MVPA and VPA in 3–5 year old children using structured activities with periods of unstructured play involving no prescribed activities and found good agreement between the two.

Mattocks *et al.* [36] established cut points for a range of MET values using self paced activities similar to those used in the current study but for an older age group (mean age 12.4 years). Their derived cut points were considerably higher than those established in the current study (moderate ≥3581 counts.min^{-1}, vigorous ≥6130 counts.min^{-1}). This may reflect differences in the approach to estimation of BMR which is needed to determine EE. Resting metabolic rate has been measured under controlled, fasted conditions [3,8] using direct calorimetry [35] in a number of studies but was not considered feasible in our study which took place during school hours. Hence in our study we calculated EE in METs using individual BMR values predicted from previously validated age specific equations using height and weight [23]. In contrast, Mattocks *et al.* [36] used the mean lowest VO_2 value recorded during their five minute sedentary activity period. Although Mattocks *et al.* stipulated a one hour fast prior to their assessment it is unclear whether this is sufficient to ensure a true measure of basal metabolic rate. Overestimation of BMR would tend to produce systematically higher cut off points and may account in part for the higher values reported by Mattocks *et al.* in comparison with the current study.

Evenson *et al.* [3] derived cut points for two age groups (5–6 and 7–8 years) and concluded, having compared the respective ROC curve analyses, that no significant differences existed between the sets of cut points and that age-specific intensity category boundaries were not needed in this age range. In contrast, other authors have argued that age-specific cut points are needed [7]. Puyau *et al.* [4] reported considerably higher cut points than in the current study (sedentary ≤800 counts.min^{-1}, light ≤3200 counts.min^{-1}, moderate ≤8200 counts.min^{-1}, vigorous ≥8201 counts.min^{-1}); this may be attributable to the sample which included children with a considerably greater age range (6–16 years). It has been postulated that variation in height, leg length, and movement economy with age may affect count values registered by a hip mounted accelerometer [7]. The wide ranging cut points reported for the various age groups examined in the literature could also be seen to support this argument. Stone *et al.* [37] investigated the effect of leg length as well as age on the accuracy of accelerometer based EE prediction equations, and found that both factors influenced predicted values. When considering the objective measurement of population level physical activity, using accelerometer thresholds based purely on physical characteristics would require a potentially infinite number of cut points and prohibitively complicate data collection. In addition, despite the range of heights in the current sample (120.2 cm–147.4 cm), height was only seen to explain a small portion of the

Table 2. Cut points in counts per minute (cpm) for each activity intensity category and their corresponding optimal sensitivity and specificity, and area under the ROC curve (AUC) values.

	Intervals (cpm)	Optimal sensitivity (%)	Optimal specificity (%)	Achieved sensitivity (%)	Achieved specificity (%)	AUC
Sedentary	≤100	99	97	99	97	0.98 ($p<0.001$)
Light	100–2240	60	83	59	83	0.61 ($p<0.005$)
Moderate	2241–3840	61	76	60	76	0.60 ($p<0.005$)
Vigorous	≥3841	95	91	95	91	0.98 ($p<0.001$)

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variation in accelerometer counts for one of the seven activities. The variation in cut points in the existing literature may be a reflection of behavioural differences in sedentary and physical activities between the age groups. Physical activity changes as a child develops, moving from sporadic informal play in early childhood to activities that begin to mirror those of adults in adolescence. When activities are self paced children of different age groups may approach what could be broadly described as the same activity or game in very different ways and with very different movement patterns depending on their own experience. That accelerometers have been shown to have more or less difficulty accurately capturing certain activities makes the way these activities are typically performed an even more central issue. The age of the individual being assessed therefore becomes of the utmost importance. We are therefore confident that the Actigraph cut points established here can be used to evaluate time spent engaged in sedentary behaviour and light, moderate and vigorous activity in children of this age group.

A number of studies have used linear regression analysis to obtain cut points [4,6,12,35]. This method is limited by its assumption that a linear relationship exists between EE and accelerometer counts; this is not always the case [38]. The slight plateaux in accelerometer counts (per minute) with continuing increase in EE appears in the fitted super smoother shown in Figure 1. This may indicate an inability of accelerometers to define physical activity accurately at high levels of EE or an anaerobic contribution to exercise metabolism which causes the relationship to become more complex [3]. In the current study LDA was used to establish boundaries for known subgroups (physical activity categories) present in the data. LDA is the natural technique to use to construct boundaries when the subpopulations (in this case physical activities) to be identified are known; this is in contrast to a situation in which they are latent or unobserved, in which finite mixture regression models [39] would be adequate. Few studies have evaluated accelerometer cut points based on the optimal sensitivity and specificity values obtained from ROC curve

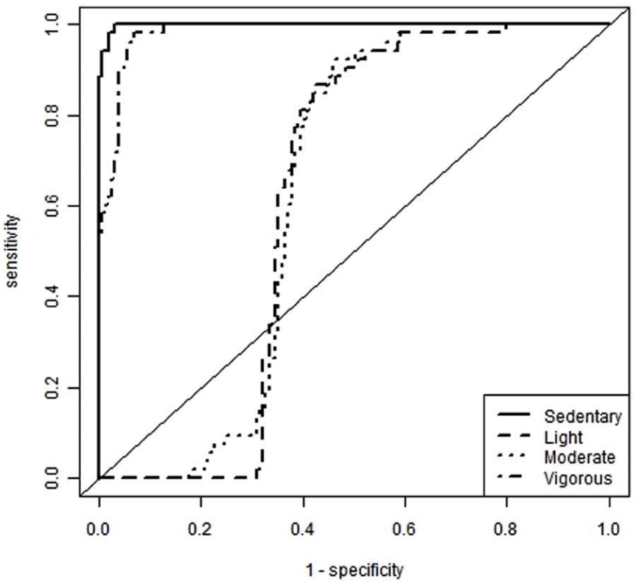

Figure 3. ROC curves including for sedentary, light, moderate and vigorous activity.
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analyses. This method should reduce the misclassification of physical activity attributed to the wide variation in accelerometer output for a given activity [40].

Strengths and limitations

We are confident that the experimental and analytical methodologies employed in the current study have enabled us to define robust cut points with which to identify sedentary behaviour and light, moderate and vigorous physical activity in 7 year old children. The use of a full range of age appropriate, self paced activities analysed at 15 second intervals will allow sensitive and effective analysis of everyday physical activity in children of this age using data from the MCS. With continuing advances in accelerometer technology it will be possible to measure free living physical activity over a number of days using even shorter epochs. It would therefore be useful to validate the cut points established in the current study using an even more sensitive measure of children's physical activity.

A number of limitations must be acknowledged in the current study. Data collection took place around the children's normal school day and it was therefore not possible to test each subject at the same time of day. Some children therefore took part in the activities directly after lunch which could potentially have influenced their metabolic rate and lead to the misclassification of light activity as moderate. However, Wilcoxon-Mann Whitney tests revealed that EE did not differ significantly depending with the time of day the protocol was completed. The age of the participants and the constrains of the school day also meant that obtaining basal metabolic measures under controlled and fasted conditions prior to each trial was not feasible. Therefore, values for BMR used to calculate MET values for each activity were predicted rather than being measured using a controlled protocol. However, the predicted mean BMR of 1.58 $kcal.kg^{-1}.hr^{-1}$ or 5.46 $mlO_2.kg^{-1}.hr^{-1}$ falls well within the expected range.

In the current study activities were chosen which provided a range of intensities and reflected free living activities typical of children of the sample age. Previous investigations have used up to 10 activities [4,6,8,12] however, practical considerations prevented this in the current study. Activities involving climbing and upper body movement which may be considered equally typical of this age group were not included due to the documented inability of accelerometers to accurately define external and load bearing work as well as topographical transition (i.e. lifting or walking on a slope) [41]. However, although studies such as this are limited by the capabilities of the accelerometer it has been previously observed that children's activity is largely comprised of locomotor activities [42].

In our study, the relationship between EE and counts was significant for all non-sedentary activities with the exception of jogging. It has been previously observed that accelerometer counts do not increase linearly at high speeds [43] which may account for this. A number of studies [3,36] allowed several minutes between activities to allow VO_2 to return close to resting values. In the current study, although a few minutes were needed to move between activities these breaks were not consistent across subjects. In addition, the two walking activities and jogging were performed continuously. This may have affected the subsequent two activities. Both counts and EE for hopscotch were significantly lower than during jogging, which may suggest an effect of fatigue from the previous 15 minutes continuous activity (slow walking, brisk walking and jogging). The basketball activity elicited the highest mean energy expenditure, but a mean counts value lower than those for either jogging or hopscotch. This indicates an inability of waist worn accelerometers to accurately determine upper body and load bearing activity [41]. The relatively low counts value for basketball compared to jogging also indicates that changes in EE may not accurately reflect changes in body movement. This would be particularly apparent in intermittent, game-type activities where body movement occurs in sporadic bursts. Treuth *et al.* [8] observed a similar effect when examining the relationship between Actigraph counts and EE during basketball. Energy expenditure would also remain high in post-exercise periods which may result in the underestimation of total EE by accelerometers [35]. Hopscotch and basketball activities were a useful inclusion as they reflect the varied nature of activities typical of this age and both demonstrated a significant relationship between EE and counts ($p<0.001$ for both). However, the jogging activity provided an adequate representation of vigorous steady state activity so data from the hopscotch and basketball activities were excluded from the linear discriminant and ROC curve analyses.

It would be useful to cross validate our findings with a larger sample of 7 year old children both under free living conditions and using controlled prescribed activities. This was beyond the scope of the current study. However, a number of studies using children of different ages have included a cross validation of cut points in their protocol [12,34] and found good agreement between structured and free living activities.

Discussion within the published literature as to the optimal way of objectively classifying population level physical activity data is ongoing. Aside from the derivation of accelerometer cut points, pattern recognition based approaches have emerged as an alternative method of broadly classifying specific activity types to estimate EE from accelerometer data. Accelerometer data can be classified as belonging to a particular activity type by comparison with pre-determined data patterns for specific activities. Such studies have shown reasonable success in classifying a small range of controlled physical activities in adults [44,45]. However, only two studies have attempted to apply these approaches to accelerometer data from children [46,47] and these focussed purely on differentiating between specific activity types rather than activity intensity. Activity misclassification was also considerably higher than in previous adult studies, potentially due to the wider variation and sporadic nature of children's activity patterns compared to adults. It must also be recognised that the utility of the pattern recognition approach to free living physical activity data from population based studies would be dependent on the development of patterns from a huge range of specific activities. For this reason, for the time being the use of accelerometers cut points remain the most important tools in the surveillance of population level physical activity levels in children.

Recommendations

The variation in cut point values derived for different age groups may be partially attributable to the different methodologies used. However, differences in the behavioural aspects of self paced sedentary and physical activities at different age groups may also have a significant effect on their measurement. Further investigation is needed into the measurement of true free living activities and the variations that could potentially exist between different age groups of UK children. Differences in the movement patterns that make up spontaneous locomotor and game type activities could certainly alter the evident relationship between EE and accelerometer counts. A better understanding of these differences may allow more effective measurement and reduce the misclassification of physical activity during objective measurement.

Conclusion

In conclusion, the Actigraph GT1M accelerometer can be used to identify sedentary behaviour and to discriminate between light, moderate and vigorous activity in 7 year old children. The cut points defined in the current study will be useful in interpreting physical activity data from the MCS, as well as other studies examining sedentary behaviours physical activity in children of this age.

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Author Contributions

Conceived and designed the experiments: RP CD LJG CR FK. Performed the experiments: RP FK CR. Analyzed the data: RP CD MCB LJG. Wrote the paper: RP MCB CR FK CD LJG.

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Appendix F: PubMed search strategy for literature review objectives

Search term number	Review objective	Search term	No. of search hits
1		explode “Child, Preschool” / all SUBHEADINGS in MIME, MJME	655389
2		explode “Child” / all SUBHEADINGS in MIME, MJME	1355604
3		explode “Adolescent” / all SUBHEADINGS in MIME, MJME	1372756
4		explode “Motor- Activity” / all SUBHEADINGS in MIME, MJME	91462
5		explode “Energy Metabolism” / all SUBHEADINGS in MIME, MJME	237169
6		explode “Sedentary Lifestyle” / all SUBHEADINGS in MIME, MJME	420
7		explode “Television” / all SUBHEADINGS in MIME, MJME	24918
8		((physical or motor) activity) or energy or sedentar* or television or computer*	1073263
9		acceleromet*	3723
10		(explode “Child, Preschool” / all SUBHEADINGS in MIME, MJME) or (explode “Child” / all SUBHEADINGS in MIME, MJME) or (explode “Adolescent” / all SUBHEADINGS in MIME, MJME)	343601
11		(explode “Motor- Activity” / all SUBHEADINGS in MIME, MJME) or (explode “Energy Metabolism” / all SUBHEADINGS in MIME, MJME) or (explode “Sedentary Lifestyle” / all SUBHEADINGS in MIME, MJME) or (explode “Television” / all SUBHEADINGS in MIME, MJME) or ((physical or motor) activity) or energy or sedentar* or television or computer*	12630111
12	1	9 and 10 and 11	729
13		explode “Data collection” / all SUBHEADINGS in MIME, MJME	1145000
14		consent or valid or compliance or feasib* or accept* or adheren* or predict* or respon* or bias	3163474
15		(explode “Data collection” / all SUBHEADINGS in MIME, MJM) or consent or valid or compliance or feasib* or accept* or adheren* or predict* or respon* or bias "Data Collection"[MeSH] or consent or valid or compliance or feasib* or accept* or adheren* or predict* or respon* or bias	3996198
16	2	9 and 10 and 11 and 15	382
17		explode “Biostatistics” / all SUBHEADINGS in MIME, MJME	249
18		data or analysis or cleaning or reduc* or spurious or wear* or day* or hr* or min*	8049386
19		(explode “Biostatistics” / all SUBHEADINGS in MIME, MJME) or data or analysis or cleaning or reduc* or spurious or wear* or day* or hour* or minute*	8049421
20	3	9 and 10 and 11 and 19	610
21		explode “Seasons” / all SUBHEADINGS in MIME, MJME	63066
22		explode “Weather” / all SUBHEADINGS in MIME, MJME	357786
23		variation or variab* or wind or humid* or rain* or snow* or sun* or temperat* or cold or hot or months or spring or summer or autumn or fall or winter	2259441
24		(explode “Seasons” / all SUBHEADINGS in MIME, MJME) or (explode “Weather” / all SUBHEADINGS in MIME, MJME) variation or variab* or wind or humid* or rain* or snow* or sun* or temperat* or cold or hot or months or spring or summer or autumn or fall or winter	2347299
25	4	9 and 10 and 11 and 24	219

Appendix G: Parent cover letter

The
child
first
and
always

Our Ref: «Serial_No»/ «Child_No»

«Main_title» «Main_forename» «Main_surname» and «Partner_title» «Partner_forename»
«Partner_surname»
«Address_line_1»
«Address_line_2»
«Address_line_3»
«Address_line_4» «Address_line_5»
«Postcode»

14 October 2012

Dear «Main_forename» and «Partner_forename»,

Child of the New Century - Age 7 Survey
Physical Activity Monitoring

Thank you very much for your help with this important part of the study.

Please find enclosed your physical activity monitor pack containing:

1. **information leaflet** - please take some time to read through this
2. **physical activity monitor and belt**
3. **timesheet** for you and your child to complete
4. **teacher letter** for you to fill in and give to your child's class teacher (if your child is at school during the 7-day monitoring period)
5. **pre-paid envelope** for posting back the monitor and completed documents

Your child should start wearing the activity monitor tomorrow morning, and continue to wear it every day for 7 days.

Please return the activity monitor, belt, and completed timesheet back to us in the pre-paid envelope as soon as possible after the 7 days. We will then send your child a certificate summarising their activity levels.

If you or your child no longer wish to take part in the activity monitoring, please return the monitor and belt in the pre-paid envelope provided. If the monitor is lost or damaged we will not charge you to replace or repair it, but please let Carly Rich know on 0800 030 4124 (free phone).

If you have any other questions or would like further information about this part of the study please call Carly Rich on 0800 030 4124 (free phone).

Yours sincerely,

Professor Heather Joshi OBE	Professor Carol Dezateux	Carly Rich
Study Director	UCL, Institute of Child Health	UCL, Institute of Child Health

Appendix H: Information leaflet

Child of the New Century

NatCen National Centre for Social Research

Child of the New Century

Age 7 Survey Physical Activity Monitoring

We would like to measure your child's physical activity using an activity monitor. This leaflet explains more about the activity monitor and activity monitor documents.

What is the Actigraph activity monitor?

The activity monitor is a small, lightweight device that is worn around the hips on a belt. It is designed to measure physical activity by measuring and recording all your child's movements.

The activity monitor contains a spring which moves up and down when your child moves around. The movements of the spring are recorded onto a micro-chip inside the activity monitor.

On the back of your child's activity monitor is a number. This will be the same number that is on your child's timesheet. It would be helpful if you and your child could remember this activity monitor number. This is because a family member, friend or another child in their class might also be wearing a monitor and we do not want them to get mixed up. Please do not take the sticker off the monitor when you return it.

How should the activity monitor be worn?

The activity monitor is worn on a belt. It should be positioned on top of the right hip (on top of the 'bony' part of the hip). The activity monitor should be fitted tightly but comfortably to your child's body. The belt can be adjusted to the correct fit. In order to accurately record your child's movement, it is important that the activity monitor only moves when your child's body moves. For this reason, it is essential that the activity monitor is fitted snugly against your child's body and that it does not have any 'free movement' i.e. it should not be allowed to 'flop around'.

It should usually be worn on top of indoor clothing. If your child prefers he or she can also wear it against the skin underneath their clothing, though they may find that the belt rubs slightly on their skin or that the monitor feels cold. It should not be worn on top of outdoor clothing like coats. Finally, it doesn't matter which way up the monitor goes.

What will happen to the information collected on the activity monitor and timesheet?

The information will be treated in strict confidence in accordance with the Data Protection Act. The information you provide will be used solely to build up a picture of life in the UK today and will not be released in any way that enables you to be identified.

Will I get any feedback about my child's activity levels?

Your child will receive a feedback certificate summarising their activity levels within 4 weeks of sending back the activity monitor.

How do I find out more about this part of the study?

This part of the study in being carried out in collaboration with the researchers at the Institute of Child Health, University College London. They are responsible for sending out the activity monitors and sending you feedback after the monitor has been returned to them. **If you have any other questions or would like further information about this part of the study, please call Carly Rich on 0800 030 4124 (free phone).**

Thank you for your help

When should my child start wearing the activity monitor?

Your child should start wearing the activity monitor on the morning after you receive it. It doesn't matter which day of the week your child starts on. The activity monitor is pre-programmed to turn on automatically at 5am in the morning of the second day after it is posted out. Unless the monitor has been delayed in the post, this should be the morning after you receive it.

If you think your monitor has been delayed in the post, this is fine. Your child should still start to wear it on the morning after it is received as normal. We will know from the timesheet when your child actually started wearing it. The monitor is not programmed to turn off on a particular date so it should remain on for 7 days (even if there is a delay receiving it).

At what times should my child wear the activity monitor?

The activity monitor should be worn every day for 7 continuous days. It should be put on first thing in the morning as soon as your child gets up and worn until your child goes to bed. The activity monitor should not be worn during swimming or when your child is having a bath or shower. However, the monitors are shower proof so it doesn't matter if they get a little bit wet in the rain. The monitors are robust so don't worry about them getting damaged during your child's usual activities even if this includes things like contact sports (e.g. rugby). It is important for us to measure your child's activity during these times. Equally, wearing the monitor during activities like these should not injure your child or other children. However, if you are concerned about this, it is fine to ask your child to remove the monitor for example during contact sports. We would like your child to behave just as they would normally.

What is the timesheet for?

You will be sent a timesheet and asked to keep a record of the dates that the activity monitor is worn, the time that the activity monitor is put on in the morning and taken off at night and any periods that the monitor was not worn for any reason. In addition, any periods spent swimming or cycling should be recorded on the timesheet.

We want to record the time your child has spent swimming as this is the only kind of physical activity for which the monitor cannot be worn. We also want to record the time your child has spent cycling because this kind of activity cannot be measured very accurately by the monitor (though it should still be worn during cycling). We would also like you to indicate whether or not the week that your child wore the activity monitor was a typical week in terms of their physical activity.

What about when my child is at school?

If your child receives their activity monitor during term-time please encourage your child to wear it at school. We hope that most teachers will be happy for children to wear the monitors at school. A letter is enclosed for your child's class teacher which explains to them why your child is wearing the monitor. You should fill in the relevant details on the letter, including your child's activity monitor number which you can find on the back of the activity monitor or on the timesheet. We understand that you may not always know if your child has taken the activity monitor off when they are at school. It would be helpful if you could ask your child if they took the activity monitor off at school for any reason, and record this on the timesheet. If your child receives their activity monitor outside term-time, they should still start to wear the monitor straight away. Please do not wait until your child goes back to school to start wearing the monitor. You don't need to give the letter to the teacher if your child is not at school during the 7-day monitoring period.

When should I return the activity monitor and completed documents?

The activity monitor, belt and completed timesheet must be returned as soon as possible after the 7-day monitoring period is over. Enclosed is a pre-paid envelope to send them back in. You do not need a stamp. It is very important that the activity monitor is returned promptly. This is because we only have a limited number and the monitor will be sent to another family.

Please try not to lose or damage the activity monitor. However, if you do lose or damage the monitor, please call Carly Rich on 0800 030 4124 (free phone). We will not charge you to replace or repair it. We would still like you to return the monitor even if it is damaged.

Appendix I: Timesheet

Child of the new Century

NatCen
National Centre for Social Research

The child first and always

Physical Activity Monitoring

Summary of key points

Child of the New Century
Age 7 Survey

Your child should wear the monitor…

- Every day for 7 continuous days starting the morning after received
- At all times from first thing in the morning to last thing at night – except when swimming, in the shower or in the bath.
- On the belt on top of the right hip (on the 'bony' part of the hip)
- On top of light indoor clothing (or against skin if preferred)
- Tightly but comfortably against body (not 'flopping around')

You should record on the timesheet (on the back of this form)…

- The dates that the monitor was worn
- The times that the monitor was put on in the morning and taken off at night
- Any periods spent swimming or cycling (the monitor should still be worn during cycling)
- Any other periods when the monitor is not worn
- Whether the week the monitor was worn was a typical week in terms of your child's activity levels

You should also…

- Fill in and give the letter about the activity monitor to your child's class teacher (if your child is at school during the 7 day monitoring period)
- Return the activity monitor, belt, and completed timesheet **as soon as possible** after the 7 day period in the pre-paid envelope provided

We will…

- Send your child a certificate and a summary of their activity within 4 weeks after the monitor is sent back
- Treat the information collected by the monitor and recorded on the timesheet in strict confidence in accordance with the Data Protection Act.
- Answer any questions you may have. If you have any questions or problems with the monitor or timesheet, please call Carly Rich from the Institute of Child Health on 0800 030 4124 (free phone)

Child of the new Century

NatCen
National Centre for Social Research

The child first and always

Timesheet

	Example	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Date	10/05/08							
Time put on in morning	7:45am	:	:	:	:	:	:	:
Time taken off at night	8:30pm	:	:	:	:	:	:	:
How many minutes spent swimming	0							
How many minutes spent cycling	65							
How many additional minutes not worn (i.e. they forgot, did not want to wear it)	45							

Was this week typical for your child in terms of their usual activity? Yes / No

IF NO: why not? (e.g. sprained ankle on day 3, not at school) . . . .

. . . .

. . . .

. . . .

For office use only

Appendix J: Teacher letter

Child of the new Century

The child first and always

Child of the New Century
Age 7 Survey

Physical Activity Monitoring
Letter for Class Teacher

Dear ……………………………………………….

My child: ………………………...………………

is taking part in the Age 7 Survey of the Child of the New Century study.

This is an important national survey which is exploring what it is like to grow up in the 21st Century by following around 19,000 children born in the UK in 2000/2001. The study is run by the Centre for Longitudinal Studies, a research centre in the Institute of Education, based at the University of London. The interviews are being carried out by the National Centre for Social Research (NatCen), an independent research organisation. Child of the New Century is paid for the ESRC (the government's Economic and Social Research Council) and other government departments from all countries of the UK.

We have already taken part in the interviews for this study. The study also involves collecting information about my child's physical activity over a period of 7 days using an activity monitor. The activity monitor is a small, lightweight device that is worn on a belt, and should be positioned on top of the right hip. This part of the study is being carried out in collaboration with researchers at the Institute of Child Health (ICH), University College London.

I am writing to let you know that my child is wearing an activity monitor for 7 days for this research project. It is important that the monitor is worn at all times, including when he or she is at school. The only times the monitor should not be worn is during activities such as swimming, bathing or showering when the monitor will get wet. The monitors are robust and can be worn during things like contact sports (e.g. rugby). They should not get damaged or injure my child or other children. I have indicated below whether or not I wish my child to remove the monitor during things like contact sports. However, if you or the school are concerned about this, it is fine to ask my child to remove the monitor during contact sports.

I wish my child to remove the monitor during contact sports: YES/NO (please delete one)

My child's activity monitor number is………….

Thank you for your co-operation

Name ....

Signed ....***Date*** ....

If you would like to know more about the Child of the New Century study, please contact the Centre for Longitudinal Studies on 0800 092 1250 (free phone), or if you have any queries on the physical activity monitor please contact Carly Rich at the Institute of Child Health on 0800 030 4124 (free phone).

Appendix K: Reminder letter

The child first and always

October 08

Dear Parent/ Guardian,

Child of the New Century - Age 7 Survey

Activity Monitor Return

A few weeks ago you were sent your physical activity monitor pack as part of the 'Child of the New Century' – an important national survey which is exploring what it is like to grow up in the 21st century.

We have not yet received your activity monitor, belt, and completed timesheet. It is very important that the activity monitor is returned promptly. This is because we only have a limited number and they will be sent to another family. We would be very grateful if you would return the activity monitor and timesheet as soon as possible. If you require further copies of any of the documents, or you require the activity monitor to be programmed to start at an alternative date please call Carly Rich (phone number below).

If you or your child no longer wish to take part in the activity monitoring, please return the monitor and belt in the pre-paid envelope provided. If the monitor is lost or damaged, please call Carly Rich (phone number below).

If you have any other questions or would like further information about this part of the study please call Carly Rich on 0800 030 4124 (free phone).

If you have already returned the activity monitor and completed documents to us in the last few days, please accept our thanks, and we apologise for writing to you again.

Thank you very much for your help with this important survey.

Yours sincerely,

Professor Heather Joshi OBE	Professor Carol Dezateux	Carly Rich
Study Director	UCL, Institute of Child Health	UCL, Institute of Child Health

Appendix L: Final reminder letter

The child first and always

March 2009

Dear Parent/ Guardian,

Child of the New Century - Age 7 Survey

Activity Monitor Return - Gift Voucher

Thank you and your child very much for your continued help with the Child of the New Century Study.

Some time ago we sent you a physical activity monitor for your child to wear as part of the Child of the New Century Study. Unfortunately, we have not yet received your activity monitor. The physical activity study is now finished and we are extremely keen to locate outstanding monitors. If you do have an activity monitor we would be extremely grateful if you could return it in the enclosed prepaid envelope. Even if the monitor is damaged please still return it. You do not need a stamp. Once we receive your activity monitor you will be sent a **£10 gift voucher**.

If the monitor is lost, please let us know by completing and returning the enclosed post card. If you posted the activity monitor back some time ago this may mean that it was lost in the post. Please also let us know if this is the case by completing the enclosed post card and posting it back to us. You will not need an envelope or stamp. You will not be charged for any loss or damage.

If you have already returned the activity monitor and completed documents to us in the last few days we will still send you a gift voucher once we receive it; please accept our thanks, and we apologise for writing to you again.

If you have any other questions please call one of the study researchers on 0800 030 4124 (free phone).

Yours sincerely,

Heather Joshi

Professor Heather Joshi OBE	Professor Carol Dezateux	Carly Rich
Study Director	UCL, Institute of Child Health	UCL, Institute of Child Health

Appendix M: Freepost postcard for lost monitors

We would be very grateful if you could tick the relevant box and return this post card if either of the following apply to your child's activity monitor:

1. **I / my child has lost the activity monitor ☐**
2. **I have already returned the activity monitor ☐**

Once complete put this card in the post. You do not need an envelope or stamp. You will not be charged for any loss or damage.

Thank you very much for your help with this important survey.

ID:1252

We would be very grateful if you could tick the relevant box and return this post card if either of the following apply to your child's activity monitor:

1. **I / my child has lost the activity monitor ☐**
2. **I have already returned the activity monitor ☐**

Once complete put this card in the post. You do not need an envelope or stamp. You will not be charged for any loss or damage.

Thank you very much for your help with this important survey.

ID:1480

We would be very grateful if you could tick the relevant box and return this post card if either of the following apply to your child's activity monitor:

1. **I / my child has lost the activity monitor ☐**
2. **I have already returned the activity monitor ☐**

Once complete put this card in the post. You do not need an envelope or stamp. You will not be charged for any loss or damage.

Thank you very much for your help with this important survey.

ID:1757

We would be very grateful if you could tick the relevant box and return this post card if either of the following apply to your child's activity monitor:

1. **I / my child has lost the activity monitor ☐**
2. **I have already returned the activity monitor ☐**

Once complete put this card in the post. You do not need an envelope or stamp. You will not be charged for any loss or damage.

Thank you very much for your help with this important survey.

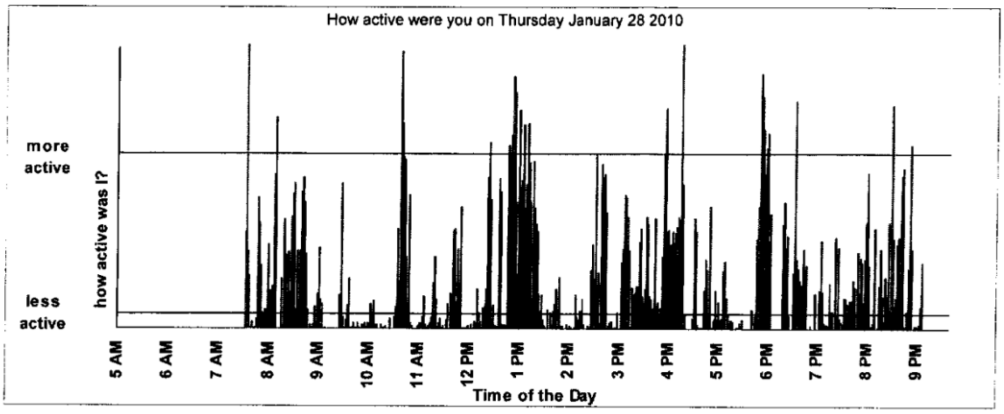
ID:2153

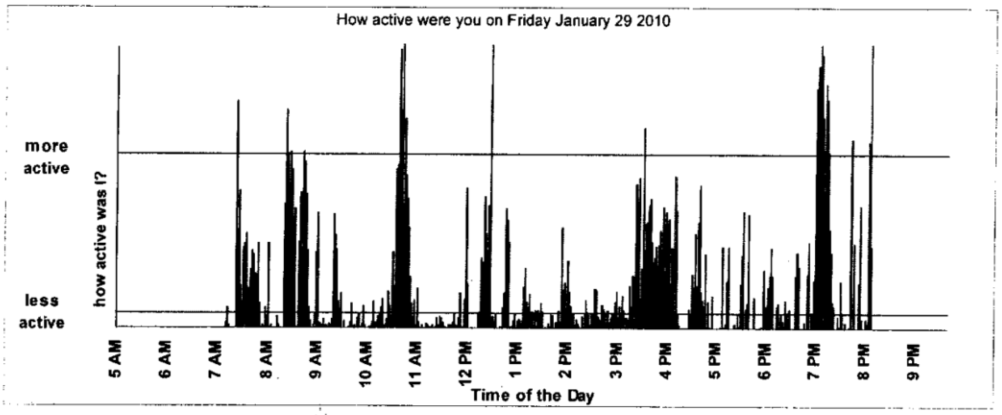
Appendix N: Feedback certificate

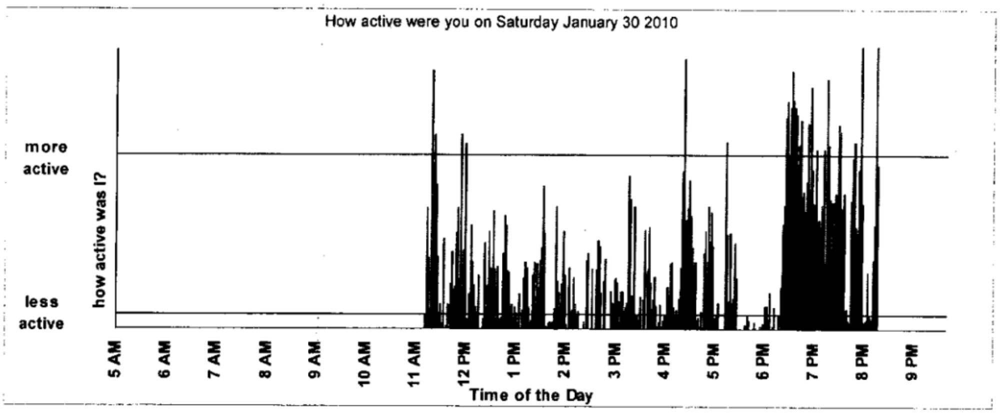
Appendix O: Set of PA graphs sent to children

The child first and always

Child of the New Century
Physical Activity Monitoring Graphs







S5_10476

Appendix P: Feedback certificate explanation letter

The
child
first
and
always

Child of the New Century – Age 7 Physical Activity Monitor Certificate

Thank you and your child very much for your help with this important part of the study.

Please find enclosed a physical activity certificate for your child and a sheet that summarises your child's activity whilst they were wearing their activity monitor. This leaflet will help you to understand the activity graphs, and also help you to explain the graphs to your child.

Your Child's Activity Graphs

For You

- Each graph shows a different day that your child was wearing their activity monitor.
- If there is not a graph for a day, the monitor may have had problems in correctly identifying activity or the monitor was not worn.
- Each graph shows how active your child was from 5 o'clock in the morning until midnight.
- The bars on the graph shows how active your child was at any particular time.
- The higher the bar, the more active your child. Low bars therefore show when you child was less active.
- If there are no bars on the graph at certain times this is when they were not wearing the monitor (e.g. when they were asleep or when they forgot to wear the monitor).
- Any bars above the 'more active' red line show when you child's activity was of moderate intensity, which refers to greater physical effort e.g. brisk walking.
- Current advice from the Department of Health is that children should exercise at this level or higher for about an hour a day on average*.

For You To Explain To Your Child

- See if your child can see the time when they first put the monitor on.
- Ask your child to spot times when the bars are higher (when they were more active).
- Your child might also be able to pick out when they went to school or when they first went out (particularly if they walked), and also when they took part in any sports activities or had a PE lesson.
- They might also be able to see when they took part in anything else active such as playing with friends, taking the dog for a walk, or going shopping.
- Try to see if your child can spot some times when the bars on the graph are lower (when they were less active).
- Your child might be able to spot times when they were sitting down (in class or at home), watching TV, having something to eat, or playing a computer game.

If you have any concerns about your child's physical activity levels please ask your GP for advice.

If you have any other questions, or would like further information about this part of the study, please call Carly Rich or one of the other study researchers on 0800 030 4124 (free phone).

*Department of Health (2004). A Report of the Chief Medical Officer: At Least Five a week: Evidence on the impact of physical activity and its relationship to health http://www.dh.gov.uk/assetRoot/04/08/09/81/04080981.pdf

Appendix Q: Feedback certificate graphs explanation letter – no graphs

The child first and always

Child of the New Century – Age 7 Physical Activity Monitor Certificate

Thank you and your child very much for your help with this important part of the study.

Please find enclosed a physical activity certificate for your child. Unfortunately, your child's monitor had problems in correctly identifying their activity. We were therefore unable to produce any activity graphs to show your child's activity whilst they wearing their activity monitor.

If you have any other questions, or would like further information about this part of the study, please call Carly Rich or one of the other study researchers on 0800 030 4124 (free phone).

Appendix R: Seasonal study invitation letter

The child first and always

Thursday, 26 February 2009

Child of the New Century
Physical Activity Monitoring
Seasonal Study

Once again, thank you and your child very much for taking part in the physical activity monitoring study. You will recall that we recently sent you a physical activity certificate for your child and a sheet that summarised your child's activity whilst they were wearing their activity monitor. As your child successfully completed this study we are writing to invite you and your child to be involved in a related study to measure children's physical activity levels each season of the year. This leaflet explains why we are doing the study and what it would involve for your child.

Why are we doing this study?
Physical activity is extremely important for children's health and to help tackle obesity. Scientists need to find out if children's activity levels change during different times of the year. This study will help us work out how active children of your child's age are during different seasons.

What will your child be asked to do?

- Wear a physical activity monitor three more times throughout the next year.
- The activity monitor should be worn in exactly the same way as before; around their waist, and every day for 7 continuous days.

When will my child have to wear the activity monitor?
If you agree to take part a member of the research team will contact you approximately 3 months after your child first wore the activity monitor to agree a date which is suitable for you and your child to wear the activity monitor again. This will be repeated another two times throughout the year so that your child wears the activity monitor in every season. We will always contact you to agree the dates which are suitable for you and your child to wear the activity monitor.

Will I get any feedback about my child's activity and energy levels?
Yes, we will provide you with information summarizing your child's activity levels for each time your child wears the activity monitor so that you can see how active your child is during every season. Your child will also receive a **£5 gift voucher for every time (£15 total)** they wear and return the activity monitor.

What will happen to the information collected during the study?
The information will be treated in strict confidence in accordance with the Data Protection Act. The information you provide will be used solely in this research study and will not be released in any way that enables you or your child to be identified.

How do I agree for my child to take part in this study?
It is up to you and your child to decide whether or not to take part. If you agree please sign the enclosed consent form and post it back to us in the provided pre-paid envelope. You do not need a stamp.

How do I find out more about the study?
This part of the study is being carried out by the researchers at the Institute of Child Health, University College London. They are responsible for contacting you regarding appropriate dates to send out the activity monitors, sending out the activity monitors, and sending you feedback after the monitor has been returned to them

If you have any other questions or would like further information about this part of the study, please call one of the researchers on 0800 030 4124 (free phone).

Thank you very much for your help.

Yours sincerely,

Professor Carol Dezateux
UCL, Institute of Child Health

Carly Rich
UCL, Institute of Child Health

Appendix S: Seasonal study consent form

CONSENT FORM

Parents/ Guardians

I have read the information letter or it has been read to me. I have had the opportunity to ask questions and discuss the study. I understand that my child has the right to withdraw from the study at any time and I understand that any personal information will be treated as strictly confidential and handled in accordance with the Data Protection Act 1998.

I would like my child to take part in the Child of the New Century 'Seasonal' Physical Activity Monitoring Study

SIGNED:……………………………………………………………………...

DATE: ……………………………………………………………………………………………………….

PRINT NAME (Parent/ Guardian):………………………………………………………......................

PRINT NAME (Child):……………………………………………………………………......................

Please sign this consent form and post it back to us in the provided pre-paid envelope.

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Appendix T: Breaches of protocol report

Study Title: Economic and Social Research Council Millennium Cohort Study Fourth Survey – Dress Rehearsal and Main Survey
REC Reference: 07/MRE03/32

Notification of serious breach of protocol

During the course of the study two serious breaches of protocol occurred in relation to the part of the study which involved measuring the child's physical activity over 7 days using a portable activity monitor. This part of the study was explained and demonstrated by the interviewer during the home visit (with reference to the information leaflets given to families). The interviewer then obtained written consent from study families for the activity monitor to be posted to them within a short period of the home visit. The breach in protocol resulted in a small number of families who had not given their written consent to this element being sent an activity monitor.

Breach 1
In September 2008, the contact details of 28 study families in Northern Ireland who had not consented to the physical activity monitoring were provided in error by the fieldwork agency (National Centre for Social Research/NatCen) to the team responsible for sending out the activity monitors (Institute of Child Health/ICH). This resulted in these 28 families who had not consented being sent an activity monitor.

This was caused by a communication error between Northern Ireland Statistics and Research Agency (NISRA/the data collection sub-contractor in Northern Ireland) and NatCen. Once identified this error was corrected immediately and did not recur for the remainder of the fieldwork.

The team at ICH sent a letter explaining the mistake and asking for the monitors to be returned to the 16 out of 28 non-consenting families who had not returned their activity monitor by the time this breach of protocol was discovered. On completion of the physical activity monitoring study 7 out of 28 children wore and returned their activity monitor, 12 non consenting families returned their monitor unworn and 9 activity monitors were not returned.

No complaints were received from any of the cohort families involved.

Breach 2
On 7th November 2008 NatCen supplied ICH with a contact file (batch 34) of Northern Ireland addresses comprising 73 cases. A problem with this file was identified by ICH on 6 February 2009. NISRA quickly identified the error with this file and delivered a corrected file.

62 of the 73 addresses had been incorrect. The home address variables had become corrupt (so that the address fields had been "rearranged" within the file) but all the other details including serial number, names etc were correct.

The impact of these errors was that:

(i) a number of non-consenting families were approached for the physical activity monitoring study (n=9), and

1

(ii) the names (parents full names and child's first name) of a number of study families were revealed to other study families (n=36) and some non-study families (n=6).

The remaining 11 families had not yet been contacted, by ICH, about the physical activity monitoring study.

This error was caused by an error by NISRA during the manual processes involved in creating this file. This error did not recur for the remainder of the fieldwork.

The team at ICH sent out three different apology letters to the 51 families that had one of the above errors in their activity monitor mailing, depending on the circumstances in which they received it. These letters were as follows:

- Letter A was sent to families that were posted an activity monitoring pack that contained the names of another family in the study and had not yet returned the monitor, or had returned the monitor worn. Families were asked to return the monitor after they had worn it (if it was currently been worn), or asked to return the monitor for recharge, if their child still wanted to wear it.
- Letter B was sent to families that were posted an activity monitoring pack that contained the names of another family in the study and as a result of this had returned the monitor unworn. These families were sent a replacement activity monitoring pack with their correct contact details
- Letter C was sent to families who did not consent to the activity monitoring. These families were asked to return the activity monitor.

None of the non-consenting families, which were approached for the physical activity monitoring study, took part in the study.

On completion of the physical activity monitoring study 15 activity monitors were not received back as a result of this breach of protocol.

No complaints were received from any of the families involved.

Appendix U: Letter explaining delay in receiving funding

The child first and always

15 October 2012

Dear Parent/ Guardian,

Child of the New Century - Age 7 Survey
Physical Activity Monitoring Apology

Thank you very much for your help with this important part of the study.

We are extremely sorry that your child has not yet received their activity monitor. Unfortunately, there was a delay in receiving funding to purchase the activity monitors. The researchers have now got the activity monitors and need to catch up in sending them to all children that have been interviewed so far. Your child should receive their monitor within the next 4 months.

If you or your child no longer wish to take part in the activity monitoring please call Carly Rich as soon as possible on 0800 030 4124 (free phone). Please also contact this number if you move address over the next 4 months in order that your child's activity monitor can be sent to your new address.

If you have any other questions or would like further information about this part of the study please call Carly Rich on 0800 030 4124 (free phone).

Yours sincerely,

Heather Joshi

Professor Heather Joshi OBE	Professor Carol Dezateux	Carly Rich
Study Director	UCL, Institute of Child Health	UCL, Institute of Child Health

Appendix V: Estimated regression coefficients and *p*-values for interactions between season and other confounders

	Adjusted (95% CI)	*p*-value
Total physical activity (counts per minute)		
Season:child's gender		
Global test		**0.664**
Spring-Girls	-12.72 (-35.01, 9.57)	0.263
Summer-Girls	-11.74 (-34.49, 11.00)	0.312
Autumn-Girls	-7.60 (-31.08, 15.87)	0.526
Season:child's ethnicity		
Global test		**0.371**
Spring-Mixed	47.25 (-64.10, 158.60)	0.406
Spring-Indian	-38.58 (-116.47, 39.31)	0.332
Spring-Pakistani/Bangladeshi	-34.58 (-121.08, 51.93)	0.433
Spring-Black or black British	-86.71 (-191.66, 18.23)	0.105
Spring-Other	9.76 (-108.30, 127.82)	0.871
Summer-Mixed	-96.97 (-208.44, 14.50)	0.088
Summer-Indian	-51.36 (-132.20, 29.47)	0.213
Summer-Pakistani/Bangladeshi	-16.08 (-116.54, 84.38)	0.754
Summer*Black or black British	-34.56 (-146.03, 76.90)	0.543
Summer-Other	-17.36 (-159.36, 124.64)	0.811
Autumn-Mixed	-39.73 (-161.45, 82.00)	0.522
Autumn-Indian	-46.00 (-127.14, 35.13)	0.266
Autumn-Pakistani/Bangladeshi	93.44 (-14.40, 201.28)	0.089
Autumn-Black or black	-34.18 (-145.69, 77.32)	0.548
Autumn-Other	-20.53 (-186.06, 145.00)	0.808
Season:child's BMI		
Global test		**0.304**
Spring-Overweight/obese	-27.40 (-58.57, 3.77)	0.085
Summer-Overweight/obese	-23.54 (-54.97, 7.88)	0.142
Autumn-Overweight/obese	-12.83 (-45.73, 20.07)	0.445
Season:maternal occupation		
Global test		**0.191**
Spring-Intermediate	11.97 (-22.32, 46.27)	0.494
Spring-Small employers & own account workers	17.77 (-27.82, 63.35)	0.445
Spring-Lower supervisory & technical	18.10 (-72.84, 109.04)	0.696
Spring-Semi-routine & routine	29.97 (-7.83, 67.77)	0.120
Spring-Non-employed	-8.96 (-40.13, 22.21)	0.573
Summer-Intermediate	10.14 (-25.16, 45.44)	0.573
Summer-Small employers & own account workers	23.33 (-21.95, 68.62)	0.313
Summer-Lower supervisory & technical	45.13 (-42.30, 132.56)	0.312
Summer-Semi-routine & routine	7.83 (-30.72, 46.37)	0.691
Summer-Non-employed	-14.52 (-46.67, 17.64)	0.376
Autumn-Intermediate	11.31 (-25.00, 47.62)	0.542
Autumn-Small employers & own account workers	20.38 (0.58, 175.87)	0.387
Autumn-Lower supervisory & technical	88.23 (22.05, 101.81)	0.048

Autumn-Semi-routine & routine	61.93 (22.05, 101.81)	0.002
Autumn-Non-employed	14.00 (-19.00, 46.99)	0.406
Season:maternal academic status		
Global test		**0.380**
Spring- Higher education/ teaching qual./ diplomas	0.16 (-26.00, 26.31)	0.990
Spring-A/AS/S-levels	5.56 (-38.86, 49.98)	0.806
Spring-O-levels/GCSE grades A-C	NA	NA
Spring-GCSE grades D-G	161.93 (-110.95, 434.81)	0.245
Spring-Other academic qualifications	-62.01 (-151.22, 27.20)	0.173
Spring-None of these	-3.19 (-55.51, 49.14)	0.905
Summer- Higher education/ teaching qual./ diplomas	16.24 (-10.30, 42.78)	0.230
Summer-A/AS/S-levels	-1.05 (-47.03, 44.93)	0.964
Summer-O-levels/GCSE grades A-C	NA	NA
Summer-GCSE grades D-G	209.27 (-64.34, 482.88)	0.134
Summer-Other academic qualifications	-51.10 (-143.79, 41.59)	0.280
Summer-None of these	36.08 (-17.46, 89.62)	0.187
Autumn- Higher education/ teaching qual./ diplomas	-7.22 (-34.33, 19.89)	0.602
Autumn-A/AS/ S-levels	-25.22 (-72.78, 22.33)	0.299
Autumn-O-levels/GCSE grades A-C	NA	NA
Autumn-GCSE grades D-G	NA	NA
Autumn-Other academic qualifications	-123.48 (-213.47, -33.48)	0.007
Autumn-None of these	-1.20 (-54.58, 52.17)	0.965
Season:country		
Global test		**0.002**
Spring-Wales	-16.53 (-52.23, 19.17)	0.364
Spring-Scotland	24.19 (-2.29, 50.67)	0.073
Spring-Northern Ireland	17.12 (-22.86, 57.10)	0.401
Summer-Wales	-26.49 (-63.21, 10.23)	0.157
Summer-Scotland	17.55 (-9.57, 44.66)	0.205
Summer-Northern Ireland	65.23 (24.34, 106.13)	0.002
Autumn-Wales	-39.26 (-77.09, -1.43)	0.042
Autumn-Scotland	-0.05 (-28.20, 28.09)	0.997
Autumn-Northern Ireland	60.13 (18.87, 101.40)	0.004
Sedentary Behaviour		
Season:child's gender		
Global test		**0.902**
Spring-Girls	-0.23 (-7.59, 7.13)	0.951
Summer-Girls	-0.25 (-7.74, 7.24)	0.948
Autumn-Girls	2.46 (-5.36, 10.28)	0.538
Season:maternal occupation		
Global test		**0.653**
Spring-Intermediate	-3.44 (-14.30, 7.42)	0.534
Spring-Small employers & own account workers	-0.82 (-15.52, 13.88)	0.913
Spring-Lower supervisory & technical	-1.85 (-31.86, 28.15)	0.904
Spring-Semi-routine & routine	-9.24 (-20.67, 2.18)	0.113
Spring-Non-employed	1.59 (-8.17, 11.36)	0.749

Summer-Intermediate	-3.39 (14.56, 7.78)	0.552
Summer-Small employers & own account workers	-3.38 (-18.02, 11.26)	0.651
Summer-Lower supervisory & technical	-6.78 (-34.64, 21.08)	0.633
Summer-Semi-routine & routine	5.74 (-6.10, 17.57)	0.342
Summer-Non-employed	4.65 (-5.26, 14.57)	0.358
Autumn-Intermediate	5.02 (-6.77, 16.81)	0.404
Autumn-Small employers & own account workers	1.50 (-13.51, 16.51)	0.845
Autumn-Lower supervisory & technical	-10.05 (-40.10, 20.00)	0.512
Autumn-Semi-routine & routine	4.51 (-7.90, 16.91)	0.477
Autumn-Non-employed	3.53 (-6.75, 13.79)	0.501
Season:ward type		
Global test		**0.687**
Spring-Disadvantaged	4.21 (-3.59, 12.01)	0.290
Spring-Ethnic	3.50 (-14.39, 21.39)	0.701
Summer-Disadvantaged	0.93 (-7.06, 8.93)	0.819
Summer-Ethnic	2.52 (-15.43, 8.93)	0.783
Autumn-Disadvantaged	7.35 (-0.93, 15.64)	0.082
Autumn-Ethnic	0.52 (-18.65, 19.70)	0.957
Vigorous physical activity		
Season:child's gender		
Global test		**0.165**
Spring-Girls	-1.99 (-3.75, -0.24)	0.026
Summer-Girls	-0.68 (-2.46, 1.10)	0.454
Autumn-Girls	-1.01 (-2.88, 0.85)	0.287
Season:child's BMI		
Global test		**0.127**
Spring-Overweight/obese	-2.93 (-5.35, -0.50)	0.018
Summer-Overweight/obese	-0.68 (-3.80, 1.08)	0.276
Autumn-Overweight/obese	-1.01 (-3.50, 1.65)	0.481
Season:maternal occupation		
Global test		**0.613**
Spring-Intermediate	0.88 (-1.69, 3.45)	0.503
Spring-Small employers & own account workers	2.96 (-0.56, 6.48)	0.099
Spring-Lower supervisory & technical	-1.35 (-8.46, 5.76)	0.710
Spring-Semi-routine & routine	2.16 (-0.53, 4.85)	0.116
Spring-Non-employed	-1.29 (-3.61, 1.03)	0.277
Summer-Intermediate	-0.34 (-2.98, 2.31)	0.803
Summer-Small employers & own account workers	1.68 (-1.79, 5.15)	0.343
Summer-Lower supervisory & technical	1.81 (-4.78, 8.40)	0.590
Summer-Semi-routine & routine	0.45 (-2.33, 3.23)	0.752
Summer-Non-employed	-1.60 (-3.96, 0.76)	0.184
Autumn-Intermediate	-0.74 (-3.53, 2.04)	0.601
Autumn-Small employers & own account workers	2.17 (-1.39, 5.73)	0.232
Autumn-Lower supervisory & technical	1.80 (-5.31, 8.92)	0.619
Autumn-Semi-routine & routine	0.65 (-2.27, 3.58)	0.662
Autumn-Non-employed	-1.01 (-3.46, 1.45)	0.421

Season:country		
Global test		**0.012**
Spring-Wales	0.67 (-1.60, 2.95)	0.894
Spring-Scotland	1.43 (-0.24, 3.11)	0.193
Spring-Northern Ireland	2.24 (-0.31, 4.81)	0.010
Summer-Wales	-0.99 (-3.34, 1.35)	0.584
Summer-Scotland	1.12 (-0.59, 2.84)	0.371
Summer-Northern Ireland	2.60 (-0.02, 5.22)	0.009
Autumn-Wales	-1.23 (-3.64, 1.18)	0.022
Autumn-Scotland	0.01 (-1.76, 1.78)	0.483
Autumn-Northern Ireland	4.72 (2.08, 7.36)	0.016
MVPA		
Season:child's gender		
Global test		**0.009**
Spring-Girls	-5.33 (-8.62, -2.04)	0.002
Summer-Girls	-3.67 (-7.03, -0.32)	0.032
Autumn-Girls	-1.44 (-4.94, 2.06)	0.421
Season:child's BMI		
Global test		**0.150**
Spring-Overweight/obese	-5.02 (-9.54, -0.49)	0.030
Summer-Overweight/obese	-1.05 (-5.61, 3.51)	0.652
Autumn-Overweight/obese	-0.65 (-5.45, 4.16)	0.792
Season:country		
Global test		**0.001**
Spring-Wales	-1.55 (-6.84, 3.74)	0.566
Spring-Scotland	3.05 (-0.83, 6.94)	0.123
Spring-Northern Ireland	6.15 (0.38, 11.92)	0.037
Summer-Wales	-3.18 (-8.65, 2.28)	0.254
Summer-Scotland	3.00 (-0.95, 6.95)	0.137
Summer-Northern Ireland	11.07 (5.18, 16.96)	<0.001
Autumn-Wales	-6.56 (-12.22, -0.89)	0.023
Autumn-Scotland	-2.88 (-7.03, 1.26)	0.173
Autumn-Northern Ireland	6.07 (-0.04, 12.17)	0.051