The impact of standing desks within the school classroom on sedentary behaviour, physical activity, health and development

by

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Abstract

Internationally, children spend most of their waking hours sedentary. Growing evidence indicates that sedentary behaviour tracks and continually increases from childhood through to adulthood. This is of public health concern because in adulthood excessive sedentary time is clearly associated with an increased risk of morbidity and mortality. Consequently, early intervention is essential before sedentary habits become entrenched and years of potentially harmful exposure are endured. Standing desks within the school classroom have emerged as one of the most promising strategies for reducing total sedentary time in children. This thesis focuses on sedentary behaviour in children and the implementation of standing desks in the school environment and the influence of standing desks on reducing sedentary time.

Chapter 2 describes a systematic review of the impact of standing desks within the school classroom. Systematic reviews are an essential component of evidence-based practice and provided vital information and direction for the research described in later chapters. The systematic review demonstrated that standing desk interventions implemented within the school classroom is a rapidly emerging area of research. There were promising early findings from pilot studies on important outcomes related to health, feasibility and development. However, more long-term studies and studies specifically measuring sitting behaviour as an outcome are needed.

Chapter 3 outlines and critically evaluates the methods and data reduction decisions made for both the activPAL and ActiGraph measurement devices relating to the research reported in Chapters 4 and 5. Many decisions made for data reduction procedures were standard practice and recommended within sedentary behaviour and physical activity research. However, with small initial samples in Chapters 4 and 5, there was a conflict between retaining as much of these samples as possible while also gaining the most valid and representative data of behaviour. Data compliance was modest in Chapter 4 and somewhat poor within intervention groups in Chapter 5, which is a limitation of the evidence presented within these chapters.

Chapter 4 describes a cross-sectional surveillance study that was designed to fill gaps in the literature about children's objectively-measured levels and patterns of sedentary time and physical activity accumulation, and to gain a greater insight into times of the day and week where interventions could be best targeted. Children in Year 5 of primary

school and of South Asian and White British ethnicity of lower socio-economic position were the population of interest. The results demonstrated that children were highly sedentary during different periods of the week; over 10 hours/day on school days and 11 hours/day on weekend days was spent sitting. This also included high proportions of waking hours spent in prolonged sitting bouts (30+ mins), particularly after school and on weekends, which has not been observed in European children previously. To inform interventions, further longitudinal research is required, with larger sample sizes spread across multiple UK areas, to better understand the levels and patterns of sitting accumulated at and away from school in children.

Chapters 5 describe the impact of the Stand Out In Class intervention pilot, the first longer-term standing desk study based in the primary school classroom in Europe. The Stand Out In Class intervention was underpinned by the Behaviour Change Wheel framework, COM-B model and Behavioural Change Taxonomy (v1). This chapter describes the impact of two different intervention designs; full desk allocation (FDA) (one per child) and partial desk allocation (PDA) (children rotated between sit-stand desks and traditional seated desks) on objectively measured classroom sitting time and physical activity in Year 5 children based in a school in Bradford, UK. Changes in sitting time and physical activity in these two classes were compared to a control class located within a nearby school. Sitting time (activPAL data) and physical activity (activPAL and ActiGraph data) were measured during a 7-day period at baseline (autumn/winter) 4 months (spring) and 8 months (summer) of desk exposure. Children were not rotated on a regular basis (as planned) within the PDA group and therefore the intervention was not implemented sufficiently. Consequently, data from this group were difficult to interpret with any clarity. Large reductions were observed in the proportion of wear time spent sitting during class time and during a total week day in the FDA group compared to the control group at both 4 months (class time -25.3%, full week day -7.7%) and 8 months (class time -19.9%, full week day -5.5%). Chapter 5 also describes the impact of the Stand Out In Class intervention on adiposity, cognitive function, musculoskeletal discomfort and behaviour-related mental health at 4 months and 8 months of intervention exposure in FDA and PDA groups. The intervention demonstrated no influence on adiposity outcomes. The sit-stand desks appeared to have a negative influence on behaviour related mental health over time in both intervention groups. No changes were observed in musculoskeletal discomfort scores or in cognitive function scores. Chapters 5 together suggest sit-stand desks in the classroom may influence reductions in sitting time over the longer-term within an FDA system although careful consideration are needed for day-to-day teaching practicalities.

Chapter 6 evaluated the implementation of the Stand Out In Class intervention within the FDA and PDA classes using focus groups with pupils and interviews with teachers. Within the FDA class, standing classes were delivered by the lead teacher, however, acceptance of sufficient intervention delivery was based on the word of the teacher and a single classroom observation only, with no other evidence available. Within the PDA class, insufficient child rotation appeared to be due to a lack of motivation from the teacher, a behaviourally challenging group of pupils, curriculum pressures, lack of space, lack of time and the distracting nature of the desks. Overall this intervention encountered many barriers to effective implementation which should be considered in future standing desk interventions adopting a PDA system. Evaluation in this study would have benefitted from daily or weekly implementation logs for teachers in both FDA and PDA classes. Future qualitative research should attempt to explore barriers and solutions to effective PDA intervention implementation as this is the more economically feasible system.

This thesis found that sit-stand desks in the classroom may influence a reduction in children's sitting time using a full allocation approach and provides important evidence for sedentary behaviour patterns, intervention design and public health and education policy for UK children. The evidence provided in this thesis is pertinent in children of South Asian and White British ethnicity of lower socio-economic position. The utilisation of standing desks in the classroom environment holds potential for reducing children's sitting time

Student contributions to this thesis

Chapter 1	This chapter was entirely written by the student. AS searched the relevant literature to identify key papers. AS reviewed and critiqued all key papers and produced the content for all sections of this chapter. AS co-designed the structure of the introduction (sub sections and order of sub sections).
Chapter 2	This chapter was entirely written by the student. AS co-designed this study. AS produced the search terms for database searches, conducted all database searchers and manual searchers within relevant paper reference lists. AS co-developed the study inclusion criteria. AS conducted all stages of the article identification process (screened titles and where necessary, screened abstracts and full articles). AS identified all eligible and ineligible papers and consulted NP and SC for papers that were unclear for eligibility. AS co-developed an in/out form used to record the outcome of potentially eligible papers, specifying why a paper was excluded. AS extracted all data from all identified studies. AS assessed the quality of all identified papers. AS produced the study quality category boundaries. AS co-designed all result table formats. AS produced most of the interpretations of the findings with the remainder established after discussions with NP and SC.
Chapter 3	This chapter was entirely written by the student. AS decided the content and structure of this chapter. AS reviewed and critiqued all cited papers.
Chapter 4	This chapter was entirely written by the student. AS co-designed this study. AS recruited and obtained consent/assent from all participants within the 2015 sample. AS conducted all assessments/measurements within the 2015 sample. AS downloaded all raw activPAL data (.pal files) from all devices from the 2015 sample. All data included in this study from the 2014 pilot study (Stand Out in Class 1) were obtained from a colleague based at the Born in Bradford project. Raw activPAL data (.pal files) were also obtained. AS fully processed all non-activPAL data. All raw activPAL data were converted to 15 second epoch files (.csv) by AS. AS sent these files to Dr Nicola Ridgers (NR) for further processing. AS co-developed the

	parameters for non-wear time, bout lengths, wear time compliance, domains (i.e. school time, after school, weekend day) and outcome variables to be explored and reported. AS condensed the Excel data sent from NR into domain and outcome categories/columns and transferred to SPSS for analysis. AS performed all statistical analysis and co-decided on the tests performed. AS designed all results tables, provided interpretation for most of the study findings and co-developed the remainder.
Chapter 5	This chapter was entirely written by the student. AS recruited and obtained consent/assent from all participants within the sample. AS applied for ethical approval for this study and gained approval. AS organised recruitment, consent/assent obtainment and data collection with both schools. AS co-developed the teacher resource manuals, the rotation plan for the partial allocation class and provided in-person teacher support on a monthly basis. AS fully applied the COM-B model, Behaviour Change Wheel and Behaviour Change Taxonomy (v1) to both intervention designs. AS co-produced all figures and tables related to theoretical underpinning. AS prepared, deployed, retained and downloaded data for all activPAL and ActiGraph devices. All raw activPAL data (.pal files) were converted to 15 second epoch files (.csv) by AS. AS sent these files to Dr Nicola Ridgers for further processing. AS condensed the Excel data sent from NR into domain and outcome categories/columns, transferred the data to SPSS and then Stata for analysis. AS co-developed the parameters for non-wear time, bout lengths, epoch length, wear time, domains and outcome variables to be explored and reported for activPAL and ActiGraph data. AS processed all ActiGraph data and transferred the data to SPSS/Stata. AS decided to use the age adjusted Freedson cut points and applied the cut points during processing. AS applied all processing parameters (wear time, non-wear time, axis use, epoch length, sampling frequency) to ActiGraph data. AS made the decision to use multi-level modelling. AS conducted all statistical analysis in this chapter. AS co-decided on the variables that were presented in the results. AS designed all results formats and provided the vast majority

	of discussion points. AS developed the remainder after consultation with colleagues.
Chapter 6	This chapter was entirely written by the student. AS co developed the measurement outcomes. AS produced the semi-structured interview/focus group questions and implemented them in the FDA class. AS processed all outcome measurement data. AS co-designed all results formats and provided the vast majority of discussion points. AS developed the remainder after consultation with colleagues.
Chapter 7	This chapter was entirely written by the student. All arguments/discussion points were developed by AS.

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Aron.

Publications

Published work

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Sherry AP, Pearson N, Johnson W, Ridgers ND, Barber SE, Bingham DD, Nagy LC, Clemes SA. Stand Out In Class: impact of an 8 month sit-stand desk intervention on children's sitting behaviour, health and development. Preventive Medicine.

Conference contributions

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Sherry AP, Pearson N, Johnson W, Ridgers ND, Barber SE, Bingham DD, Nagy LC, Clemes SA. The effectiveness of sit-to-stand desks to reduce sitting time within a primary school classroom: an 8-month controlled trial. Oral presentation at the 2017 Annual Meeting of the Health-Enhancing Physical Activity conference (HEPA), Zagreb, Croatia.

Abbreviations

BCT – behaviour change technique

BCW – behaviour change wheel

BMI – body mass index

COM-B – Capability, Opportunity and Motivation to change Behaviour

CI – confidence interval

CVD – cardiovascular disease

FA – full allocation group

HDL – high density lipoprotein

HSE – Health Survey for England

Hz – Hertz

LPA – light physical activity

LPL – lipoprotein lipase

MET – metabolic equivalent

MVPA – moderate to vigorous physical activity

NCD – non-communicable disease

NHANES - National Health and Nutrition Examination Survey

NHS – National Health Service

PA – physical activity

PAR – partial allocation group

RCT – randomised controlled-trial

SB – sedentary behaviour

SBRN – Sedentary Behaviour Research Network

SEP - Socio-economic position

SCT – Social Cognitive model

TPB – Theory of Planned Behaviour

TTM – Transtheoretical Model

TV – television

USA – United States of America

WHO – World Health Organisation

Table of contents

List of Figures

List of Tables

CHAPTER 1 - Introduction

1.1. Development of the 21st century lifestyle: health and economic implications

Human beings for 99% of existence have lived as hunters and food gatherers (1). During this time, high levels of physical activity (PA) were required and food was inconsistently available from day-to-day, with the human physiology developing to avoid a negative energy balance (2). During recent history, a series of evolutionary periods occurred which have drastically altered the environments in which we now live.

The industrial period (1800-1945) influenced overcrowding, poor nutrition, poor public health measures and inadequate medical care, resulting in high proportions of infectious diseases in developed countries (3). During the mid-20th century, a technological revolution proliferated, which witnessed advances in public health measures and consequential improvements in infectious disease rates in developed countries (3). However, at the same time major environmental and technological changes led to the ever declining need for human movement in all aspects of daily living, along with widely available food that is energy dense and inexpensive (2). Continual advances in modern technology has resulted in reductions in physical activities associated with daily living, and in sedentary behaviour (SB) becoming ubiquitous within the community, home, at the work place, within the educational setting and during transport. It is also possible that our full potential (peak) of daily sitting time is yet to be reached as these developments continue (4). These dramatic societal shifts have ultimately resulted in humans living 21st century lifestyles but with hunter gatherer genes (3), with major consequences for energy balance and cardio-metabolic health. This is clearly reflected in weight gain trends; currently more than one in two adults and one in six children are overweight or obese internationally, with projected obesity rates predicted to further increase by 2030 (5). With modern environments strongly influencing weight gain, substantial conscious effort is now required to maintain a healthy weight (2).

The 21st century lifestyle has led to an acute rise in non-communicable chronic diseases (NCDs) such as cardiovascular disease (CVD), type 2 diabetes, respiratory diseases and cancer, which are now responsible for approximately 70% of all deaths worldwide (6). This has triggered an epidemiological transition in developed countries; a shift from infectious disease as a predominant cause of morbidity and mortality towards NCDs. This shift is now materialising in developing countries (7).

A demographic transition is also taking place worldwide where countries at various stages of development are experiencing increased life expectancies (7). Risk factors of common NCDs (i.e. impaired glucose tolerance, lower HDL cholesterol) and the conditions themselves (i.e. CVD, type 2 diabetes) would appear to be developing at ever earlier stages of life (7,8). These developments are resulting in individuals being burdened with ever increasing numbers of life years spent in ill health and attenuated quality of life.

The treatment of chronic conditions is a continually increasing economic burden; patients live longer as treatments improve which therefore extends the treatment period. Furthermore, prolonged years of life spent in disability that is brought about by NCD has a detrimental effect on occupational productivity, absenteeism and presenteeism (attending work while unwell), causing a further (indirect) economic burden that may exceed direct costs (7).

It is estimated that common NCDs collectively are 80% preventable and that positive lifestyle change such as healthy nutrition, regular exercise and smoking cessation can modify the development and progression of even genetic NCD risk factors (7). Primary prevention, that is action taken before the disease has had chance to develop, has enormous potential to improve population health. This includes influencing positive lifestyles in children and young people with the intention that such healthy behaviours will remain throughout the life course. The evidence of the health benefits of regular PA across age groups is compelling (9–11) and the potential gains for reducing or interrupting the time spent in prolonged SB is rapidly emerging (12,13). Consequently, integrating regular PA whilst limiting the time spent in SBs during the early stages of life could provide major societal benefits to population health and to local and national economies.

It has been estimated that just 4% of government health spending has been directed at preventative health strategies in the UK (14). With continual strain on the National Health Service (NHS) due to an expanding population that is growing older, with increases in morbidity and the developing of health problems from earlier ages, more investment, research, and policy development into primary prevention may be critical for future generations.

1.2. Sedentary behaviour: definitions and characteristics

Since the rapid expansion of SB research from the early 2000s (15), it has been common for SB or a sedentary lifestyle to be referred to as simply a lack of PA (16). This still occurs in some research disciplines (16), despite the initial emergence of SB definitions in 2012. SB is currently defined as 'any waking behaviour characterised by an energy expenditure of ≤1.5 metabolic equivalents (METs) while in a sitting, reclining or lying posture' (16). While reclining and lying postures are included in the definition, the vast majority of time an individual (young people and adults) spends sedentary will be in a sitting position during waking hours. Indeed, the Latin origin of the word sedentary means to sit (17). This definition acknowledges the importance of posture but also energy expenditure in defining SBs. However, SB continues to be misinterpreted across research disciplines (16). Consequently, the Sedentary Behaviour Research Network (SBRN), which consists of members from 35 countries across all inhabited continents, undertook a recent Consensus Terminology Project to address the need for clarity and standardisation across research disciplines, sectors and industries (16). Key terms and definitions relating to SB and PA, some of which were developed by the Consensus Terminology Project, are summarised in Table 1.1.

Table 1.1. Key terms and definitions relating to sedentary behaviour, some of which were recently developed by the Consensus Terminology Project (16).

Term	**Definition**
Physical activity	Any bodily movement produced by skeletal muscles that results in energy expenditure (18)
Physical inactivity	An insufficient level of physical activity to meet physical activity recommendations (19)
Screen time	The time spent in screen-based behaviours (20), can be performed either sedentary or while being physically active
Non-screen-based sedentary time	The time spent in sedentary behaviours that do not involve a screen
Stationary behaviour	Any waking behaviour while lying, reclining, sitting, or standing, with no ambulation, irrespective of energy expenditure (16)
Stationary time	Time spent in any waking behaviour while lying, reclining, sitting, or standing, with no ambulation, irrespective of energy expenditure (16)
Sedentary behaviour pattern	The manner in which sedentary behaviour is accumulated throughout the day or week while awake (e.g. the timing, duration and frequency of sedentary bouts and breaks) (21)
Sedentary behaviour bout	A period of uninterrupted sedentary time (22)
Sedentary behaviour interruption/break	A non-sedentary bout in between two sedentary bouts
Passive standing	A non-sedentary ≤2.0 MET stationary behaviour

Term	Definition
Active standing	A stationary ≥2.0 MET physical activity

The 1.5 METs threshold for SB has been the subject of much debate but overall it received a broad base of support for all age ranges within the SBRN during the Consensus Terminology Project (16). The term “stationary time” is a very recent term that replaces “sedentary time” when describing accelerometry data since accelerometer devices, when worn on the hip, cannot distinguish between sitting and standing postures (23) (see section 1.4.2.1). “Passive standing” and “active standing” were developed based on findings from controlled laboratory studies (16). Although a definition for a sedentary bout has been established, there is no consensus on the minimum amount of time that constitutes such a bout as yet (although ≥10 min has been proposed (16)). A break in sedentary time can be in the form of standing, light PA (LPA) or moderate-to-vigorous PA (MVPA), however the specific time limit to constitute a break rather than simply a change to a PA (i.e. five minutes of standing), is yet to be determined (16). For consistency and clarity, these definitions, including “stationary time” when describing studies that have used accelerometer (movement-based) data to determine sedentary time, will be used throughout this thesis.

It is important that a clear distinction is made in health research between PA and SBs as evidence suggests that they have contrasting behavioural mechanisms (24), different determinants (25), track differently (26) and have some contrasting health consequences (27). In terms of adopting healthy sedentary and PA habits, it is important to understand that an individual can easily meet PA guidelines (i.e. 30 min/day of MVPA for adults (28)) yet also be highly sedentary (see Figure 1.1). Furthermore, it is very possible for an individual to be inactive (fail to meet PA recommendations) but not excessively sedentary, with lighter physical activities making up a large proportion of a waking day. Figure 1.2 details how SB fits within the 24-h movement continuum alongside sleep and PA. It demonstrates that sitting, reclining and lying postures can be adopted in sleep, SB and PA categories. It is the level of energy expended that is the distinguishing factor between SB and PA.

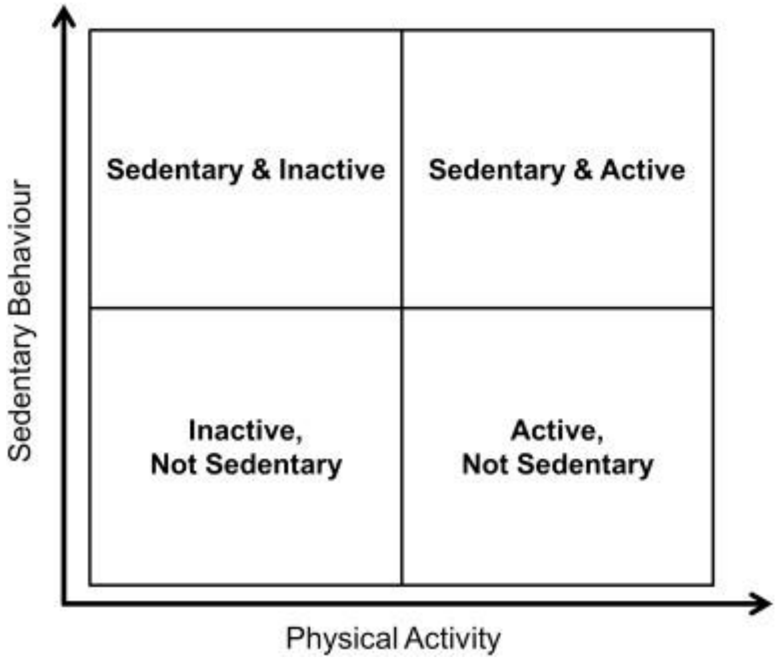

Figure 1.1. Sedentary behaviour and physical activity as distinct constructs. Active means an individual meets physical activity recommendations (e.g. ≥ 60 minutes of daily MVPA for children (28)). Sedentary refers to the time spent in sedentary behaviour as defined by the current definition (any waking behaviour characterised by an energy expenditure of ≤1.5 metabolic equivalents (METs) while in a sitting, reclining or lying posture (16)). While current evidence is unable to provide specific thresholds for the amount of time that is regarded as excessively sedentary, in this figure, a 'sedentary' person can be broadly interpreted as towards the higher end of the daily sedentary time scale (i.e. >8 hr/day spent sedentary) whereas as a person who is 'not sedentary' can be broadly interpreted as towards the lower end of the sedentary time scale (i.e. >8 hr/day spent sedentary). Source: Saunders et al. 2014 (29).

During waking hours, an individual is either sedentary or physically active. The displacement hypothesis suggests that SB and PA displace one other at any given moment (30). This has led to the hypothesis that participation in PA is hindered by time spent sedentary (31). A systematic review and meta-analysis of observational studies in young people reported that SB is inversely associated with MVPA but the relationship is weak (31). The authors concluded that the two behaviours should not be considered 'opposite sides of the same coin' and that while the direction of the relationship supports the displacement hypothesis, the small magnitude does not support direct substitution

(31). Consequently, it would seem that the two behaviours can co-exist with time. The association between LPA and sedentary time however is large because typically, time spent in SBs is more commonly and more easily replaced with standing or light ambulation (32).

Instead of exploring the benefits of reducing or increasing the time spent in different movement or non-movement behaviours in isolation, very recent research efforts have focused on the combined effect of PA, SB and sleep during a 24-h period on health outcomes (33). This is based on the premise that opportunity for each of the three behaviours are finite during a 24-h period, each behaviour has demonstrated independent effects on health (9,34,35) and therefore exploring an optimal combination of these behaviours may be the logical next stage of research. Also, it is argued that exploring whether one of these behaviours has an effect on health outcomes independent of the other behaviour may be conceptually wrong; time spent in one behaviour is naturally co-dependent on time spent in the others and therefore the overall 24-h composition should be considered together (36). Unsurprisingly, a combination of high PA, low SB and high sleep has demonstrated the most promising effects in health outcomes in young people, albeit in low quality observational studies (33). The growing interest and support for a 24-h movement continuum approach has culminated in the very recent Canadian PA/SB guidelines for young people being based on this concept (see section 1.10) (37).

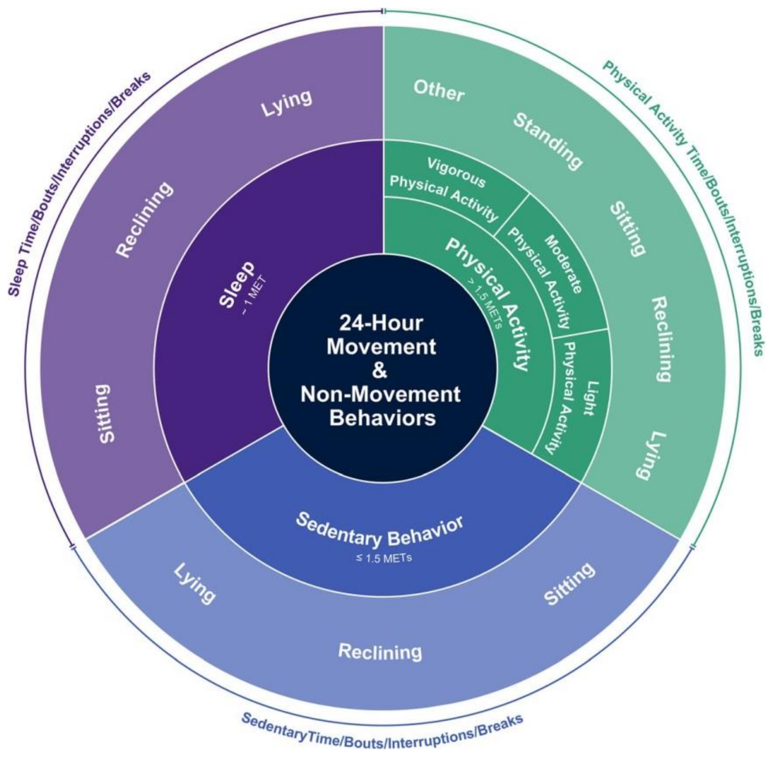

Figure 1.2. Illustration of the conceptual model of movement-based terminology arranged around a 24-h period, developed by the Sedentary Behaviour Research Network. Source: Tremblay et al. (2017).

1.3. Different types of sedentary behaviour

The recent Consensus Terminology Project (16) broadly outlined the different types of SB. Generally, SB falls into two categories; screen-based and non-screen-based. Whether using a screen or not, the individual must be in a sitting, reclined or lying position and expending low energy (≤1.5 METs). During early SB research in the 1980s and again in the 2000s, TV viewing was the predominant SB of interest (15). Later, as technology developed, research spread to other forms of leisure time screen-based behaviour (computer use, video game play) and screen time in total (15). Technology continues to evolve, resulting in more screen-based options. Portable tablets and mobile phones that provide more diverse forms of entertainment are now widely used across age groups (including children). These highly prominent screen-based options are a more complex behaviour because they can occur during any time of the day in many settings, in shorter sporadic periods, and often intermittently between being sedentary or physically active.

Until relatively recently, screen time, and TV viewing in particular, has often been used as a proxy indicator of total SB (38). Despite the vast array of screen-based sedentary options, international evidence suggests that screen time only accounts for approximately 30% of total daily sedentary time in children (39). Screen time does correlate with objectively assessed total sedentary time but the association is small (40). Furthermore, the determinants of total SB are not the same as the determinants of screen time (41). Consequently, screen time is not an appropriate representation of total SB despite some studies still using measures of screen time and total sedentary time interchangeably (39). Non-screen-based SBs can include sitting to read a book, completing homework, sitting in work/class, sedentary travel (sitting in a car) or simply sitting and talking with peers/colleagues. Clearly a person can be engaging in a vast array of non-screen-based activities whilst sedentary. Surprisingly, some forms of SB have demonstrated different relationships with health and development-related outcomes, both negative and positive in children (15,42–45) and are discussed in section 1.7.

1.4. Measurement of sedentary behaviour in children

Typically, SB has been measured either by self or proxy-report or by wearable devices that objectively determine sedentary time by a lack of movement or postural allocation. All of these methods have strengths and limitations (29).

1.4.1. Self and proxy-report

In children, self-report and proxy-report tools are typically administered by one or two methods: 1) children or their parents/guardian are asked to estimate the amount of time spent in common SBs (i.e. TV viewing, computer use, car travel) which may be combined in an attempt to estimate total sedentary time or 2) they are asked to estimate the total amount of time spent sitting on a daily basis (29). Although these subjective approaches have largely been replaced by objective measurements in recent times, particularly in smaller scale studies, they are still popular in national level data collection due to their ease of administration, low cost and relative ease of data analysis (29). A major strength of this approach is that the context and mode of SB can be captured. This has enabled the discovery that some SBs have different impacts on health, learning and development-related outcomes in children (42,43). Despite this, these approaches are limited by high levels of error and recall bias (46–48). While some tools generally display acceptable reliability and validity in measuring SB (49), others demonstrate limited validity compared to objective measures (50). Furthermore, total sedentary time data can be limited by the types of SB measured, with some modes (and therefore some sedentary time) likely to be missed. It is common sense to think that the often intermittent and sporadic nature of children's sitting and PA patterns would be extremely difficult for children or their parents/guardians to accurately recall during waking hours, particularly away from the school environment that follows a structured timetable. Conversely, specific behaviours such as TV viewing may be more easily and accurately recalled due to the structured nature of TV programmes (15). It is yet to be determined which self and proxy-report questionnaires are the most valid and reliable for assessing total sedentary time, specific modes of SB, and SB patterns (16).

1.4.2. Objective measurements

1.4.2.1. Accelerometry

As outlined in section 1.2, accelerometer-derived data when measuring sedentary time is referred to as stationary time, based on the recent Sedentary Behaviour Research Network consensus paper (16). The use of objective measures, specifically accelerometry, has increased rapidly in recent years. For example, in the review exploring the relationship between SB and health outcomes in children and adolescents by Carson et al. (42), 35 studies that used accelerometry were identified from 2010-2015, whereas in the preceding review (35), not a single study was identified from searchers before 2010 that used an objective measurement of sedentary time. There are several accelerometer devices widely available, however, the ActiGraph is the most commonly adopted (39). The ActiGraph can be worn in several locations on the body but the hip has traditionally been the most common position adopted, although recently there has been a shift towards wrist-worn devices (51). Accelerometers measure the frequency and amplitude of acceleration of the body section in which they are attached to in up to three axes, sampling at typically 30-100Hz, which is then converted to movement counts (38). These devices detect stationary time based on a lack of movement under a specific counts-per-minute-threshold (52), which has commonly been established at <100cpm, in the vertical axis, in children (53). The threshold is based on criterion measures of energy expenditure determined by indirect calorimetry and subsequent regression or receiver operating curve analysis (23,54). These devices are able to measure the total volume of stationary time by accumulating all segments of time recording movement below the sedentary threshold. Furthermore, breaks in stationary time (and therefore stationary bout length) can be detected when the sedentary threshold is briefly exceeded and stationary time is then resumed. This outcome, as well as time spent in different bout lengths, cannot be provided by self/proxy-report measures (38). In addition, due to data being time stamped, time spent stationary during specific periods of the day can be extracted (38). However, hip-worn accelerometers cannot accurately distinguish between sitting and standing postures and therefore sitting time is not accurately determined (23). The distinction between sitting and standing is important because standing, whether active or passive, is associated with higher energy expenditure and may therefore influence different physiological responses and effects on health outcomes than sitting (55–57). Furthermore, there are a wide range of settings and data management options to navigate with accelerometer data such as non-wear time criteria, minimum wear time, valid number of days of data, sampling rate, epoch length, cut points, operationalisation of sleep and the use of axis data (typically uniaxial or triaxial). The parameters of many of these factors can vary widely between studies which is a major issue because many of these data management components have the potential to affect the outcome variable of interest (58). For example, associations between stationary time and metabolic risk factors have been found to be moderated by the choice of cut points, with stronger associations found in a higher stationary threshold (59). With sitting time often misclassified with standing and the heterogeneous settings and data processing methods implemented across studies, the SB literature is somewhat littered with potentially inaccurate and invalid evidence.

1.4.2.2. Posture monitors

Posture monitors such as the activPAL have more recently been adopted in SB research due to their ability to distinguish between sitting and standing more accurately (93). These devices are typically worn on the anterior aspect of the thigh between the hip and knee. Instead of using movement accelerations to determine sedentary time, the angle and position of the thigh mounted inclinometer are detected, classifying body position as either sitting/lying, standing or stepping (52). Consequently, sitting and standing time is directly measured and recorded. The activPAL is also an accelerometer, allowing for the detection of non-wear time from periods where no movement is detected. Like the ActiGraph, the device can provide data on total sedentary time, breaks in sedentary time (i.e. brief change in posture followed by a return to a lying, reclining or sitting posture) and bouts of sedentary time. Furthermore, information on sit-to-stand and stand-to-sit transitions, cadence, steps/day and estimates of energy expenditure are produced (38), and all data can be extracted during specific times of a 24-h period. More consistent device settings would appear to be utilised within the literature (i.e. sampling rate of 10Hz, epoch length of 15s) compared to the ActiGraph, which provides better comparison between studies. Also, these monitors can be waterproofed using a nitrile sleeve and medical adhesive dressing, which enables 24-h wear time and potentially improves wear time compliance compared to the ActiGraph (often removed when the participant is in water and during sleep at night). The activPAL has demonstrated an almost perfect correlation with direct observation for time spent sitting/lying, standing and walking in simulated free living activities in primary school children as well as strong correlations for sit-to-stand and stand-to-sit transitions (r = 0.99) and step counts (0.88-1.00) (60). The device has also demonstrated good accuracy and precision for assessing time spent sitting (Rho (mean difference) = 0.86 (-5.6%)) and standing (Rho = 0.78) during free living within the school classroom in 9-12 year olds (52). However, misclassification between sitting and standing postures can occur in irregular sitting styles (i.e. sitting on the edge of a seat) where the thigh position is more towards a vertical plane instead of a horizontal position (52). Furthermore, like with all objective measures, posture monitors cannot provide information on the context or modality of SB, and consequently the use of both self/proxy-report and direct measurement tools is recommended whenever possible (29).

1.4.3. Key data collection and reduction decisions in objectively determined sedentary or stationary behaviour

There are a wide range of decisions to be made when implementing accelerometer and inclinometer devices for SB and PA research. As already stated, objective evidence of SB is predominantly derived from ActiGraph and activPAL devices. This section critiques common decisions required prior to data collection and during data reduction once the data has been obtained from these devices.

1.4.3.1. Number of days of monitoring

A device monitoring period ideally depends on the design and purpose of a study (61). Studies in children and adults typically use a 7-day wear protocol which is generally recommended for inclinometer and accelerometer devices (61,62). However, ideally a 14-day period (the recording memory limit of an activPAL device) would be optimal in potentially providing more valid days of data (61). More valid days of data should subsequently boost the sample size. A 14-day period in children, however, is likely to result in more cases of lost devices, issues with skin irritation from Hypafix adhesive dressing (activPAL) and generally be more burdensome for the participant when completing the monitor log and wearing the device. A 24 h wear time protocol and water proofing the activPAL device provides the possibility of increased wear time compliance, compared to a waking hour or 24 h plus water-based activity removal protocols (63). Within accelerometer research it is currently recommended that a 24 h wear time protocol is used to boost valid data compliance (62).

1.4.3.2. Valid wear day and valid number of days

It is generally recommended that a range of valid wear day and valid number of day criteria are applied to get the best compromise between sample size and reliable data (62). Small scale studies and those of a more exploratory nature (e.g. cross sectional) may opt for a more lenient hours per day protocol (e.g. 8-10 h of a full waking day). While this will help maximise the sample size, it will have an impact on sedentary behaviour and physical activity outcomes (64). Furthermore, in children that marginally meet the valid day criteria, large portions of waking hours will be unaccounted for. For example, a child with a mean wear time of 8 hours could provide data from 6am-2pm. Consequently, parts of the school day afternoon and all time spent after school would be missing. Conversely, an included child could provide data from 3pm – 11pm (8 h) and therefore school hour data could be missed. However, within the non-wear algorithm within the processing software that is applied to activPAL data, if sleep occurred or the device was removed after 6am and before 11pm, this will not have been identified as wear time and therefore more wear time will have been needed to be identified elsewhere to meet the minimum thresholds. While parameters within previous studies should be considered, a data driven approach can also be utilised; a maximum number of valid days and hours within a day are attempted while also trying to retain as large a sample as possible. This balance may be weighted more towards the latter in studies with small samples of children.

1.4.3.3. Isolating key periods of interest in the data

Monitor logs can be informative and be a source for quality checking of the monitor data. Such information can assist in isolating periods of interest within the data, such as waking times or when monitors were removed or attached, school hours, or the after-school period. However, this method has not been validated and accurate strategies for collecting such data are currently lacking (61). During school hours, the absence of a diary will be less of an issue since the school timetable can be applied to activPAL and ActiGraph data using filters. Schools typically follow these timetables closely and is therefore a reliable guide.

An important decision to make is whether to apply a minimum threshold of data compliance within a period of interest. A method used within activPAL data reduction is to apply a 50% threshold to a period of interest. This ensures that the participant has provided data for the majority of that period of interest. Without this rule, you may get incidences where very short periods of data have been provided (e.g. 20 minutes) within a period of interest (e.g. first lesson of a school day: 2 hours). Consequently, this may result in the participant registering, for example, just 15 minutes of sitting time, acting as an outlier to the data. In reality they may have sat for 1h 30 mins during this period. It would be wise to remove this outlier from the analysis.

There is a risk that bouts of activity (sitting, standing, stepping) could cross over from one filter of time (e.g. class time) to another (e.g. break times) and therefore there is the issue of dissecting a bout rather than capturing it in its entirety. In scenarios where a bout of sitting or standing spans across two periods of interest, the bout may be included within the period of interest it began. However, it is fair to assume that a change in school time period and probable location will result in a change in posture and/or activity (61). Bouts of activity crossing different periods of interest can be an issue during evenings if a blanket removal of estimated sleep time is made (e.g. from 11pm). A child may be engaging in a sedentary bout (e.g. sitting watching television) from 10-11.30pm, however, if sleep time is identified from 11pm, this bout will have been reduced to 1h instead of 1h 30 mins. This would generally apply to all waking behaviour that occurs beyond 11pm. Furthermore, this blanket approach of removing sleep time assumes that sleep occurs in a continuous single occasion for all participants. It may be that sleep occurs in several segments, separated by brief periods of movement (i.e. going to the toilet) (61).

The method of applying a blanket sleep period to all data to identify all sleep periods, is limited (61). For example, a sleep period of 11pm-6am would result in 1020 mins of waking data per day, however, a child could go to sleep at 9pm and wake up at 7am, meaning 3 h of data has been miss-classified as waking hours. However, to identify periods of sleep during designated waking hours (6am-11pm), 3-axis acceleration data can detect periods of no movement. If these periods exceed 20 mins then this period will be excluded as non-wear. For example, before 11pm, if a child goes to bed but is still awake with small movements that repeat within every 20 mins (e.g. legs fidgeting while reading), this will be identified as sedentary time (sitting/lying). However, if the child goes to sleep and is stationary for >20 mins (and therefore recording zero accelerometer counts) this will be identified as non-wear or sleep and therefore excluded from the waking hour analysis. The effect of the non-wear criteria on sleep removal and waking hour data is discussed in Chapter 4 section 4.4.2.

The use of non-wear methods (e.g. Troiano (65)) to identify sleep periods is a strategy currently recommended within activPAL research (61). Like all data reduction methods, this approach has limitations. It is very possible that a participant could be asleep but still has some movement at somewhat regular intervals, resulting in sleep time registered as sitting/lying time during waking hours. For example, if a child fell asleep at 10pm but had very subtle movements up to 11pm, the acceleration channel will detect movements and 1 h of sleep time is therefore recorded as a sedentary waking hour. Consequently, some sitting time data during evening periods may be more erroneous than perhaps daytime (e.g. school-based) sitting data. A debate within the sedentary behaviour literature has recently emerged around how to classify the period of time where an individual first goes to bed in the evening and is lying in bed attempting to fall asleep (66). While the person is still awake, this is commonly interpreted as sedentary time since they are not asleep. However, it has been recently argued that this should be described as sleep-related behaviour which may be part of a natural and healthy sleep-wake cycle (66). Engaging in an activity prior to this phase, such as reading a book, could still be classified as sedentary time. Automated algorithms are likely to systematically overlook or miss classify these two different phases of behaviour prior to sleep (66). These behaviours are also likely to vary between populations (e.g. children, adults, males and females). This highlights the benefit of including sleep logs however these are burdensome and often insufficiently completed by younger ages (61,66).

Currently there is a lack of validated methods for removing sleep from a 24 h activPAL wear protocol in children. A recently implemented strategy in adults has included identifying the first standing event after ≥2 h of sitting/lying between midnight and 9am as waking, and the final standing event before >3 h of sitting/lying after 22:30 as the beginning of sleep (67). This approach allows for varying waking periods for each participant; however, it is unlikely that all individuals once awake, immediately stand up out of bed or instantly fall asleep as soon as they lie in bed at night. Recently, an activPAL processing algorithm identifying sleep periods from event.csv files has been developed and validated in adults (68). This algorithm identifies the longest sitting/lying and sitting/lying/standing bouts >5 h as sleep within a 24 h period. Furthermore, behaviours either side of these bouts are searched and added as sleep if complying with one of several rules. Such an algorithm would be hugely beneficial in children since adequate monitor log compliance is particularly challenging in younger ages

1.4.3.4. Sampling frequency and axis data

The default activPAL sampling rate is 20hz, providing triaxial data however this can be set at 10hz (providing uniaxial data) or 80hz. Similarly, with ActiGraph devices, the default setting is 30hz but 100hz is a common practice and general recommendation for physical activity research in children (62). The sampling frequency affects the processing of ActiGraph acceleration data to activity counts and the signalling of thigh inclination within activPAL acceleration data. Brond and Arvidsson (69) found that with ActiGraph devices, 100hz resulted in up to 1600 more counts per minute compared to 30hz during fast running. While a higher frequency is recommended (100hz), if manufacturer methods are being used for data processing, it is suggested that 90hz is used since it is a multiple of 30 and the filter processers are developed for 30hz (62). Different sampling frequencies may have more of an impact on ActiGraph activity counts than the identification of thigh inclination because activPAL data (sitting/lying, standing or stepping) is categorical with only three possible outcomes. Conversely, accelerometer counts are scale-based and as Brond and Arvidsson (69) identified, can vary the number of counts registered substantially between different sampling frequencies. However, no study to date has compared data produced by different sampling rates from the activPAL monitor. Consequently, this is an area of uncertainty in the literature.

When uniaxial data, rather than triaxial data, from the ActiGraph device is utilised, movement data is only being included in data processing from the vertical axis. While intuitively the use of triaxial data may seem more accurate due to more information gained from two additional planes (antero-posterior and medio-lateral), within accelerometer research it is unclear whether uniaxial or triaxial data are more accurate in quantifying different PA intensities (e.g. Kelly et al. (70)). Furthermore, limited studies have validated cut points based on triaxial data (i.e. vector magnitude) in children to date. As stated earlier, the validation of the Freedson age-adjusted cut points were based on uniaxial data and it therefore seems prudent, and it is recommended, to align with this approach (62).

1.4.3.5. File types and epochs

A common practice when processing activPAL data is to use 15-second epoch.csv files, which carries some limitations. These files during each 15-second period do not recognise the order in which postures occur, only simply to identify the postures that occurred during those 15 seconds. For example, a child may sit for 5 seconds, stand for 5 seconds and then sit again for the remaining 5 seconds. However, the epoch.csv files will only identify that there were 10 seconds of sitting and 5 seconds of standing, with no chronological order to this information. Within macro data reduction, a bout of a particular posture will be determined by collating consecutive epochs of that same posture. Any epoch with a combination of postures would break this bout. A limitation here is that a combination epoch will not contribute to the amount of time spent within a bout of a posture. For example, 8 consecutive epochs of sitting followed by an epoch consisting of 10 seconds of sitting and 5 seconds of standing would result in 120 seconds (2 minutes) of a sitting bout from the macro data. However, it may be that the additional 10 seconds within the final bout continued the sitting bout, with a total duration of 130 seconds of sitting, broken by 5 seconds of standing. Since these epoch.csv files do not identify the order in which different postures occurred within the 15 second epoch, this is the only way in which the macros can reduce the data. Consequently, the duration of sitting, standing or stepping bouts will be inaccurate in many cases. It should be highlighted that this potential error time would be less than 15 seconds in each bout, which is less than 5% of the duration of a 5-minute bout and less than 2.5% of a 10 min bout. This potential error is more impactful on shorter bouts of posture time since the proportional error time is greater. More recent techniques use Event.csv files, which are not based on epochs but rather the chronological order and duration (bouts) of "events" that occur (sitting, standing, stepping) (61). Using this data may be a more precise method for determining time spent in different postures (61) and future research may move more towards these forms of data. The EventsXYZ.csv files also provide acceleration data from all three axes which consequently enable the detection of physical activity intensities (LPA, MVPA) in addition to postural data.

A 15 second epoch setting within activPAL and ActiGraph devices is advised for children, however, shorter epochs are also recommended (1-15 s) (62) due to intermittent short bursts of physical activity in children. If a shorter epoch were to be selected (e.g. 5-s), this may result in more time recorded in higher intensities of PA (71) (ActiGraph data). It may also result in less time established as sitting/lying time and more time standing and stepping according to the activPAL data; standing and stepping activity, as already stated, may occur at times in very brief periods (i.e. <5-s) in between periods of sitting (the predominant posture during waking hours in children). A further limitation of the use of 15-s epochs in ActiGraph data is that it does not match the 1-s epoch set within the Trost study that validated the Freedson age-adjusted cut points utilised within Chapter 5 (62). However, other related studies have used 15-s which should also be considered when deciding on an epoch length (62).

1.4.3.6. Cut points

Within accelerometer research in children a wide range of cut points have been applied (64) and one of the drivers of this is the varied MET values applied to intensities of PA (light, moderate and vigorous). Trost et al. used MET values that closely approximate the intensity thresholds applied within most of the original calibration studies and to adhere to the most consistent evidence from other validation studies in children. It is generally recommended that data reduction parameters within accelerometer studies align with those of validation studies (62). Other thresholds have been recommended for MPA (3-6 METs (62)), however, Trost et al. pointed out that there is consistent evidence (e.g. 26,27) that brisk walking, a key behavioural indicator of moderate intensity PA, is associated with approximately 4 METs in children. If a lower MET threshold is applied for MPA (e.g. 3 METs), this would have resulted in less time classified as LPA and more time as MPA. Consequently, more children will be classified as sufficiently active within a sample.

1.5. Prevalence of sedentary behaviour and physical activity in youths

1.5.1. Screen time

Until recently, screen time (an accumulation of screen-based SBs such as TV/DVD viewing, computer use, smartphone/tablet use etc.) has been the most commonly researched SB (74). Screen time is often measured by self/proxy-report in number of hours or minutes per day, and studies commonly report this outcome in relation to meeting or exceeding screen time recommendations for children of <2h/day currently set in the USA, Canada and Australia (75–77).

Internationally, evidence suggests that most children exceed the screen time recommendation (39). As part of the International Study of Childhood Obesity, Lifestyle and the Environment (ISCOLE), LeBlanc et al. (39) measured self-reported 7-day retrospective total screen time in 5,844 children (9-11 years) from 12 countries of diverse socio-economic position, set across six continents. Overall, an average of 2.6h/day of screen time was reported, with 54% of children exceeding the screen time recommendations of <2h/day. Screen time and the proportion of children not meeting screen time recommendations ranged from 1.8h and 31% in India to 3.7h and 72% in Brazil respectively. Just two countries reported that most children met the recommendation; China (66%) and Portugal (51%). Boys reported higher screen time in all 12 countries compared to girls. This study used standardised measures of SB across all data collection sites and the authors stated that ISCOLE is 'the most culturally and geographically diverse, up to date and robust study of lifestyles associated with obesity-related health in children.' Previous international evidence has also indicated that most children spend more than two hours a day watching television, therefore exceeding the screen time recommendation (78).

Nationally representative data in children (n = 1218) from the USA National Health and Nutrition Examination Survey (NHANES) reported that 45% of children exceeded daily screen time recommendations outside of school hours between 2009 and 2010 (79) from retrospective proxy-report. More 9-11-year olds failed to meet the recommendations (52%) than 6-9 year olds (41%) suggesting screen time increased with age. Furthermore, obese children were more likely to exceed screen time recommendations compared to children of normal BMI (79).

Nightingale (80) surveyed daily screen time in 4495 children aged 9-10 years old across three cities of England. Children chose one of four categories for self-reported total screen time which combined TV viewing, video game and computer use. 4% reported no screen time, 37% 1h or less, 28% reported 1-2h, 13% reported 2-3h and 18% reported more than 3h of screen time per day. Consequently, just 31% of children exceeded 2h/day of screen time which is low compared to international and USA data (39,79). This prevalence contrasts with the UK sample within the ISCOLE study, where 68% of children (n = 407) from two English cities exceeded 2h/day. The manner in which screen time was self-reported differed between studies which may be one explanation for this disparity. Nevertheless, these data demonstrated the large variations present within a country.

Overall, it would seem that large proportions of children engage in more than 2h/day of screen time and that this is observed in the majority of children internationally. As stated in section 1.3, the nature of screen time behaviour is continuously evolving due to the emergence of mobile phones and portable tablets that include many popular options for entertainment and communication. Consequently, some of the older evidence (i.e. 2009-10 NHANES data (79)) presented in this section may be less valid for contemporary screen time behaviour in developed and developing countries and should be interpreted with some caution. Future studies should try to explicitly capture the prevalence of daily mobile phone and tablet engagement in young people and determine the proportions to which these screen-based behaviours occur either when sedentary or physically active.

1.5.2. Total sedentary time

Accelerometer data consistently demonstrates that children spend the majority of waking hours stationary (39,81–84). Data from the ISCOLE study (39) reported that children across 12 geographically and culturally diverse countries spent an average of 8.6h/day stationary. Total stationary time ranged from 7.9h/day (Australia) to 9.4h/day (China). In contrast to the differences observed in screen time prevalence between sexes, girls spent more time in total stationary time than boys in every country (39). Accelerometer data from the Health Survey for England (HSE) in a nationally representative sample of 1,707 5-15 year olds showed that young people spend on average 7h/day in stationary behaviour (85). Overall, like in the ISCOLE study, boys spent less time stationary than girls (85). In a sample of 1862 English children aged 9-10 years old, 64% of waking hours were reportedly spent sedentary, which equated to 7.5 hours in total stationary time (81). Similar proportions of waking hours in stationary time have been reported in children and adolescents from North America (46,86).

Accelerometer data also demonstrates that children spend the majority of school time stationary (87–89). For example, across five European countries, Van Stralen et al. (88) reported that 65% of the time spent at school was stationary in school children aged 10-12 years old (n = 1025).

More recently, research has turned to inclinometer devices to more accurately measure total sedentary time. To date, inclinometer data from Australian, Malaysian and Scottish children (ages 8-12 years) further confirms that the majority of time at school (70-71%) (109), on weekdays (53-69%) and weekend days (60-73%) is spent sedentary (90–93).

1.5.3. Bouts and breaks of sedentary time

With the more recent use of objective measures, attention has turned towards how sedentary time is accumulated in terms of sedentary bout durations and the frequency of breaks in sedentary time, although the evidence is in its early stages. As stated in section 1.2. a sedentary bout is defined as a period of uninterrupted sedentary time and a break is defined as a non-sedentary bout in between two sedentary bouts (16). Verloigne et al. (113) conducted a thorough cross-sectional exploration of time spent in different bout lengths of sedentary time in 577 Belgian children (10-12 years). Accelerometry data demonstrated that almost 50% of the time spent stationary (60% of waking hours) was accumulated in bouts of 2-5 and 5-10 min on weekdays, weekend days, at school and after school, and approximately 13-15% of weekdays and weekend days was spent in bouts of 10-20 min. Children engaged in between 0.7 and 1.3 bouts lasting 20-30 or 30+ min on weekdays and weekend days, equating to between just 23 and 34 min/day (less than 6% of total stationary time). The authors also estimated that 25% of stationary time was accumulated in bouts lasting less than 2 mins. Stationary time predominantly accumulated in short bouts was also observed by Altenburg et al.

(94) in a cross-sectional study with 647 children (10-13 years) across five European countries using accelerometry. During waking hours, just 2 bouts lasting more than 20 minutes and 1 bout lasting more than 30 minutes were observed, which equated to less than an hour and around just 30 minutes of daily stationary time, respectively. Conversely, 22 stationary bouts lasting at least 5 min were observed, equating to 225 mins/day. This evidence taken together suggests that European children do not accumulate stationary time in prolonged bouts (i.e. >20 min). This finding is consistent with accelerometer data in 120 US children (8 years old), where the median frequency of bouts lasting ≥ 30 min during waking hours was just 0.2, with some children not engaging in any stationary bouts of this length and the maximum frequency at just 3.1 (95). The sample median frequency of stationary bouts lasting ≥20 min was also low at 0.8, with the highest in the entire sample at just 6.1 bouts/day.

In contrast, Australian children (10-12 years) have demonstrated large proportions of time spent in prolonged stationary bouts (87). On school days, weekend days, at school and after school, children spent between 10% and 20% of wear time (75 min at school, 129-132 min during total waking hours) in stationary bouts of ≥30 min. However, this was with just 53 children and with a different accelerometer device (Actical) compared to the other studies mentioned (ActiGraph). Nevertheless, this evidence suggests that some children may spend considerable proportions of time in more prolonged bouts.

Overall, it would seem consistent that children spend most of their waking hours sedentary/stationary, with most of this accumulated in shorter stationary bouts (i.e. <10 min). With time, children gradually spend greater proportions of waking hours stationary with fewer breaks and more time accumulated in prolonged stationary bouts during the transition towards adolescents (96).

1.5.4. Physical activity

The International Children's Accelerometry Database (ICAD) synthesises and standardises accelerometer data from cross-sectional, longitudinal and experimental studies across 10 countries (although most participants were from the USA and UK) and has reported on data from 10,741 young people (97). Across countries, just 9% of boys and 1.9% of girls aged 5-17 years of age met international MVPA recommendations of ≥60 mins/day (98), with the highest values reported in Norwegian boys and girls (13%). Such low proportions of young people meeting guidelines is in contrast to Kalman et al. (99) who explored secular trends of MVPA across 32 countries (Europe and North America) between 2002-2010 (*N* = 479,674). In 11, 13 and 15 year olds, 23% of boys and 14% of girls self-reported engaging in ≥ 60 min of MVPA over a 7-day period. The difference of accelerometry compared to self-report measures may partly explain the contrasting PA levels reported. Nevertheless, the evidence suggests that the vast majority of children and adolescents are insufficiently active internationally.

In England, as part of the 2008 HSE, accelerometers were deployed over 7-days in 1,707 children and adolescents (5-15 years) (85). Overall, boys spent on average 85 mins/day in MVPA whereas girls spent 61mins/day. 51% of boys and 34% of girls aged 4-10 years old met UK PA guidelines whereas only 7% of boys and not a single girl aged 11-15 years met UK PA guidelines. These HSE data are the most recent that are based on accelerometry. In the most recent PA statistics from the HSE for children (100), PA was self-reported. In the same age range (5-15 years old), 23% of boys and 20% of girls met PA guidelines over a 7-day period. These are similar to the values reported in 2008 although boys were more active in 2008 and there is less difference between sexes in 2015. These data suggest English children are mostly inactive, similarly to international evidence.

Consistent trends across these studies were that boys were more active than girls across ages, MVPA declined with age and obese children were less active than normal weight children. These findings are also consistent in children from the USA (aged 6-11 years) from NHANES data (79).

1.6. Sedentary behaviour and health in adults

The potentially detrimental health effect of excessive sedentary time was first discovered in the 1950s by Jeremy Morris and colleagues where London bus drivers were found to have a twofold increased risk of myocardial inFDA ction compared to active bus conductors (101). However, the authors attributed the increased risk of myocardial inFDA ction in the bus drivers to an absence of PA rather than the time spent sitting in this study. Indeed, until relatively recently, research has mainly focused on the benefits of MVPA rather than the risks of SB (102). However, with most adults and young people now spending large proportions of waking hours in sedentary activities in modern society, research into the potential health risks of SB has increased dramatically in the last 20 years.

The first study to review the impact of SB on health in adults beyond TV viewing, and while also using an active definition of SB at the time (waking behaviours characterized by energy expenditure <1.5 metabolic equivalents while in a sitting or reclining posture (103)), was by Wilmot et al. (102) in 2012. This systematic review and meta-analysis explored the associations of sedentary time in adults with morbidity and mortality outcomes. This review included 16 prospective studies (mean follow-ups of 3-21 years) and two cross-sectional studies, with just under 800,000 participants (mean ages 38-63 years), set across seven countries and four continents, with nearly all studies reported as either moderate or high quality. By comparing the higher half of recorded sedentary time with the lower half in each study, the authors reported that higher sedentary time was associated with a 112% increase in the relative risk of type 2 diabetes, 147% increase in the relative risk of cardiovascular disease, 90% increase in the relative risk of cardiovascular disease mortality and a 49% increase in the relative risk of all-cause mortality. These associations were reported as strong and consistent across studies. The direction of association was also consistent across different types of SB (TV viewing, sitting time), differently quantified sedentary time and geographical locations (i.e. USA vs Japan). One of the major findings from this study was that these associations were largely independent of MVPA. This not only suggested that replacing sedentary time with LPA could reduce the risk of chronic disease and mortality, but that meeting PA guidelines (i.e. 150 mins/week of MVPA (98)) was not sufficient to protect against the health risks of SB. Despite the evidence being of mostly moderate-to-high quality, all studies used self-report measures which were likely to have poor validity and weaken the association with health outcomes (102), particularly when assessing total sedentary time. Also, some studies only measured TV viewing or screen time and not total sedentary time.

In 2015, Biswas et al. (104) conducted a similar systematic review and meta-analysis, and also observed an increased risk in the same outcomes (type 2 diabetes, CVD, CVD mortality, all-cause mortality) as well as in cancer incidence and mortality from total sedentary time and screen time, independent of PA. However, the level of risk was somewhat lower compare to Wilmot et al; type 2 diabetes 91% vs 112% increased risk, CVD incidence 14% vs 147% increased risk, CVD mortality 18% vs 90% increased risk, all-cause mortality 24% vs 49% increased risk. Cancer outcomes were also of a similar level of risk (incidence 13% increased relative risk, mortality 16% increased relative risk). Like in the Wilmot review, of the total study sample (N = 47), most were prospective and all but one study used self-report measures of sedentary time. However, Biswas et al. (104) extracted the least adjusted models which will most likely have included stronger associations with health outcomes before further potential confounding factors were included in subsequent models. One reason why this review found weaker associations could be that only total sedentary time or screen time was used as a main outcome measure. In contrast, the Wilmot review included studies that only measured TV viewing and this SB had previously been found to have consistent adverse associations with morbidity and mortality (105). Also, unlike Wilmot, Biswas included models that adjusted for adiposity, which is a potential intermediate pathway of the SB-health relationship (102) and may have reduced the strength of association. Furthermore, studies were only included if PA was statistically adjusted for, whether MVPA or other forms and PA appeared to moderate the relationship. For example, all-cause mortality risk from high sedentary time was reduced by 30% in individuals with higher levels of PA compared to individuals of lower PA levels. Consequently, this variable, like adiposity, may have weakened the SB-health association. Nevertheless, the authors concluded that the SB-morbidity/mortality relationship ‘may indeed be causally linked.’ Between the two review studies however, it is not entirely clear what effect PA has on the SB-health relationship. Both reviews adjusted for PA, which, due to the collinearity of SB and PA, may be conceptually wrong and provide erroneous results (36).

To directly examine the relationship between specific levels of SB and PA with all-cause mortality, CVD mortality and cancer (breast, colon, colorectal) mortality, Ekelund et al. (106) conducted a systematic review and meta-analysis that included more than one million adults. In this review, self-report sitting time / TV viewing and MVPA was harmonised across studies by separating individual data into quartiles (sitting time 0-4, 4-6, 6-8 and >8h/day; TV viewing time <1, 1-2, 3-4, >5h/day; MVPA ≤2.5, 16, 30, >35.5 MET-h/week) from 16 high quality prospective studies (mean follow up from 2 - 18.1 years). Overall, a clear dose-response relationship was observed between high sitting time, low PA and all-cause mortality. A major finding from this analytical approach was that in individuals with the highest level of PA (>35.5MET-h/week), there was no relationship between mortality and any sitting time quartile compared to the low sitting quartile (<4h/day). This suggested that if an adult performs ≥60 mins/day of MVPA, it entirely removes the risk of mortality from excessive daily sitting. The increased risk of mortality from high sitting time (>8 h/day) was still present when individuals met PA recommendations (16 or 30 MET-h/week), but the level of risk was lower compared to individuals who performed low levels of PA (≤2.5 MET-h/week); 10-12% increased risk vs 27% increased risk. Consequently, this evidence suggests that meeting current PA recommendations is not sufficient to remove the risk of high volumes of daily sitting but provides some protection. In terms of health messaging, this would mean that adults need to be encouraged to meet PA guidelines as well as reduce the time spent sitting during waking hours.

This review also provided evidence for mortality risk of TV viewing in a sub sample of prospective studies. In individuals of high TV viewing (>5h/day), an increased risk of mortality was observed across all levels of PA compared to the low TV viewing category (<1h/day), including the >35.5MET-h/week category, unlike in total sitting time. Consequently, even very high amounts of daily MVPA cannot completely remove the risk of high TV viewing. Furthermore, the level of risk was greater in high TV viewing (>5h/day) compared to high total sitting time (>8/day) in relation to respective sedentary reference groups at every quartile of PA; 44% vs 27% (PA Q1), 29% vs 12% (PA Q2), 41% vs 10% (PA Q3), 15% vs no increased risk (PA Q4), respectively. This further emphasises that TV viewing is a particularly harmful SB and that some SBs are more harmful than others. Nevertheless, despite the protective effect of PA observed in this large-scale review, high volumes of sitting time are likely to be common and therefore hazardous in most adults. All studies were conducted in developed western countries and so the evidence may be limited to these regions. Furthermore, since all evidence is based on self-report, future studies need to explore the link between total sedentary time and health outcomes using objective measures of SB and PA that will more accurately capture these outcomes.

1.6.1. Mechanisms of the sedentary behaviour-health relationship

Hamilton et al. (4) proposed that if sitting does cause disease, cells within the body (i.e. skeletal muscle) must detect and then respond to the stimuli of prolonged sitting. With the varied and complex health outcomes that SB is associated with (i.e. type 2 diabetes, CVD, cancer), there is likely to be a vast array of potential physiological mechanisms. However, the activity of lipoprotein lipase (LPL) was the first and main cellular process that has received much attention in this regard. This protein has been explored to understand how metabolism within skeletal muscle directly influences lipoprotein risk factors (i.e. triglyceride uptake, reduced HDL levels) in relationship to time spent sedentary. It is based on the concept that when sedentary, there is a distinct lack of muscle contraction which may influence reduced LPL expression (4). An early study that prevented standing and light ambulation for prolonged periods in the hind legs of rats observed a suppression of LPL activity across all types of quadricep muscle (postural muscle) fibres compared to rats that were able to perform light ambulation but not exercise (exercise wheel removed) (107). This resulted in a reduction of plasma HDL cholesterol of around 20% after several hours, as well as several days, in the experimental group compared to the control group. These effects were not due to muscle atrophy or alterations in dietary intake as steps were taken to avoid these changes. Other early studies demonstrated similar results (108) and it was proposed that the suppression of LPL appears to be due to cellular processes that are different from those that increase LPL expression during PA (4). This led to the ‘inactivity physiology’ paradigm, where SB was viewed as not merely the absence of PA but its own distinct behaviour with some differing chemical and molecular processes (109). It has also been suggested that muscle inactivity via SB has a FDA greater influence on LPL activity compared to MVPA in rats (4,107), further emphasising the potentially hazardous cellular effect of sitting, in which most children and adults spend large proportions of waking hours every day. However, evidence supporting the impact of muscle inactivity from SB on LPL is based on rat and mice studies, and therefore this relationship needs to be confirmed in human trials.

The reviews by Wilmot, Biswas and Ekelund (102,104,106) all suggested that TV viewing is a particularly harmful SB, with larger health risks observed than total daily sedentary time. It is unlikely that this difference is due to cellular processes but rather in other co-existing behavioural factors. TV viewing typically occurs during the evenings and often following a meal and consequently prolonged postprandial sitting may influence impaired glucose and lipid metabolism (13). Also, it is possible that during earlier times of the day (i.e. at work), sedentary time is interrupted more frequently which is beneficially associated with several cardio-metabolic risk factors (13). TV viewing is also associated with snacking behaviour (110) and ‘mindless’ eating, potentially causing over consumption and therefore deleterious effects on body composition (15).

Morbidity and mortality from NCDs manifests during adulthood, however, the precursors to these outcomes (i.e. adiposity, reduced insulin sensitivity, low HDL cholesterol) develop during earlier stages of life (7,8). Consequently, SB may influence risk factors during childhood. During these early stages of the life course however, there are complex biological processes unfolding during pubertal maturation. These developments are likely to have varying impacts on sleep, nutritional intake, physical activity and SB. Furthermore, dramatic changes in body size, shape, and composition will be taking place. Consequently, any relationship between SB and health and development related outcomes should be interpreted with a consideration for these complex changes. The following section outlines growth and development in children and adolescents to elaborate on these dynamic processes.

1.7. Growth and development in children and adolescent

During childhood and adolescence, a series of overlapping and complex physical, hormonal and cognitive developments occur (111) that impact upon growth and development. Normal growth and development in children and adolescents are critical for positive health and well-being (112).

To determine whether a child's somatic growth is normal, a child can be compared to peers by referring to a suitable growth chart (112). A child would be classified as having normal growth if they are within the 95% confidence interval for a specific population at each measurement (112). Cross-sectional data from populations of children of many different ages are generally used to derive standard growth charts (112). Standard height curves from these data can be used as a guide to a child's growth pattern but children rarely if ever adhere to these standard curves, particularly during the rapid development phase of puberty (112). Nevertheless, plotting a child's growth over time can determine whether their growth is average, a variant of the norm or indicative of growth failure (112). Height velocity is also an important parameter of growth, which should be derived from measurements taken more than once a year (112).

Tanner staging is widely used to objectively capture and track the development of secondary sexual characteristics in children and adolescents during puberty (111). Based on longitudinal data, this measurement includes separate scales for identifying the development of external genitalia (111). These scales range from 1 (pre-puberty) to 5 (adult form) and population norm data are available for individuals to be assessed against. If values fall outside two standard deviations of the mean this could be indicative of irregular pubertal development and may require further investigation (111).

Prior to puberty, growth is a relatively stable process (113). From the age of four, boys and girls average a rate of 5-6cm/year and 2.5kg/year until puberty begins (114). There is much variance in growth velocities during childhood between individuals, with a wide range encompassing what is regarded as normal. A child may be placed at a low percentile for height (e.g. $<5^{th}$) at any one time, but if their growth velocity is on the 60^{th} percentile, they will gradually elevate to higher (and more desirable) height percentiles.

Puberty is a dynamic stage of development manifested in rapid change in body shape, size and composition (113) although the process is generally predictable in terms of onset, sequence and velocity (111). During this stage, children develop adult secondary sexual characteristics and reproductive capability (115). The initial stage of puberty is identified as the appearance of breast buds in girls and genital changes in boys. The onset of puberty has been reported to range from 8-13 years in girls and 9-14 years in boys (111). An early study by Marshall and Tanner (116,117) in the 1960s reported the average onset of puberty as 11.2 years in girls and 11.6 years in boys from a longitudinal study in UK children, using Tanner staging (114). Later studies in Switzerland, the USA and Denmark roughly supported these ages (118). However, recent data have reported that girls from the USA are entering puberty as young as 6 years of age, with 6.7% of 7-year olds and 14.7% of 8-year olds clinically demonstrating puberty onset (119). In the last 20 years or so, emerging evidence such as this has led to the conclusion that children may be entering puberty at younger and younger ages (120). These recent developments have partly been attributed to changes in environmental factors such as stress, obesity and endocrine disruptors (121). Nevertheless, girls generally enter and complete each stage of puberty earlier than boys but there is considerable variation in the tempo and timing of puberty, even within the same gender and ethnicity (113).

The adolescent growth spurt, a hallmark of puberty, occurs during mid puberty, earlier in girls than in boys but not to the same extent (113). It has been reported that on average girls reach a peak height velocity of 9cm/year at around 12 years of age during tanner breast stage 3, with a total gain in height of approximately 25cm during the pubertal growth period (122). Boys can on average reach a peak height velocity of 10.3cm/year at age 14, tanner genital stage 4, with a total growth of around 28cm during this period (117). The combination of a greater pre-pubertal growth duration and larger peak height velocity results in an average height difference of 13cm between men and women (114). There is significant weight gain during the pubertal period, with 50% of an adult's body weight gained during this time (113). A boy's peak weight velocity is roughly in line with peak height velocity at 14 years, with on average 9kg/year. In girls the peak weight velocity lags behind peak height velocity by approximately 6 months at 8.5kg/year at 12.5 years of age (123).

Dramatic and contrasting changes also occur in the body composition of boys and girls during childhood and adolescence, including the proportion of water, muscle, fat and bone (113). From ages 5-10 years, boys have more fat free mass (FFM) than girls but FFM is accrued at similar rates (113). There are similar amounts of fat mass between ages 5 and 10 years between sexes, however, girls have a higher proportion of body fat during this period; approximately 1% more at age 5 and 6% more at age 10 (113). During puberty, FFM is accrued at a much greater rate and for a longer period in boys; young adult FFM is attained at 19-20 years of age in males but as early as 15-16 years in females (124). Girls increase in the proportion of body fat during puberty whereas boys' body fat remains stable but overall body fat percentage reduces during this time due to gains in FFM (113). Changes in the distribution of body fat (i.e. central vs peripheral, upper vs lower body) result in the typical gynoid and android patterns of fat distribution of older adolescents and adults (125). By the end of adolescence, males are generally taller, have greater FFM, muscle mass and strength compared to females. Females have a higher proportion of body fat and distributed more towards the lower extremities of the body (i.e. hips) than males. As height velocity declines in later adolescence, fat accumulation continues in both sexes but is twice the rate in girls (113). Typically, skeletal mass is at 90% of its peak by the age of 18 in males and females (113).

There are a host of factors that influence the growth and development of children and adolescents, with the most influential being nutrition, genetics and hormones (113). The most common cause of growth retardation worldwide is poverty-related malnutrition (112). Nutrition and physical activity during these stages of the life course influence the development of important bodily tissue including body fat, skeletal muscle tissue and bone (126). Nutrition certainly plays a more important role in healthy growth and development than physical activity, however, it may be that a combination of suitable nutrition and regular physical activity will influence more healthy patterns of maturation consistent with an individual's genetic potential (127). The dramatic rise in the prevalence of childhood obesity in developed countries in recent years has led to a proliferation of lifestyle interventions to reverse these trends. It is important that when interpreting the impact of a lifestyle intervention on outcomes relating to physical health (i.e. body composition), researchers should also bear in mind the host of complex physical developments also taking place during that period, accounting for them where possible (i.e. measuring stages of pubertal maturation, changes in z-scores over time).

Despite the difficulty of interpreting the relationship between lifestyle behaviours (such as SB) and health outcomes, when considering these complex biological transitions, considerable attention has been dedicated to investigating the SB-health relationship in young people in recent years. The following section explores this evidence base.

1.8. Sedentary behaviour and health in children and adolescents

Tremblay et al. (35) conducted a large scale systematic review in 2011, synthesising the evidence from 232 studies in school aged children. The main finding from this review was that more than 2h/day of TV viewing was unfavourably associated with body composition, fitness, self-esteem, pro-social behaviour and academic achievement. Despite the large volume of studies, few were of high quality with the vast majority being cross-sectional, used self-report or proxy-report measures of sedentary time which are prone to bias (49,128), and most of which capturing TV viewing, missing other SBs.

Mitchell and Byun (129) reviewed studies exploring SB and health outcomes in children and youth (6-18 years old) from 2008-2012. The review included a diverse set of study designs (observational and experimental) that explored several health outcomes using both self-report and objective measures of sedentary time. Screen-based SB was positively associated with obesity and had an attenuated association with cardio-respiratory fitness and insulin sensitivity, mostly independent of MVPA. The links between screen-based SB and obesity was independent of dietary intake, and the links between screen-based SB and cardio-respiratory fitness and insulin were both independent of obesity. While screen time was consistently associated with several health outcomes like in the Tremblay et al. (35) review, objectively measured SB demonstrated inconsistent associations with health outcomes across study designs and particularly when controlling for MVPA. This review provided some of the first synthesised evidence in children demonstrating disparities between not only screen time and total sedentary time but also between self-report and objectively-measured sedentary time evidence in relation to health effects.

More recently, Carson et al. (42) conducted a comprehensive systematic review, exploring a holistic range of health outcomes, with different measures of SB, study designs, different types of SB, and different dimensions of sedentary time accumulation (total time, bout durations, frequency of breaks). The review included 235 studies with 1,657,064 children and adolescents across 71 countries. Like in the previous two reviews mentioned, TV viewing and/or screen time was found to be detrimental to almost all aspects of health examined. Conversely, non-screen-based reading and doing homework were beneficial to academic achievement. Computer and video game use was not consistently associated with any physical health indicator but positively associated with emotions and social health indicators. Taken together these findings further support the notion that different types of SB have different effects on physical and mental health outcomes and thus should be treated as individual behaviours. A gradient effect of screen time and health outcomes was observed in 73 studies and generally supported the current 2h/day screen time limit recommended for children in some countries (37,75,77). Consistent with Mitchell and Byun (129), in 35 identified studies using objective measures of sedentary time, there were no consistent associations found with total sedentary time, breaks in sedentary time or in bout lengths of sedentary time in any health outcome. Consequently, the authors stated that it was difficult to draw any conclusions on the maximum dose of total sedentary time for optimal health in young people. However, all studies measured sedentary time with hip-worn accelerometry which cannot distinguish between sitting and standing postures (23) and consequently it is unlikely that sedentary time will have been measured accurately. Furthermore, very few studies had explored patterns of sedentary time accumulation. Across all SB outcomes, the review identified largely observational studies, most of which were cross-sectional, and all low to moderate quality, with just two experimental studies identified. A large proportion of studies used self-report measures of SB that were not tested for reliability or validity (42). Furthermore, as screen time is continually changing via portable hand-held devices such as tablets and mobile phones, the nature of current screen-based behaviours may contrast to those measured within many of the studies in this review, somewhat reducing the validity of the evidence.

Another recent review (43) exclusively explored the associations of objectively measured sedentary time with health and development in 2-18 year olds. In 88 identified studies, all of which were observational (most were cross-sectional), 20-50% found an association in each outcome (adiposity, cardio-metabolic outcomes, fitness, bone/musculoskeletal health, psychosocial, gross motor skills, and cognitive outcomes). The authors concluded that there was ‘limited available evidence demonstrating that total sedentary time is associated with health and development in children and young people, particularly when accounting for MVPA or studies with low risk of bias’. All but one study used accelerometry to measure sedentary time and therefore the evidence is limited by the accuracy of this method. The authors also concluded that ‘without further experimental evidence testing subtle shifts from sitting to standing or LPA, it is premature to conclude that excessive SB does not adversely impact on health and development in children and adolescents' (43).

These reviews highlight that, as with adults, screen time demonstrates a stronger association with health outcomes compared to total sedentary time in children and youths. The same potential screen-based mechanisms outlined for adults also apply to young people. TV viewing (particularly advertisements) as well as passive video game play would appear to influence an increase in calorie intake in children and adolescents (130,131) which will have implications for adiposity and cardio-metabolic outcomes.

There are several possible reasons for the inconsistencies between sedentary time and health across studies in younger ages. Many studies are of low quality and cross-sectional (35,42), whereas in the adult literature, more high quality studies of longitudinal and experimental design have been implemented (102,106). Another theory is that children accumulate sedentary time differently to adults, often in shorter bouts, and frequently interrupting sitting periods compared to adults, which may therefore reduce the potentially hazardous influence of sedentary time (94). Furthermore, young people for the most part are relatively active, less sedentary, have had less years of exposure to SB or physical inactivity and are mostly free of NCDs compared to adults. Therefore, weaker associations should perhaps be expected between SB and health indicators at this stage of life (15).

It is worth noting that most research exploring the impact of SB on health have included nationally representative samples of children and adolescents (29) in western countries. These participants, who may be largely of White-European ancestry, are of reduced risk of cardio-metabolic outcomes compared to some ethnic groups (e.g. South Asian) (132,133). Furthermore, individuals with a family history of chronic conditions may have a more attenuated SB-health prospect (134). Consequently, higher health risk groups may have stronger associations between total sedentary time and health outcomes but are likely to be only a small proportion of samples in reviewed studies. There is also evidence that youths with less favourable health profiles have benefitted more from SB interventions compared to healthy individuals (135). In a recent systematic review and meta-analysis (135), SB interventions designed to reduce BMI in children and adolescents observed the greatest reductions in overweight populations, which the authors stated as ‘likely to be clinically significant at a population level.’ In terms of disease prevention policy, ‘proportionate universalism,’ whereby strategies are implemented for all children but with greater resources focused on higher risk groups (136), may be the most prudent approach in tackling SB for population health gain.

1.9. Tracking and trends of sedentary behaviour, physical activity and obesity

1.9.1. Sedentary behaviour

Despite inconsistencies between some domains of SB and health outcomes in children and adolescents, the hazards of excessive sedentary time are more clear and consistent in adults (104,106). Preventive measures of SB during early stages of the life course are important for two reasons. Firstly, there is consistent evidence that SB during childhood tracks (defined as “a tendency of individuals to maintain their rank or position in a group over time” (137)) into adolescents and then adulthood. Secondly, daily time spent sedentary increases continuously during this transition.

Several reviews have examined SB tracking. A recent review (138) of 19 individual samples of children observed tracking of both screen time and overall sedentary time in the range of r = 0.3-0.5 (moderate-strong) during the primary-middle-high school transition. It was estimated that this equated to a 20-30 min/day increase in total sedentary time per year. A systematic review by Biddle et al (139) explored tracking of SB in young children through to adulthood. In 21 independent samples in prospective studies, follow ups ranged from one to 27 years. Across all age ranges (3-5 years; 6-11 years, 12-18 years) and lengths of follow up, there appeared to be consistent tracking at a predominantly moderate level (r = 0.30-0.49) in TV viewing, computer and video game use and screen time. Total sedentary time demonstrated moderate tracking in 3-5 year olds after 1, 2 and 3 year follow ups and in adolescents tracking was small into early adulthood in accelerometer and questionnaire data after two years follow up (no studies were included with children aged 6-11 years). Tracking was generally stronger in studies with shorter periods of follow up in all measures of SB, and TV viewing demonstrated the strongest tracking values. The combined evidence was limited to mostly self-report measures, mostly short follow-up periods and being set across just four developed countries (mostly USA, New Zealand, Australia and the UK). Furthermore, the authors stated that almost all studies used correlation coefficients to report tracking, which was the only statistic the review authors reported for comparability purposes, which carries several potential inaccuracies (139). Nevertheless, this review demonstrated that different types of SB, even when measured differently, appears to track from childhood into adolescents and through to adulthood in both boys and girls.

Total sedentary time, has been seen to track from childhood into adolescents and continually increase in duration during this transitional period in a UK cohort (96). In a longitudinal study with a demographically diverse sample, children wore an accelerometer for 7-days at four measurement periods; 7 years, 9 years, 12 years and 15 years of age (three follow ups). Total stationary time and breaks in stationary time tracked moderately from 7 to 15 years of age. At every follow up period, total stationary time and median stationary bout duration increased and the frequency of breaks in stationary time declined. These trends were consistent across all levels of stationary time. During waking hours the proportion of time spent stationary increased by 22.9% at 15 years old compared to 7 years old, with increases of 4.2%, 9.2% and 8.8% observed between 7 and 9, 9 and 12 and 12 and 15 years of age, respectively. The evidence taken together suggests that excessive sedentary and stationary behaviour, deleterious to health in adulthood, originates in childhood and adolescence (96,139). These trends have also been observed in self-report screen time in a prospective study with UK children (140). Between the school years of 7 and 11 (10-16 years of age), screen time increased every year, with an average increase of 2.5h/week in boys and 2.8h/week in girls (140).

Current UK evidence of sitting and stationary time in adults (office workers) consistently demonstrates that over 10 hr/day is spent sedentary in self-report (141,142), accelerometer (143) and inclinometer determined data (144). As already detailed in section 1.6, adults who spend >8h/day sitting have an increased risk of all-cause mortality of between 10% and 27%, depending on daily levels of PA. While meeting PA recommendations provides some protection from excessive daily sitting, most adults, both male and female, young and old, fail to meet PA recommendations in the UK (145), which is outlined in the next section. Furthermore, as outlined in Figure 1.3, TV viewing would appear to increase continuously from young adulthood to middle ages and beyond in UK adults (145). This all suggests that the progression from childhood into adulthood is accompanied by tracking and a continual increase in sedentary/stationary behaviour, which results in many adults in the UK being highly sedentary/stationary and probably of elevated risk of mortality and morbidity (102,104,106).

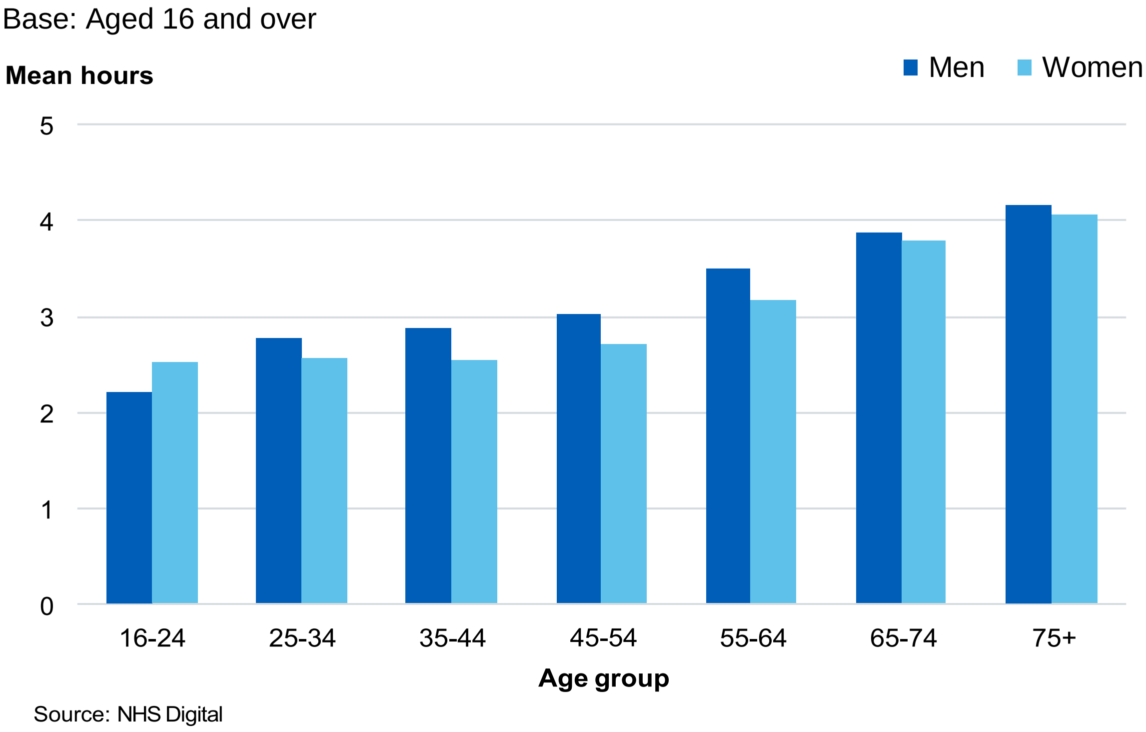

Figure 1.3. self-reported mean TV viewing by sex and age in adults from Health Survey for England data (2016). Source: Health Survey for England (2016) (145).

1.9.2. Physical activity

As already stated in section 1.1, the evidence for the importance of regular PA on health outcomes during all stages of the life course are compelling (10,146). Unfortunately however, unfavourable trends in PA from childhood into later years are apparent. In a recent review of reviews, longitudinal studies and data from the ICAD, the evidence seems to suggest that a decline in MVPA first occurs around early childhood (i.e. five years of age) in both sexes and not during adolescence as previously thought (97,147). In agreement with Janssen (96), the overall evidence also suggested that an increase in sedentary/stationary time first occurs during this stage. Reductions in PA and increases in sedentary/stationary time occurring around early childhood have also been observed in other recent prospective studies with objective data in UK samples (148,149). For example, accelerometer data (*N* = 545) from the Gateshead Millennium Cohort study demonstrated a continuous reduction in MVPA every two years from age 7 to 15 years. Between these ages, MVPA reduced by 24mins/day (from 76 mins/day to 51 mins/day) in boys and by 22mins/day (63 mins/day to 41 mins/day) in girls. In 1299 children from a city in England, Jago et al. (149) observed annual reductions in MVPA of 7 min/day in girls and 3 mins/day in boys as well as an annual increase in stationary time of 84 mins/day in girls and a 74 mins/day increase in boys between year 1 and year 4 of primary school.

The continual decline in PA from early childhood to late adolescents outlined in these studies is a trend that continues through adulthood. Figure 1.4 represents the self-reported proportion of men and women meeting aerobic and muscle strengthening recommendations within the PA guidelines from Health Survey for England data in 2016 (145). The figure clearly demonstrates that in both males and females, there is a continual decline in health-enhancing PA from early adulthood through middle age and older ages.

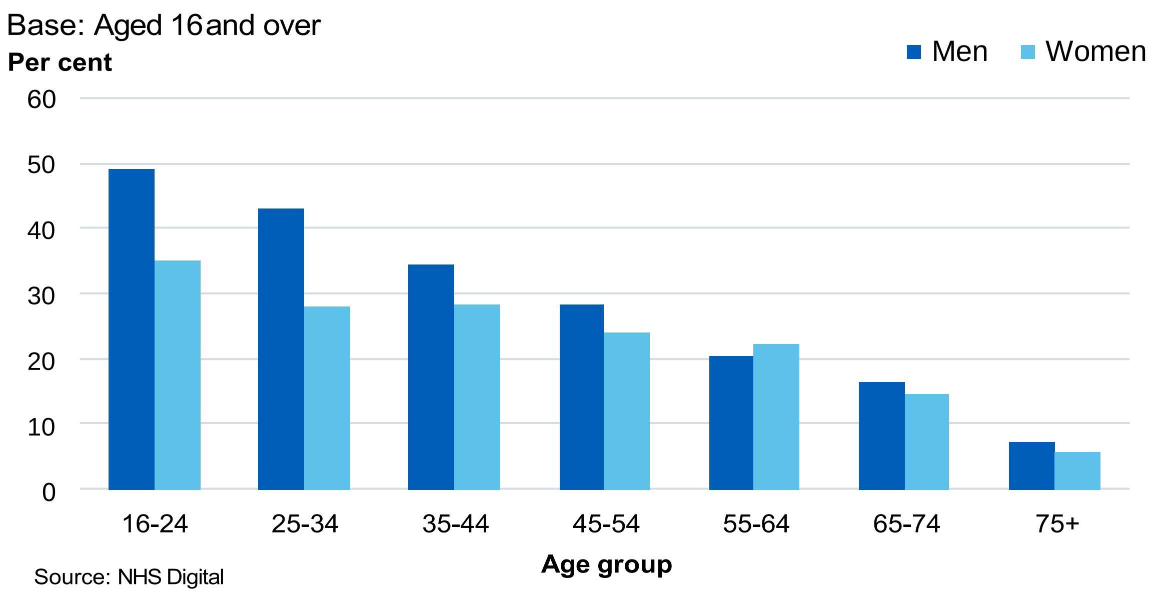

Figure 1.4. Self-reported proportions of men and women meeting aerobic and muscle strengthening recommendations within the UK PA guidelines from Health Survey for England data (2016). Source: Health Survey for England (2016) (145)

1.9.3. Obesity

The development of obesity during childhood not only influences impaired health (i.e. hyperinsulinemia, impaired glucose tolerance) at this stage of life (150,151), but also increases the risk of cardio-metabolic health issues in later life (152). Rates of obesity (defined by BMI z-scores) have increased in recent decades in children in developed countries (153,154) and currently one in six children internationally is overweight or obese (5). There is longitudinal evidence that BMI increases continuously from childhood into adolescents (129) and national survey data in England (HSE) clearly demonstrates that obesity rates increase from childhood through to adulthood, with BMI and waist circumference generally highest during the later stages of middle age (155). It is important to consider the development of obesity during the life course within the context of SB and PA because some domains of SB and low levels of PA contribute to the development of obesity during childhood (11,42). Furthermore, these relationships may be bi-directional where obesity in children influences more time spent sitting (15) and less PA (156). Figure 1.5, taken from HSE data in 2016 (145), highlights how sedentary time increases as BMI category increases from normal weight to overweight to obese in adults.

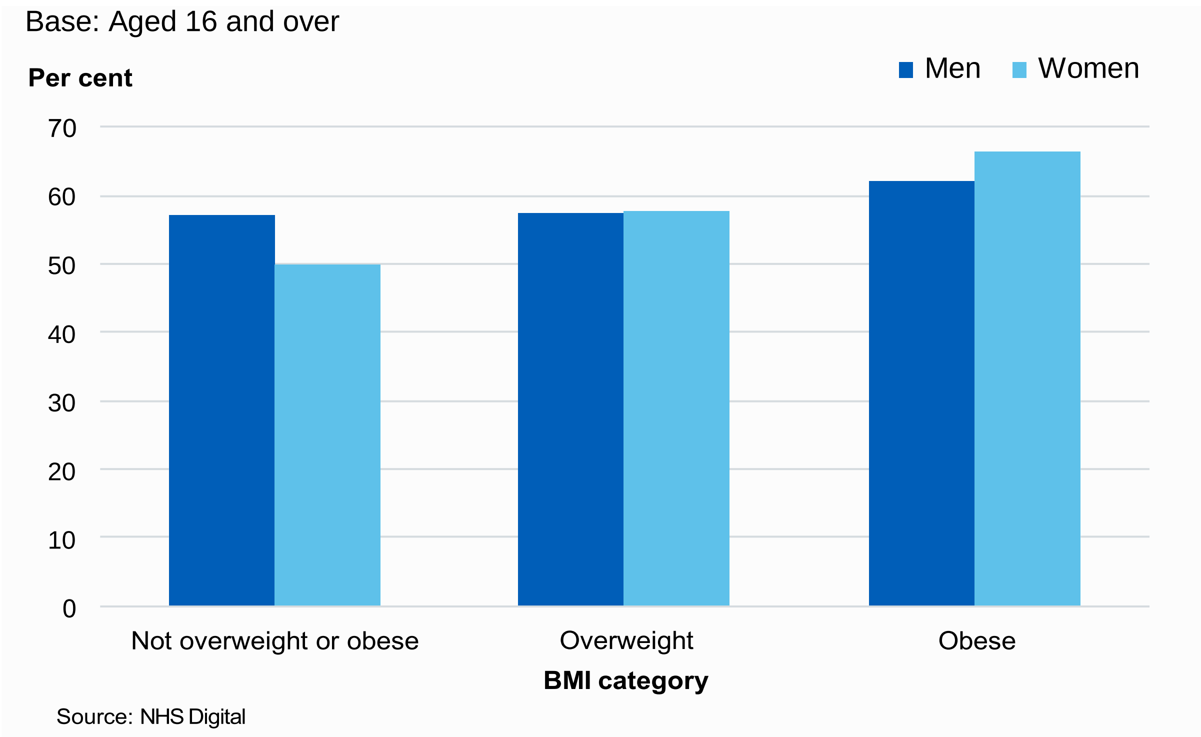

Figure 1.5. Self-reported proportions of adults that were sedentary for four hours or more per day on weekdays by BMI category and sex. Source: Health Survey for England (2016)

1.9.4. The need for lifestyle interventions during childhood

Low levels of PA and some domains of SB are negatively associated with obesity and other health outcomes during childhood (9,10,42). Furthermore, adulthood is when common NCDs typically manifest clinically (157) and when excessive SB/stationary time, low PA and obesity typically have a greater attenuating health effect. With SB/stationary time and obesity rates continually increasing (96,155) and PA decreasing beyond childhood (147), and the initial development of many NCD risk factors occurring during childhood (8), it would seem critical for healthy lifestyle strategies to be implemented during an early stage of life. This includes SB, not only by reducing time spent in more harmful behaviours (TV viewing), but also by reducing total daily sedentary time and breaking prolonged periods of sitting. Interventions during childhood can create positive daily SB profiles before SB patterns become entrenched into adult living habits (41). Furthermore, early modification can limit the number of life years that are spent exposed to potentially harmful sedentary time. The need for this preventative action is reflected in the worldwide development of policy and research interventions to reduce SB in children currently taking place (96).

1.10. UK Sedentary behaviour and physical activity guidelines for children and adolescents

PA guidelines have been in the UK since 1998, however, recommendations for SB first appeared in 2011 (28) and are still within the guidelines available to date. These recommendations, ‘Start active, stay active,’ are a UK wide document primarily aimed at providing guidelines on the volume, duration, frequency and type of PA required across the life course to achieve general health benefits. The recommendations are based on disease prevention and do not include the role of PA or SB for the treatment of pre-existing conditions. They were developed by an expert advisory working group using evidence from scientific reviews conducted by USA and Canadian governments, an evidence review conducted by a BASES consensus process and additional individual high quality evidence missed by the previous two processes. After a series of reviews and translations were conducted, a final set of recommendations were produced for Children and adolescents (5-18 years of age), stating that:

1) they should engage in MVPA for at least 60 minutes and up to several hours every day;

2) vigorous intensity activities, including those that strengthen muscle and bone, should be incorporated at least 3 days a week;

3) all children should minimise the amount of time spent being sedentary (sitting) for extended periods.

The report states that these guidelines apply across the population, irrespective of gender, race or socio-economic position. However, they should be interpreted with consideration of individual physical and mental capabilities. The guidelines state that regular PA at higher levels (beyond the minimum recommended) will provide additional health benefits. Conversely, inactive children and youths may experience health gains by performing some PA that is less than that recommended. Furthermore, overweight and obese individuals can have health benefits from meeting the guidelines in the absence of weight loss. To achieve or maintain a healthy weight however, it is recommended that an additional increase in PA and a reduction in calorie intake may be required (28).

The SB recommendation is somewhat vague compared to the PA recommendations which provide specific thresholds for volume, frequency and duration. This was due to a lack of good quality and consistent evidence of the sedentary time-health relationship to precisely quantify a suitable time limit (28), which is still apparent to date (42,43). Nevertheless, reducing total sedentary time and breaking up prolonged periods of sitting is ‘strongly advised.’ This SB recommendation is aimed at managing overweight and obesity and metabolic markers of health in children and young people. The report states that reducing time spent sedentary will increase time spent in LPA which in turn will benefit overall energy expenditure and a healthy weight.

1.11. Guidelines in other countries and globally

The first guidelines related to SB world-wide were those proposed by the American Association of Paediatrics in 2001 (75). They proposed that media use should be limited to 2h/day in children and adolescents. This was based on not only the negative influence of TV viewing on nutrition, diet and obesity, but also on behaviour, substance abuse, sexual activity, body image and school performance, with this time potentially displacing more active and meaningful pursuits (75).

Following the comprehensive systematic review by Tremblay et al (35) in 2011, the first Canadian SB guidelines were developed (separate but complimentary to the Canadian PA guidelines) (37), which were in line with those in the US, recommending that recreational screen time (e.g. TV viewing, computer use) is limited to 2h/day in children and youth (5-17 years). The Australian government have provided guidelines specifically for children (5-12 years) that similarly recommended less than 2h/day of electronic media use for entertainment (77). Similar to current UK guidelines, children are also broadly advised to limit the amount of time spent sitting or lying down and to break up prolonged periods of sitting, without specific times or values provided (77).

The current World Health Organisation (WHO) guidelines (98) do not include any instruction for SB. This will most likely be due to the diverse levels of technological development across low, middle and high-income countries and therefore the varied prevalence of SB. The PA guidelines closely match the UK recommendations for children and adolescents (5-17 years). Again these recommendations are for the purpose of the prevention of NCD and not disease management. They are also recommended for all children unless a medical condition prevents it. No recommendations are provided specifically for overweight or obese children.

Current PA guidelines for the USA were developed in 2008 and are close to identical to the WHO guidelines. This includes the absence of any SB recommendations (although the Secretary of Health and Human Services refers to the health risks of a sedentary lifestyle in their opening statement in the recommendations). Although consistent data suggests that many Americans are highly sedentary, the evidence of the health implications of excessive sedentary time may have been insufficient at the time of guideline development.

Very recently, Canadian recommendations have been developed that are a transition from what is currently advised internationally (98) and nationally in developed countries (28,77,158). The Canadian 24-h movement guidelines for children and youth (5-17 years) integrate time spent in PA, SB and sleep. The authors of the recommendations state that sleep, SB and PA make up a 24-h period where an increase in one will result in a decline in another, making the variables time dependent and collinear. These recommendations put forward a healthy movement profile; to achieve optimal health benefits, 5-17 year olds should achieve high levels of PA, low levels of SB and sufficient sleep every day. Recommendations for MVPA are in line with those stipulated in international and other national guidelines. The 24-h recommendations include:

- Uninterrupted 9-11 h of sleep per night for those aged 5-13 years and 8-10 h per night for those aged 14-17 years, with consistent bed and wake up times;
- An accumulation of at least 60 minutes per day of MVPA involving a variety of aerobic activities. Vigorous physical activities and muscle and bone strengthening activities should each be incorporated at least 3 days per week;
- Several hours of a variety of structured and unstructured light physical activities;
- No more than 2 hours of recreational screen time;
- Limited sitting for extended periods.

Another notable inclusion is time spent in LPA which has not been recommended before internationally. This is important because evidence of the health benefits of LPA (i.e. to adiposity and cardio-metabolic risk factors) is growing (159,160). Furthermore, a considerable amount of time during waking hours can be spent in this movement behaviour and time spent sedentary can be replaced with LPA more easily than MVPA. The authors state that the 24-h movement guidelines are informed by the best available evidence, novel new analysis, expert opinion, stakeholder feedback, and end user feedback (the latter a first for national/international movement-based guidelines). However it is recognised that much of the evidence that informed the guidelines is low quality (37) and almost no research exists on integrated movement behaviours and health outcomes. Consequently, some researchers may argue that this approach is not yet justified by the available evidence. Nevertheless, this progressive stride towards a 24-h movement profile is designed to push research towards this integrated approach. The approach is logical and allows for day-to-day variability which is inevitable in some children.

1.12. Sedentary behaviour interventions in young people

SB is a complicated behaviour, particularly total sedentary time accumulated throughout a waking day. Some undesirable behaviours, such as the consumption of unhealthy foods and drinks, can be completely avoided by children whereas sitting behaviour can only be reduced. Since current evidence is insufficient to provide specific thresholds on how much time children and adults should or should not be sedentary, the promotion of reducing sedentary time is a less clear and compelling message than that for increasing PA, for example. Furthermore, the mode of SB (i.e. sitting in class, TV viewing) and manner in which it is accumulated during a day (i.e. prolonged bouts of sitting) has varying impacts on health and development. Consequently, while the message of reducing sitting time is a simple message, the impact on health outcomes may depend on how it is reduced and what it is replaced with. SB interventions not only involve promoting the reduction of time spent in sitting behaviours (i.e. TV viewing, sitting in the classroom) but also need to consider what form of PA (standing, LPA, MVPA) should replace sedentary time. Consequently, some SB interventions may involve two distinct behavioural systems (161), further complicating the behaviour change process. These complications highlight the potential challenges for interventions designed to reduce sedentary time.

Recently, Altenburg et al (162) reviewed interventions specifically targeting SB of any kind as well as time spent in SB in 0-18 year olds. This was important for determining the true effect of SB interventions without complications from other lifestyle-related components (i.e. PA, dietary strategies). Of 21 identified studies, most were implemented with children (6-12 years old). All but one study used knowledge transfer as an intervention design, mostly aimed at parents with many targeting the parent and child in combination. The home / family were the main setting of interventions, but the school/pre-school/day care setting was also common, with some studies targeting both. Screen-based interventions were common, with a budget time system implemented for TV/DVD viewing, computer use and playing computer games proving popular. The evidence was limited by most studies being of weak quality, despite all but one being a RCT design. Furthermore, many studies described interventions poorly and had unclear outcome measures or were of inadequate validity and/or reliability (163). Overall, the authors stated ‘there was inconclusive evidence of the effectiveness of SB interventions.’

The Altenburg review (162) demonstrates that SB intervention research in young people is in its early stages, with few studies dedicated to this area to date (n=21). Many are small scale, and most are of weak quality which will therefore have limitations in providing evidence of behaviour change. Within the review, no attention was given to distinguishing between studies that were preliminary studies and those that were main intervention trials. This is important because these types of study designs should have different aims and objectives to each other and the evidence should not be interpreted equally. Within the early stages of intervention research, preliminary studies, typically referred to as pilot and feasibility studies, are a common feature. There is much debate within public health research around what pilot or feasibility studies are, how they differ, when to implement them and what their objectives should entail. The following section examines these issues, providing some context of the current SB intervention evidence base in children to date.

1.12.1. Pilot and Feasibility study designs

The Altenburg review demonstrated that there is a need for more larger scale randomised controlled-trials (RCTs) evaluating SB interventions in children. There are a number of different factors that can impede the evaluation of a large-scale trial such as inadequate compliance, intervention delivery, recruitment and retention. To maximise the evaluation process, it is important that preliminary studies are undertaken to identify and minimise such potential issues (164). Researchers are encouraged to publish preliminary work in advance of main trials (165). Such preliminary research is usually labelled as a pilot and/or feasibility study; however, these terms are often used inconsistently and inter-changeably (166) but have some distinctions that warrant discussion. Preliminary studies of large-scale complex intervention trials with several modes of 'treatment' may be particularly susceptible to these inconsistencies as the different stages of trial development are less well defined and clear cut (165). Nevertheless, review studies of preliminary research have attempted to define and distinguish pilot and feasibility studies using study methodologies, with the consistent conclusion that differences between the two are generally not clear (167,168).

Feasibility can be broadly described as a study designed to assess whether a larger or full-scale study is possible (can it be done?) (165). The Nation Institute for Health

Research Evaluation, Trials and Studies Coordinating Centre (NETSCC) states that important parameters should be estimated for a main trial such as the number of eligible participants, willingness of participants to be randomised, response rates, follow up rates, adherence rates, time required to collect and analyse data and willingness of relevant individuals to support the intervention (169).

A pilot study has been described as a miniature version or "scale model" of a main trial to explore if and how the main components of the study all combine together (164,169). The term 'pilot' is relevant in that an intervention or application of an intervention is novel (165). The main uncertainties established during trial development should be addressed and amended before a full-scale trial is undertaken (164,170). A pilot should focus on the processes of running a main trial (e.g. recruitment, treatment, randomisation, follow-up assessments), providing training and experience of the main trial (165). Pilot studies have been used to help establish a sample size calculation for a later main trial (167), however, pilots usually have small samples which offer inherent imprecision; a meaningful effect size estimate is not provided and therefore this practice is not advised (165,167).

Despite attempts to define and clarify pilot and feasibility studies, such studies are often poorly reported (167) and there remains much confusion around the terms (165). Furthermore, studies may be labelled as a feasibility or pilot study correctly or incorrectly depending on the definition used (165). There appears to be some consensus that mutually exclusive definitions of pilot and feasibility studies cannot be applied (171). Nevertheless, in a recent review of current practice and editorial policy, Whitehead et al. (165) concluded that pilot studies are consistently distinct from feasibility studies by:

- Using more strict study methodology
- Having a plan for further work
- Focusing on trial processes
- Being a smaller version of a main trial

A more flexible methodology has been ascribed in part to pilot studies often being a miniature version of a main study and therefore some outcomes will be specifically designed to inform this trial (165,167). Conversely, a feasibility study can be an isolated study (165). A plan for further work from a pilot study is crucial because otherwise these studies may be underpowered, unethical and therefore provide limited scientific use

(165). Some pilot studies do perform hypothesis testing (167), however, in this instance, a control arm is required (167) and since pilots are often not sufficiently powered to test effectiveness, the findings should be reported cautiously (164,172).

Pilot studies may test the feasibility of a larger study and therefore it could be argued that a pilot study is also a feasibility study (165). In fact, within a recently developed framework attempting to define pilot and feasibility studies, it specifically states that pilot studies are a subset of feasibility studies (171). However, the inverse cannot be said of feasibility studies being pilot studies (165) since feasibility studies may be conducted in isolation. Whitehead et al. (165) suggest that "a pilot study is a special type of feasibility study which has a plan for further work and mimics the envisioned definitive trial." Whitehead et al. also concluded that attempting to define a feasibility study may be futile since all preliminary work could be described as 'feasibility'. Conversely, Arian et al. (167) suggest that despite varying definitions between health research funding bodies, authors should be aware of the different requirements of pilot and feasibility studies and report them appropriately, with a recommendation to use the NETSCC definitions. Eldridge et al. (171) stated that three distinct study types make up feasibility studies; randomised pilot studies, non-randomised pilot studies and feasibility studies that are not pilot studies. The latter involves research attempting to understand whether an aspect of an intervention to be evaluated can be done without actually implementing the intervention within a preliminary study (171). Eldridge et al. also suggest that researchers should consider feasibility as an overarching concept and that all studies conducted with the objective of informing a main trial are a feasibility study (171). With an expected increase in complex interventions in future trials (164,168), and the recommendation from the MRC that preliminary studies are conducted before main trials, it is important that researchers carefully consider the different definitions and characteristics of feasibility and pilot studies, clearly reporting their reasons for adopting such criteria.

When designing an intervention, including during pilot and feasibility phases, it is important to consider the behaviour change theory in which to underpin the intervention. The following section explores the theories, models and frameworks that have been previously applied to SB and their suitability.

1.12.2. Behaviour change theory, sedentary behaviour and sedentary behaviour interventions

One important finding from the Altenburg review was that most identified studies did not base the intervention on a behaviour change framework or theory (162). This has also been observed in sedentary behaviour (SB) interventions with adults (173,174). Theoretical frameworks are important because they can be used to explain the likely processes and mechanisms of a targeted behaviour (175) and enhance the likelihood of intervention effectiveness (176). There are a vast array of behaviour change theories, models and frameworks that researchers can utilise. In studies that adopted some form of behaviour change theory within the Altenburg review, the Social Cognitive theory (SCT) was the most commonly utilised (177).

1.12.2.1. Social Cognitive Theory

SCT can be broken down into nine key concepts; reciprocal determinism, outcome expectations, self-efficacy, collective efficacy, observational learning, incentive motivation, facilitation, self-regulation and moral disengagement (178). Table 1.2 provides definitions of these concepts and examples of how each concept could be linked to SB. A prominent characteristic of SCT is reciprocal determinism; the dynamic interplay of personal, behavioural and environmental influence within human behaviour (see Table 1.2). While the environment in which individuals and groups operate will influence behaviour, individuals and groups can also influence their own behaviour by altering and constructing the environments around them (178). Outcome expectation involves the beliefs about the likelihood and value of consequences of behavioural choices. These expectations are subjective where individuals will evaluate the perceived benefits or costs of engaging in a behaviour. In relation to SB, an individual may first consider the benefits and costs of reducing their sedentary time (i.e. reduce sitting time after school) and their capability to make this change. Furthermore, SCT emphasises how humans have the ability to work towards distant goals (e.g. 6 and 12 month weight loss targets), overlooking immediate costs and the short-term benefits of alternative actions (178). However, in children, this may be less prominent with more immediate and hedonistic outcomes likely being more pertinent. Instead it may be parents or teachers that are focused on distant goals (e.g. reduce TV viewing and increase physical activity to reduce risk of obesity in the child). Outcome expectations consists of two important sub-components; social outcome expectations and self-evaluative outcome expectations. Social outcome expectations, corresponding to the concept of subjective norms within the Theory of Planned Behaviour (see section 1.12.2.4.2), involve the perception of how others will evaluate our behaviour and our willingness to be guided by that judgement (178). Self-evaluative outcome expectations suggest that an individual's behaviour can be partly dictated by their own anticipated feeling of whether they do or do not perform a particular behaviour (178). Self-evaluative outcome expectations can be more powerful than social or material outcomes in some individuals (178). These concepts may be particularly relevant within the classroom setting. Many SB intervention functions are dictated to children (e.g. standing classes for all children at a fixed time and duration). However, where there is free choice to sit or stand, such as with a standing desk and stool, social (i.e. classmates) or self-evaluative outcomes could play major parts in decision making. It is likely that a child's behaviour is influenced by their peers, however, the extent to which a child evaluates their own behaviour based on their own expectations and standards may be less influential on their classroom behaviour.

Self-efficacy belief (179), a key component and the most well-known aspect of SCT, may be one of the less influential concepts for SB interventions in children. Self-efficacy has demonstrated to be more influential in behaviours of more progressive complexity and difficulty (179); It is likely that in most cases, reducing or replacing SB would not be perceived as complex or difficult by children. However, this concept may be more relevant to parents and teachers attempting to change child behaviour. For example, a parent may lack belief in their ability to reduce their child's weekly computer game use. Intervention developers may subsequently design parent and child educational sessions and provide strategies for reducing computer game use (e.g. time use budgets, rewards, goal setting, providing options for alternate behaviours). In turn the parent gains the necessary self-efficacy belief to implement behaviour change techniques. There are several sources that influence self-efficacy belief including prior success and performance attainment, imitation and modelling and verbal persuasion (180). Performance attainment is thought to be the most influential source of efficacy since it is based on an individual's own experience of success or failure (180). However, modelling may have a strong influence for non-sedentary behaviour, such as standing during class time (180).

Observational learning is described as central to SCT (178) and involves four stages according to Bandura (181,182): 1) attention, 2) retention, 3) production, and 4) motivation. Peer modelling is a well-established method for influencing behaviour (183). Children are more likely to imitate other children who are the same age or older (184). Escobar Chaves et al. (185) implemented observational learning within a TV viewing reduction intervention using positive peer role model stories via newsletters with families. This form of storytelling may be more effective than the presentation of directly didactic or persuasive messages (186).

According to reciprocal determinism, no amount of observational learning will influence behaviour change unless the environment supports the new desired behaviour (182). Incentive motivation, a basic environmental determinant of change, has been utilised within SB interventions in children by parents when screen time reduction goals were met (187,188). SB interventions in children to date (162) have prioritised incentivising positive behaviour change (e.g. completing homework) rather than punishing continued undesirable SB (e.g. TV viewing). Facilitation is another fundamental environmental change within SCT. The best example of this within SB would be the provision of standing desks within the school classroom. Without this facilitation, the option to replace sitting time with a non-sedentary behaviour, i.e. standing, may be extremely limited. The provision of standing desks, where the option to avoid SB is within the individual's control, as with facilitation in general, is an empowering intervention function (178).

Table 1.2. Concepts, definitions and illustrations related to sedentary behaviour of the Social Cognitive theory. Source: McAlister et al. (2008) (178).

Concept	Definition	Illustration related to sedentary behaviour
Reciprocal determinism	The environments in which individuals and groups function will influence behaviour but individuals and groups can influence the environments they operate in, regulating their own behaviour.	To reduce sedentary car travel, a school incentivises pupils to cycle to school in groups. Pupils enjoy cycling with friends and the reduced car traffic on roads which further motivates pupils to cycle to school and avoid sedentary travel
Outcome expectations	Beliefs about the likelihood and value of consequences of behavioural choices	Educating children and parents about the potential harmful effects of watching TV advertisements
Self-efficacy	A person's belief about their ability to perform certain behaviours to achieve desired outcomes	Improving parent's belief about their ability to reduce the amount of time their child plays computer games per week
Collective efficacy	Belief of a group's ability to perform tasks to achieve desired outcomes	The collective belief of teachers within a school to incorporate physical activity breaks for pupils during class time to break up periods of prolonged SB
Observational learning	Learning to perform new behaviours by exposure to interpersonal or media displays, particularly through peer modelling	A film, observed by school children, demonstrating children replacing after school TV viewing with reading or non-sedentary activities and showing the benefits.

Incentive motivation	The attempt to modify behaviour using rewards or punishments	Parents reward children with a trip to a play park when daily/weekly TV viewing reduction targets are achieved.
Facilitation	The provisions of tools, resources or environmental restructuring to help enable new behaviours	Standing desks placed within a classroom that enable standing during class time
Self-regulation	The use of self-monitoring, goal setting, feedback, self-reward, self-instruction, and enlistment of social support to control one's behaviour	A child sets weekly goals for reducing media use and records daily media use in a self-monitoring log
Moral disengagement	Disengaging with moral standards to enable the concept of influencing suffering to oneself and to others as acceptable	Parents rationalising that frequent late-night TV viewing and unhealthy snacking as a family behaviour is not harmful. E.g. "children are growing all the time…. they run around all day…. it [unhealthy snacking] won't do any harm at this age"

Self-regulation within SCT involves the human capacity to endure short-term negative outcomes to benefit from anticipated long-term goals through regulating one's behaviour (189). We can influence our own behaviour by creating rewards and facilitating environmental changes that can be organised by ourselves (178). Bandura (179) describes six ways in which this can be achieved; 1) self-monitoring, 2) goal setting, 3) feedback, 4) self-reward, 5) self-instruction and 6) enlistment of social support. These techniques whether in isolation or in combination have been implemented repeatedly with SB interventions in children (187,188,190–192), typically with emphasis on reducing weekly TV or screen time use. Such techniques have been implemented exclusively through parents, particularly in studies with young children (<6 years of age), or with both parent and child involvement. Often the parameters of these techniques, such as goal setting and feedback, have been dictated by the parent and often by the research team on behalf of the child. Consequently, these techniques are not technically self-regulation from the child but via parents and others. Since self-regulation requires the maturity and discipline to adopt a behaviour without immediate benefit (but immediate loss), the ability and therefore applicability of self-regulation in children may be somewhat limited.

There may be little relevance of moral disengagement to SB. According to SCT, individuals can avoid violence and cruelty to others by learning moral standards of self-regulations (178). While SBs, particularly TV viewing, may be harmful to the health and development of children (42), this influence is not as acute or damaging to the individual or others from a public health perspective compared to behaviours typically associated with this concept (i.e. violence, acts of war).

On the whole, SCT describes behaviour as a purposeful action that is largely under the control of the individual through self-regulation and self–reflection (193). Consequently, this suggests that SB, when engaged in, is a conscious decision that involves an evaluative process. This theory is multi-faceted and considers the different levels in which individuals operate that may determine behaviour. Such an expansive ambitious theory may have some applicability to SB which itself is multi-modal, ubiquitous of modern society, and the most prominent behaviour across all settings for both children and adults. However, the more instinctive unconscious pathways associated with SB, which may be particularly relevant in children, are generally overlooked within SCT. Consequently its utility to SB is somewhat limited (180).

Despite the limitations of SCT to SB, it has been one of the more common theories applied to SB interventions in children. In the Altenburg review (162) of SB interventions in young people, interventions were typically designed to reduce screen-based behaviours, although two studies did concentrate on reducing total sedentary time. Interventions consistently included knowledge transfer and parental skills, all targeting the family/home setting with one study including the school setting. Overall it would appear that intervention developers aimed to educate children and parents on the health implications of SB and to motivate a reduction in sedentary time through action reasoning. Two of six studies using the SCT were effective in reducing sedentary time but one was reported as low quality by Altenburg et al. (163). The other study (192), conducted with 8-10 year old children, was reported as moderate quality and targeted screen time using a multi-function intervention that included a 10-day TV turnoff period, a TV control device, knowledge transfer (children received 18 lessons of 30-50 mins each, parents received newsletters) parental skills (rewarding child behaviour) and goal setting (set by researchers). Although the authors stated that the intervention techniques were based on the SCT, the reason for this decision and explicit details of how the theory underpinned the intervention strategies were not discussed. Nevertheless, TV viewing reduced by 37mins/day in the intervention group compared to the control group. No effects were found in other SBs suggesting this reduction in TV viewing was replaced with PA, however this behaviour was not measured which is a limitation of this study and common in other SB intervention studies. The intervention was effective over a relatively long period (6 month follow-up) which is very encouraging because this type of SB appears to be particularly detrimental to health and development (42). However, this intervention required substantial time and effort from parents and researchers and therefore scalability and sustainability are potential issues.

Other behaviour change frameworks implemented within the interventions identified by Altenburg et al. (163) included the Socio-Ecological model (194,195) and the Chronic Care Model (196). The latter was implemented in a clinical setting, which aimed to reduce TV viewing time in obese children (2-6 years) (196). The model is based on changing a health care system to achieve a desired behavioural change, with the necessity that all members of a health care team (i.e. nurses and physicians) are involved in delivering the intervention to the patient and family. Knowledge transfer and TV monitoring techniques were implemented with children and parents, which were successful in reducing TV viewing time compared to a usual care control group (−0.36 hours/day; 95% CI: −0.64, −0.09). This model is however specific to clinical populations and therefore is not applicable to healthy children.

1.12.2.2. Ecological models

Ecological models propose that behaviour is influenced on multiple levels including the intrapersonal (biological, psychological), interpersonal (social, cultural), organisational, community, physical environment and policy level (197). Consequently, individual behaviour, placed within an ecosystem, is dependent on the dynamic relationship between correlates and determinants that operate at the different levels (198). These models can be used to develop comprehensive interventions that target mechanisms of change at each level of influence on behaviour (197).

There are four key concepts of ecological models of health behaviours (197):

1) Specific health behaviours have multiple levels of influence; intrapersonal, interpersonal, organisational, community and public policy level
2) Influences on behaviour interact across the different levels
3) Ecological models should be behaviour specific, identifying the most relevant potential influences at each level
4) Interventions that operate at multiple levels should be the most effective for behaviour change

Ecological models generally emerged due to the ineffectiveness of strategies focused on individual level factors when attempting to influence health behaviour change (199,200). While each level or layer of ecological models may be important for effective behaviour change, targeting just one layer through intervention, is less likely to be effective than a multi-levelled strategy that considers key determinants of behaviour at every level of the model (as stipulated within core concepts one and four above) (201). Individual level interventions tend to reach individuals who have chosen to participate in behaviour change, whereas environmental and policy level changes are expected to influence entire populations (202). Single level interventions are unlikely to have powerful or prolonged population effects (197). Similarly, community, environmental and policy approaches may be insufficient for meaningful influence on behaviour if not supported by communication, education and motivational approaches.

According to the first core principle of ecological models described earlier, change in SB, for example replacing sitting with standing in the classroom, would be maximised when multiple levels of the model facilitate behaviour change. This would require physical environments and policies to support standing during class time (i.e. standing desks provided and a standing class school policy), for social norms and community support for this change to be positive (standing in class is regarded as normal behaviour and pupils, parents and teachers support this behaviour), and for individuals to be educated and motivated to sit less and stand more in class (i.e. children have been educated on the benefits of reducing daily sitting and motivated by a reward system and the autonomy and control over their posture when studying in class).

The second core concept states that different levels of influence within a model may interact, however, a limitation of ecological models is that the connections between the different levels are not explained (203). Indeed, there are likely to be multiple influencing factors at each level of the model for any given behaviour, which makes identifying the most relevant interactions within a model even more complex (197).

As stated within the third core concept, ecological models must be behaviour specific, for example sitting within the classroom setting, since the determinants of this behaviour may be specific to this context (204). While all levels of ecological model may play an important part in SB, the environmental context may be a particularly influential determinant of behaviour (204). For example, within the school classroom, children are typically provided with traditional desks and chairs that dictate a sitting posture during classroom tasks. Even if a child is motivated to stand (individual/intrapersonal level factor), the environment does not facilitate this behaviour. While not included in the four core concepts described earlier, the environmental context as a significant determinant of health behaviours can also be considered as a key principle of ecological models (205).

Generally, ecological models are frameworks that can be used to guide intervention design rather than a theory that can help explain behaviour. Ecological models may broaden perspectives on determinants of change, however, they do not identify the specific variables and the mechanisms by which those variables are expected to influence behaviour, as do many individual-level psychosocial theories of health behaviour (197). Beneficially, more explicit individual-level theories such as the SCT, can be incorporated into this broader framework (204).

The Socio-Ecological model has been widely applied to PA behaviour (198) and it has been suggested that such comprehensive models are essential for accounting for the multiple levels that may interact and influence SB (206). A strength of ecological models within SB research is the emphasis on the behavioural setting in which behaviour occurs; sitting will take place in numerous contexts with likely distinct determinants that require different approaches (207). Four domains of SB are identified as leisure, household, transport and occupation in adults (207) and in children and adolescents, occupation would be replaced with education. Different modes of SB will occur within these different domains (i.e. sedentary car travel to school, sitting at a desk in the school classroom) and the extent to which each of the different levels of the ecological model determine specific SBs will vary depending on the behavioural context (204).

The two studies that implemented the Socio-Ecological model within the Altenburg review, which were both based on the same overall 'UP4FUN' international intervention study, used knowledge transfer, child involvement and goal setting techniques to influence potential intrapersonal, interpersonal (parent) and organisational level determinants of SB. The intervention targeted the reduction of screen time, total sedentary time and an increase in interruptions to sitting time in 10-12 year old children (194,195). Despite a comprehensive intervention development process and being implemented in a large sample of children set across several European countries, reductions in sedentary time were not observed.

SB interventions based on these models may involve a complex blend of multi-level factors. Designing and measuring the influence of the intervention at each constituent part and conceptualising and implementing the intervention across different levels will be more challenging for research teams than individual level interventions (197). Furthermore, to isolate the effects of an experimental multi-level intervention from the natural ecosystem in which an individual interacts will be conceptually challenging (197).

1.12.2.3. Habit formation

Since sitting is the most prevalent posture during a waking day, in most cases this is likely to be a habitual behaviour. It is suggested that SBs are often undertaken with little conscious processing or decision making and therefore, the concept of habit needs to be considered when designing SB reduction interventions (208). There is debate over how habits should be conceptualised and operationalised (209). Within health psychology, habit is described as situational cues automatically prompting a certain behaviour due to learned cue-behaviour associations which have strengthened incrementally (210). Habits form through the repetition of behaviour within a specific context (209). As this behaviour becomes reinforced, the habit is automated and occurs through a more impulsive pathway in the absence of awareness, conscious control, cognitive effort or deliberation (211). A sedentary habit could be TV viewing after a school day; the child encounters the home context and the habitual response to this cue is to typically sit on the sofa and turn on the TV. Many SBs have become more and more attractive and accessible (i.e. larger and higher quality TV screens with multiple channels, improved modern furniture), that potentially increase the likelihood and frequency of sedentary habits (180). Excessive SB can be described as a bad habit that needs to be eliminated, or more realistically, reduced. Optimally, a healthy (non-sedentary) behaviour would replace this sedentary time and become a new habit. This new healthy habit should persist when conscious motivation wanes (211), therefore optimising the chance of long-term change (212).

Discussions within habit formation may identify behaviours as either ‘habits’ (automated responses to specific cues) or ‘non-habits’ (non-automated responses). However, automaticity is more likely developed on a continuum (213). Repeating a behaviour in the presence of consistent cues can lead to the behaviour becoming more automated (209). Initially, repetition of a behaviour will generate large increases in automaticity, but thereafter each new repetition will result in smaller increases in automaticity until a limit of automaticity is reached (209). Previous evidence has demonstrated that the average time for participants to achieve automaticity was 66 days, with a range from 18-254 days (209).

During habit acquisition, repetition within the same context is needed to achieve a sufficient level of automaticity. This repetition may be largely dependent on whether the individual has the desire to continue with this new behaviour (209). The outcome of response to the behaviour may be pivotal in this regard. Satisfaction is suggested to be an important consequence if habit acquisition is to progress to an established habit (213). A challenge for reducing or replacing SBs in children is that many SBs, particularly screen-based, provide satisfaction and pleasure and are probable primary reasons why children engage in those behaviours. While it may be feasible to encourage children to reduce screen time, such as TV viewing and computer game use on several occasions, it may be particularly challenging to promote the repetition of such actions consistently and over a prolonged period of time. It would probably be wrong to expect that children will experience satisfaction from reducing popular screen-based behaviours on a regular basis unless this was replaced with equally satisfying and rewarding behaviours. Many SB interventions have included rewards to encourage children to reduce popular screen-based SBs such as TV viewing (188,214,215). A goal for reducing TV viewing for a child may therefore be to receive an extrinsic reward. Even if this behaviour were to reach automaticity, this is not habit formation; goal-directed automated behaviour would likely be discontinued if the reward was removed however habitual action would not (216). A more prudent approach would be to try and instil intrinsic motivation to reduce SB and/or engage in a desirable replacement behaviour. This will increase the chances that repetition of the desired behaviour when a cue is encountered will occur during the more vulnerable habit acquisition phase. A major challenge in this regard may be in identifying a desirable replacement behaviour, whether non-sedentary or non-screen-based, that provides the same (or any) pleasure or satisfaction. For example, would a child take pleasure from avoiding a habitual hour of computer game play with one hour of homework or an activity with the family? This will likely vary between individuals and it would be logical to consult each child when choosing potential replacement activities that the child might be intrinsically motivated to engage in on a regular basis. Children may favour replacing sitting with standing or light physical activity (e.g. slow walking) when engaging with screen-based activities, if they are unwilling to replace these pleasurable activities. Simple behaviours, like many sedentary pursuits, are more likely to be automated than complex behaviours (213). Consequently, from a habit formation perspective, it may be beneficial to promote simple behaviours (i.e. classroom restructuring to enable standing during class time) that replace or interrupt undesirable SBs. As suggested within the SCT section, attempts to reduce and replace a sedentary habit with a non-sedentary behaviour will require the individual to identify and subsequent adjustment their behaviour in response to specific contextual cues. This transition will require conscious evaluative processing and self-control which children may lack the necessary maturity and discipline to effectively execute.

Self-regulatory techniques can be beneficial in promoting the repetition of targeted non-sedentary behaviours and such techniques have been implemented in several SB interventions in children (187,188,217,218). Self-monitoring can highlight the compliance of a particular behavioural goal which may provide the child with some satisfaction (213). This, however, may depend on the extent to which the child was involved in setting those goals. Several SB interventions have included researchers, teachers or parents planning specific behavioural and outcome-based goals, such a reducing total weekly screen time, on behalf of the child (187,219). Consequently, the child may not be particularly motivated by such goals nor gain any pleasure from complying with them. Studies that involved children in the goal setting process may observe that repetition of the desired behaviour (and therefore development of automaticity) is more likely. The child may in turn gain gratification from observing compliance with their own behavioural goals through self-monitoring. Two studies within the Altenburg review (162) incorporated children into the goal setting process; one demonstrated positive influences from the intervention in reducing electronic media use (220) whereas the other study did not observe any change in daily sedentary time (221). However, these were both low quality preliminary studies and therefore clear conclusions of intervention effectiveness cannot be made.

Conscious intention is also required during the early stages of habit formation. However, intention, while a significant precursor of the initiation of behaviour, is no guarantee the behaviour will be performed consistently for habit formation (209). Planning can help the individual act upon an intention when the opportunity arises. Implementation intentions is an example of such a tool, where a cue is identified within the targeted behavioural context and a desired behavioural response is planned. This typically is in the form of "if situation A is encountered then I will enact B to achieve C". Within a SB context, this could be "when I arrive at home after school, I will put my trainers on and walk to my friend's house, to spend more time outdoors with my friend", with the attempt of avoiding habitual television watching after school and replacing it with physical activity.

In attempts to break an unwanted habit or to develop a favourable habit, cues that prompt habitual responses may vary in frequency and form between different settings and contexts. Generally, salient features within a specific context or salient points of the day that are more easily identified can provide the most influential cues for behaviour (222). Within the home setting, cues that trigger SBs may be easily identified. For example, when arriving home and seeing the sofa and TV, this may trigger a response of sitting and watching TV, or when finishing an evening meal with the family this may initiate walking to the bedroom to play computer games. Within the classroom setting, it is likely that the beginning of a class will provide a host of cues (i.e. the teacher walks in the classroom, a bell rings) to trigger the response to sit at the desk. However, if standing desks were introduced within the classroom, where the child has the opportunity to sit or stand over prolonged periods of time, the cues to change posture are less obvious. It could be that different cues initiate a standing behavioural response between individuals. Cues may not be salient events or times of the day but rather personal feelings such as a feeling of excessive energy that prompts the desire to stand or through the discomfort of sitting for a prolonged period. Intervention developers may choose to allow users to sit or stand on their own volition when planning a classroom-based sit-stand desk intervention for example. A potential risk in this strategy is that insufficient context specific repetition of standing during the early stages of desk exposure occurs, automaticity is insufficiently developed, and therefore the window for habit formation has passed. It may be beneficial to specify the required frequency of the behaviour and potential cues for stimulating standing behaviour (e.g. teachers specify that the first 20 minutes of a lesson is conducted standing up), supplemented with some self-monitoring, to aid the necessary repetition of the context specific cue-behavioural response for effective habit acquisition.

Despite the relevant features of habit formation to SB, little empirical attention has been given to the sustainability of habits over time within health psychology research (211). Of all individual level behaviour change theories, Habit formation may be the most applicable to SB due to the more impulsive processes in which SBs are determined by. However, little attention has been given to this model within SB research to date. Understanding how a SB habit may be broken or reduced and subsequently replaced may be one of the more prudent directions within SB intervention research. Adulthood may consist of a host of SB habits that have been formed and subsequently endured since childhood. It may be obvious to think that the longer a habit has existed, the more challenging it may be to break and replace it. This certainly strengthens the argument for the necessity to implement habit formation-related SB strategies during earlier stages of the life course.

1.12.2.4. Other behaviour change theories and models

In adults, behaviour change frameworks applied to SB interventions, beyond those already described, have included the Transtheoretical model and the Theory of Planned Behaviour (173).

1.12.2.4.1. The Transtheoretical Model

The Transtheoretical Model (TTM) includes six stages of behaviour change (pre-contemplation, contemplation, preparation, action, maintenance and termination) through which an individual can transition between to ultimately achieve the desired behaviour on a permanent basis (223) (see Table 1.3). Ten behaviour change processes (i.e. consciousness raising, self-liberation) can be applied to enable transition. Further concepts of the model include decisional balance, self-efficacy and temptation. Decisional balance occurs when an individual weighs up the pros and cons of changing a behaviour. Self-efficacy, taken from the SCT, refers to the individual's confidence in their ability to cope with high risk situations without relapsing to previous undesired behaviours (223). Conversely, temptation refers to the intensity of an individual's urge to engage in a specific behaviour when in challenging situations. The TTM proposes that stages of change are both stable and open to change, much like chronic behavioural risk factors are stable and open to change (223). Furthermore, the model stipulates that specific principles of change should be emphasised at specific stages to enhance efficacy (223). Due to this model being successful within interventions promoting other health behaviours (i.e. smoking cessation, high fat diets), it is suggested that this framework may be suitable for SB change interventions (224).

Table 1.3. Stages of change within the Transtheoretical Model. Source: Prochaska et al. (2008) (223).

Stage of change	Definition
Precontemplation	A person does not intend to take action (change behaviour) within the next six months
Contemplation	A person intends to change behaviour, or is considering changing, within the next 6 months
Preparation	An intention to act soon, usually within the next month
Action	Specific and overt modification to a lifestyle behaviour has taken place within the last six months. This behaviour must be interpreted as achieving the desired goal (e.g. complete smoking cessation) rather than efforts towards the desired goal (e.g. reduce smoking or substitution to e-cigarettes).
Maintenance	Specific and overt modifications to a lifestyle behaviour have taken place with efforts towards avoiding relapse. Change processes are applied to a lesser extent than at the action stage.
Termination	There is zero temptation to revert to unwanted behaviours. The person has total belief that they will maintain the desirable health behaviour through barriers and challenges.

Originally, the TTM was specifically designed for smoking cessation, which is a discreet behaviour. The specific behaviour and ultimate objective are clear and is why there is a termination stage (smoking cessation indefinitely). The application of the TTM to SB is less clear and simple. With SB being ubiquitous within modern society, in several different forms (i.e. TV viewing, reading a book, sitting in car), across multiple settings (home, transport, leisure, occupation/education) and with varying influence on health outcomes depending on the type of SB, the TTM cannot be applied to SB interventions in a general sense. Rather, the setting and mode of SB may need to be clearly specified such as TV viewing during dinner time at home or sedentary commuting. Another complication could be whether the aim is to simply reduce sedentary time only or replace an undesirable SB with an alternative desirable behaviour. If SB has been successfully reduced over a sustained period of time (e.g. reduced TV viewing in the evenings by 1 hour a day) but the replacement behaviour has not been successfully adopted (e.g. failure to go for a walk for 1 hour every evening), how would this be interpreted within the stages of change? For clarity and practicality reasons, it may be that single specific behaviours are the focus. Furthermore, the temporal factor within the TTM may not be tangible for children. It is unlikely that children will be able to evaluate their behaviour in a meaningful way in accordance with the time frames stipulated within the model, such as a long-term goal to maintain a desirable reduction in a SB for longer than 6 months. Frequent monitoring and goal setting may be required by parents and teachers on behalf of the child. Also, children's attitudes and intentions towards SBs and the time spent sedentary may be more transient and sporadic compared to older age groups. Consequently, applying the rigid stages of change over the long-term to child SB may be somewhat impractical. Daily TV viewing may be the most suitable long-term behavioural goal for this model since it is a specific SB, will most consistently occur in the home or family setting and there are specific and enduring guidelines that can be targeted (<2 hours/day) (37,75).

Since most of the behaviour change principles within this model are based around self-regulation, there is an absence of consideration for the more impulsive and hedonistic determinants more relevant to child behaviour compared to adults. Essentially, children may lack the maturity required for the TTM to be effectively applied during the behaviour change process. Constant parent and teacher involvement may be essential when applying this model to SB interventions with children. Since all SBs are not entirely harmful and can all probably be beneficial in some capacity when performed in moderation, it may be too simplified to set specific and fixed boundaries for most SBs long-term, particularly in children who will develop and alter psychologically and physiological during periods of accelerated growth and maturation. For example, the maintenance stage has been estimated to last between 6 months and 5 years (225). If this is applied to a child of ten years of age, the transition from child to adolescent may also occur during this time and therefore the motives, beliefs and determinants for any given stage of behaviour change could alter, complicating the application of the model.

1.12.2.4.2. The Theory of Planned Behaviour

The Theory of Planned Behaviour focuses on an individual's motivational factors that determine the likelihood of performing a specific behaviour (226). This model assumes that intention is the best predictor of a behaviour, which in turn is determined by three sources; attitude, subjective norms and perceived behavioural control (227).

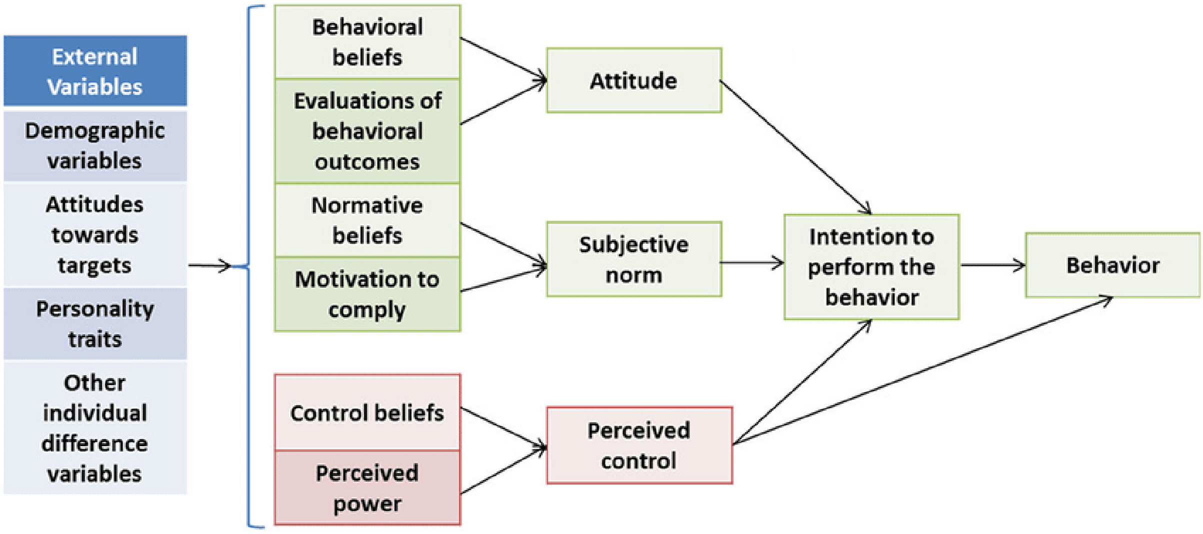

Figure 1.6. Theory of Planned Behaviour. Source: Montano (2008) (226)

Figure 1.6. demonstrates the constructs of the TPB. Attitude is determined by the individual's belief about the outcome of performing a behaviour (behavioural beliefs) which are weighted by the evaluation of those behavioural outcomes. Subjective norms are determined by normative beliefs (i.e. do peers or important others approve or disapprove of a particular behaviour) and in turn the motivation to comply with the opinions of relevant and important others. Perceived control is governed by control beliefs which are the perceptions of the presence or absence of facilitators and barriers to behaviour performance, weighted by the perceived power of each control factor to facilitate or inhibit behaviour (226). This theory has been effective in predicting and explaining a range of health behaviours and intentions including exercise (226). this approach, much like the TTM, suggests that an individual's evaluation and conscious decision making of SB engagement is fundamental for behaviour change.

Attitudes have both cognitive and affective aspects, with the latter usually the more important for behaviour change (180). This may also be the case for SB; many SBs are designed or marketed for apparent ‘pleasure’ such as comfortable chairs, modern automobiles and TV viewing (180). Consequently, the attitude towards many frequently available SBs is that of pleasure, making the shift from SBs to non-sedentary behaviours (e.g. public transport, being active in the evenings) all the more challenging. Within the Altenburg review (162), many interventions were designed to educate children and parents of the potential harm of screen-time and to promote the benefit of alternative activities. Therefore, it seems apparent that these strategies were used in an attempt to raise the concept of screen-time behaviours during leisure time into the consciousness and encourage the individual to evaluate these actions. Intervention developers will have therefore hoped that attitudes towards undesirable SBs (e.g. TV viewing) can be altered. This in turn, may change intentions to be sedentary or not, which may lead to behaviour change within the family/home setting.

Normative beliefs, the subcomponent of subjective norms, may be a powerful influence on sitting behaviour, or the willingness to change to non-sedentary behaviours, since sitting is ubiquitous in most domains. The transition from childhood into adolescence may certainly be a time in which an individual desire to comply with peers sitting or non-sedentary behaviour becomes stronger. Even if the opportunity to reduce sitting time is available, for example with the provision of a sit-stand desk, a child or adolescent may be far less likely to stand during periods when no other children are standing, in fear of not complying with the norm. Generally, targeting subjective norms has been overlooked within SB interventions in children to date (162), which may be due children being less motivated by peer influence compared to adolescents and adults. It may also be due to the fact that most interventions to date have been implemented within the home setting, where social norms may have less of an influence (the child may typically engage in screen-based SBs without peers present). Escobar Chaves et al. (185) used positive peer role modelling stories related to media consumption within family newsletters. This intervention was based on SCT and therefore may have used this technique to influence the core concepts of Observational Learning and the social component of Outcome Expectations within this theory, although this was not stipulated within the study. Nevertheless, the latter corresponds with Subjective Norms within the TPB.

With regard to perceived behavioural control, sitting is very easy with few obstacles. In fact, it is often the easiest posture to adopt in most contexts. SB interventions can impede access to SBs and promote or facilitate non-sedentary activity. Alternative actions, if competing with SBs, will also probably need to be perceived as easy, if they are to replace sedentary time. Hinckson et al. (228) provided standing workstations and removed chairs within the school classroom. Children could rest by using balls, matts and beanbags provided however standing was the primary posture available to children during class time. This intervention therefore shifted the perceived behavioural control of sitting, where this posture has become far more restricted, and their control of adopting a standing posture has become very strong. In contrast, a standing desk system that provides choice between sitting and standing at any time (e.g. stand biased desks provided with a stool) may provide more equal perceived control of the two postures; both can be adopted at any time and both are easy to adopt. These contrasting systems raise the question from a moral perspective, to what extent should SBs be inhibited? By diminishing the perceived control of an alternative option, as created by the intervention design of Hinckson et al. (229), a non-SB may feel imposed on the individual, rather than chosen. While sedentary time may be successfully reduced, once the individual enters the next phase and setting of a day (e.g. the home), they may feel the urge to seek sedentary pursuits now that restrictions do not apply, where they can exert more control over behaviour. However, since SBs in children may be more impulsive and subconscious, restricting access to SBs may be necessary at this stage of maturity. Once in adolescence and adulthood, more democratic and evaluative approaches may be more suitable. Within the Altenburg review (162), several interventions restricted the access to screen time within the home. This included TVs being removed from the bedroom and banned during mealtimes, screen time budgets, TV turn off times and restricted access to TV during specific periods of the day. These barriers to screen time may be perceived as powerful barriers that diminish the individuals perceived control over this behaviour because such rules have been enforced by parents; parents will most likely have the strongest influence on values and attitudes during childhood. The individuals perceived control may change, however, as they progress to adolescence and the urge to challenge such rules and restrictions develops.

According to the TPB, the intention to be sedentary or not is the key component for behaviour change and as discussed in section 1.12.2.3. it may be challenging to influence this intention to be sedentary in children. Within the Altenburg review (162), several interventions involved behavioural goals being set by parents, teachers or researchers without involving the child; this is unlikely to sufficiently motivate the child to reduce time spent sedentary. Extrinsic rewards are also a common component of SB interventions in children; however, this is unlikely to establish intrinsic motivation within children to change behaviour, a more effective form of motivation to establish long-term behaviour change. Once such rewards are removed, will the child still have the intention to perform the replacement behaviour? As discussed within the Habit Formation section (1.12.2.3), ways in which to establish intrinsic motivation to reduce and replace SBs in children are not obvious and warrant investigation.

In some circumstance, intention alone is not enough to reduce SB. Within the school classroom, traditional furniture dictates that children sit at a table and chair during lesson time without a physically active alternative. If a child were to attempt to change their posture during class time (e.g. standing up intermittently, walking around the classroom) this is likely to result in conflict with teaching staff. This example therefore highlights the limitation of the TPB to the broad range of SB settings and determinants. Nevertheless, when considering the hedonistic aspect of SB, the frequent opportunity to sit across all domains (i.e. transport, school, home), and the subjective norm to sit within so many contexts, the TPB can at least help us understand why SB is ubiquitous in children and underlines the challenge of changing this behaviour.

The behaviour change theories and models commonly applied within the SB literature have been adopted partly because they have been successful, albeit to varying degrees, within PA interventions (161). This is problematic because PA and SB are two distinct behaviours with key qualitative differences (204). One key difference is the extent to which conscious and unconscious processes determine behaviour. Dual process models propose two parallel processing systems of a behaviour; reflective (more conscious decision making) and impulsive (more unconscious decision making). While MVPA requires processes largely on the reflective pathway, many SBs, such as leisure time television viewing or sitting within the classroom, are influenced more by impulsive instinctive processes (161). Consequently, theories that are based more on conscious evaluative processes such as the SCT and TPB, lack relevance to SBs (although aspects of the TPB do provide some insight into why individuals are sedentary and why sedentary behaviour change can be challenging). Furthermore, individual level models, whether more reflective or unconscious, do not account for broader social and contextual attributes that can influence behaviour (204) and are therefore not considered to be sustainable in the longer-term (64). SB is thought to be complex and multi-faceted and consequently an approach addressing just one dimension or level of influence is limited. Theories related to habit formation not only focus on the more instinctive aspect of behaviour but also account for environmental and contextual cues to behaviour. This further emphasises the suitability of habit formation model to SB. Such models need to be tested in different types of SBs and within different contexts to shed more light on the determinants of SB (161) as habit formation has rarely been applied to SB and little is known of its predictive power. A major challenge of interventions based on ecological models is that it is difficult to design, evaluate and measure interventions operating on multiple levels of influence (204). It is also challenging to unpick which levels of influence are most effective (204). Furthermore, such approaches require multi-disciplinary research teams of broad expertise which consequently requires greater time and resources (204). As stated earlier, ecological models do not specify the connections between different levels of influence, unlike individual level theories (204). Therefore, an ecological model can help guide intervention design but perhaps the addition of individual level theory is necessary.

Generally, the definition of SB has continually adapted and at times been poorly articulated (161) which has hindered progression in the understanding of SBs on the whole. There is a demand for more psychological research on SB (230), with more application and development of behavioural theories (231). Ecological models (i.e. socio-ecological model) have dominated health behaviour research in recent times and while they have been applied to SB, may only provide a broad guidance (206). Consequently other models have been encouraged in exploring SB and the mediating processes for reducing sitting time (231). Within the Altenburg review (163), only nine from twenty one studies adopted a behaviour change theory or model. These nine studies did not clearly explain how the intervention was specifically underpinned by the core concepts of these models. Consequently, the justification for some components of the intervention may be lacking. Furthermore, without knowing how specific intervention components apply to the theory or model, conclusions about the influence of using such models cannot be made. As a result, the applicability of different behaviour change theories and models to SB interventions in children is largely unknown. At present, intervention developers when designing a SB intervention for children, for the most part, can only choose a behaviour change theory or model based on whether it appears conceptually relevant, rather than drawing from any evidence base. Prior to the intervention development phase, more observational research exploring the extent to which different theories, such as Habit Formation and SCT, can predict different modes of SB within different settings needs to be conducted in children. Theories that can predict SBs within this demographic may then potentially be successful in interrupting or replacing such behaviours through interventions that manipulate the mediating processes that govern SB. Future intervention studies should also seek to implement logic models that will explicitly detail how a behaviour change theory or model informs the intervention, as these were not evident within studies within the Altenburg review (162). These models can help structure data collection and analysis to directly test the influence of key components of an intervention (232). Therefore, if a specific function of an intervention is based on an aspect of a theory, the findings will help establish whether the theory provides benefit for reducing child SB. Optimally, theories and models will be applied to SB interventions in children via large scale randomised control trials, beyond the predominant small scale and often low quality pilot and feasibility studies implemented to date, to enable stronger conclusions about intervention and therefore theory/model/framework effectiveness.

1.12.2.5. The Behaviour Change Wheel

The Behaviour Change Wheel (BCW) has received increasing attention within the SB literature (161,173,224). The BCW (see Figure 1.7), a recently developed framework, was formed by synthesising other frameworks within the behaviour change literature (233). The developers of the BCW have stated that previous frameworks are not comprehensive and few are conceptually coherent. Furthermore, behaviour is assumed to be driven by different factors between frameworks, such as beliefs and perceptions compared to unconscious bias or social environments. The BCW brings these factors, all of which are important, together in a coherent manner, allowing for the BCW framework to be applied to any behaviour in any setting (233). At the 'hub' of the BCW is the Capability, Opportunity and Motivation (COM-B) model (233) which together determines the sources of behaviour and therefore provides targets for intervention. Each component can be split into two further domains; capability can be both the physical (e.g. skills, strength) and psychological (e.g. knowledge, stamina) capacity to change behaviour; opportunity can be physical (e.g. time, resources) or social (e.g. interpersonal influence, social cues); motivation can be reflective (plans and evaluations) or automatic (e.g. emotional reactions, desires). Around the COM-B model are nine intervention functions that can be used to influence behaviour change. They are described as functions because an intervention may consist of more than one of these components (233). Finally, the outer layer of the wheel consists of seven types of policy in which intervention functions can be delivered through. Due to the limited understanding of determinants of SB (161) and the potential complexities in attempts to reduce sedentary time already discussed, it would seem suitable to utilise the BCW, a comprehensive framework, to underpin and better guide SB interventions

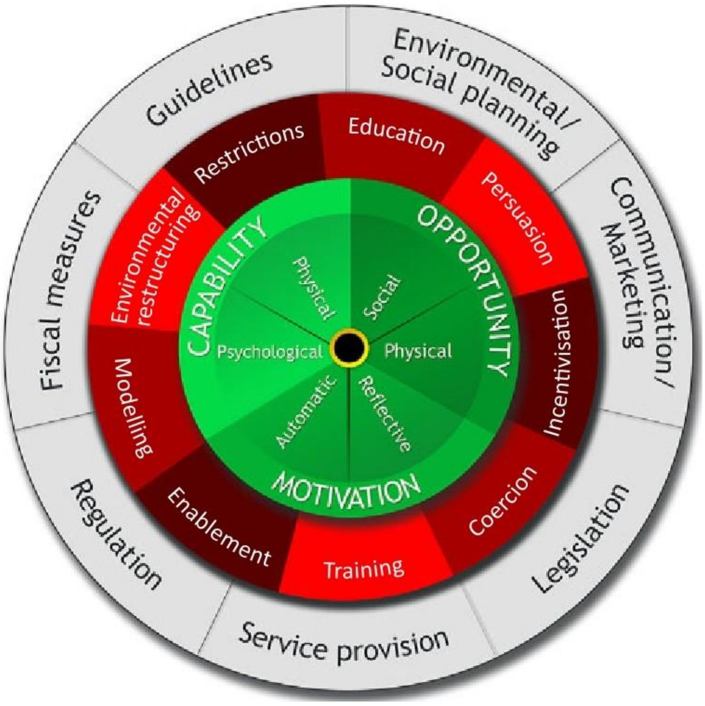

Figure 1.7. The Behaviour Change Wheel. This consists of the COM-B model (centre), nine intervention functions (middle ring) and seven policy categories (outer layer). Source: Michie et al. (2014) (233).

One particular intervention category within the BCW that has consistently demonstrated effectiveness in reducing sitting time is environmental restructuring (163,173,234). Within the Altenburg review (162), of the moderate quality intervention studies identified, one study replaced traditional primary school classroom desks with standing workstations, with the provision of exercise balls, bean bags and mats for resting from standing. Daily sitting time reduced by approximately one hour a day, the highest reduction of any SB intervention within the review. Although rated as moderate quality by Altenburg et al. the study was only four weeks in duration, included just one intervention class and had a very small control group (N = 7). Nevertheless, standing desks have also been found to be effective in adult workplaces in reducing sedentary time (173,234). Typically, standing desk interventions have lacked a theoretical framework that underpins the intervention (162,173). In the absence of theory utility, the specific intervention functions that intervention developers choose can provide some indication of their perceived reasons for why individuals spend their time in sedentary pursuits (175). By restructuring the classroom environment with standing desks, it suggests that intervention developers base the cause of SB on physical opportunity and therefore external variables. These factors could certainly be critical within the school classroom setting since traditional classroom furniture dictates that children spent most of the time in class sitting (84). While environmental restructuring has potential, other SB intervention functions and techniques may also be important for scalability and sustainability of behaviour change since opportunity is only one domain of the COM-B model that dictates behaviour change (233).

The school environment is an important setting to target sedentary time because children spend most of their waking day at school (235). Consequently, the following section explores SB interventions implemented within the school setting.

1.13. Sedentary behaviour interventions within the school setting

Hegarty (236) conducted a systematic review of SB interventions based within the school environment. The review identified 11 papers reporting eight controlled and three non-controlled trials. Studies were limited to the UK, Australia, New Zealand and Belgium, with children of varied socio-economic position, samples ranging from 26 – 2221 children, ages from 7-12 years and interventions of between 4 weeks and 18 months duration. Half of the studies included multi-component interventions, where reducing sedentary time was part of a wider lifestyle-based intervention. The remaining four interventions were single-component, designed to reduce sedentary time only. The multi-component interventions also involved parents assisting their child with intervention activities at home.

The only intervention design that consistently demonstrated a reduction in sedentary time was in those using standing desks within the classroom. Although these studies (*n*=3) included small samples (Intervention class, n ≤24), had no theoretical underpinning, were single-component interventions and were of short duration (≤10 weeks), they all demonstrated reductions in classroom sitting time of approximately 20-60 min during daily class time (and in total day sitting time in some cases) within intervention groups (91,237,238). The authors concluded that 'standing desk interventions may be more effective than multi-component school-based interventions in reducing sedentary time.' Furthermore, it was quite clear that implementing environmental restructuring in this way resulted in very high intervention exposure time compared to other intervention designs. For example, in the Australian trial of the Clemes et al. (91) study, children received a sit-stand desk each and since children remain in one classroom for a full school day at primary school, the potential exposure was approximately 20-30h/week (4-6h/day of classroom time five days a week). The next best exposure time in a non-standing desk intervention was 150 min/week in a multi-component intervention that included teacher-led educational classes, standing lessons, PA breaks and newsletters (190), with other interventions providing around just 1h/day of exposure.

Based on the reviews of Altenburg et al (162) and Hegarty et al (236), standing desks appear to be one of the more promising solutions for reducing total sedentary time in children. Crucially, the school setting is a distinct environment that has many potential benefits and challenges that must be considered before any health intervention is implemented.

1.13.1. The school setting for sedentary behaviour intervention

The school setting has been previously identified as an important environment for influencing healthy behaviours (136), partly because children spent most of their waking hours during week days at school (239). A key benefit of this setting is that large numbers of children can be accessed in a single location, which is highly structured with children being closely supervised by teaching staff. Crucially, most schools are likely to include children of diverse demographics (84), with some of higher health risk (i.e. obese, low household income, ethnic minority) who may be more challenging to reach within the community setting. Importantly, in mid-childhood to adolescence (9-15 years), a key stage of maturation occurs where parental influence on behaviour begins to dissipate and the influence of peers becomes stronger (240).

Children spend most of their school time, particularly during class time, sedentary (39,81,88). During class time there is evidence that children sit for between 70% and 90% of the time across all subjects, with total sitting time and mean sitting bout lengths increasing as children progress through the school years/grades. (84). Consequently, the classroom would appear to be an important environment to implement strategies for reducing sitting time.

Any health intervention or program that is based within a school setting will need to compete with often crowded school curriculums. Teaching staff and parents will certainly prioritise learning and development-related outcomes on a day-to-day basis. Consequently, any intervention that places demands on academic staff certainly runs the risk of insufficient implementation, compliance and sustainability. This can be further attenuated in teachers who are sceptical of the necessity of a lifestyle-related intervention in an age group that is largely healthy. Insufficient intervention implementation by teachers, mainly due to conflicting curriculum needs, has been evidenced in school-based PA interventions (237). To be sustainable, it may be critical that an intervention is integrated into a school environment with minimal disruption to the school schedule or common daily practices. Furthermore, any intended changes in behaviour brought about by intervention (i.e. reduced sitting time, increased PA) will need to influence either no change or a positive change in academic performance and on/off task behaviour if it is to have any chance of acceptance as a permanent classroom modification.

Despite these challenges, interventions promoting PA have been successfully implemented during physical education class, during break times, and before and after school hours (9,241). Furthermore, when PA has been used as a teaching tool as well as a short activity break during class time, positive effects have been observed in classroom management, student attention and focus on task (242).

1.14. Standing desks within the school classroom

Replacing traditional desks with standing desks is by no means a small modification to a primary school classroom. However, this type of intervention design has many promising characteristics, including:

- High potential daily intervention exposure time per day and over a full academic year
- The simple self-service design has little demand on teaching staff for implementation, compared to other common intervention designs (i.e. educational classes).
- The autonomous, subconscious nature of using standing desks removes the conscious effort of the user to engage in a healthy behaviour (standing) and to reduce the negative behaviour (sitting) (236)
- The user has the option to not only reduce total sedentary time but also frequently interupt prolonged bouts of sitting with standing or light ambulation.
- A full classroom of standing desks, assuming they remain operational, can be used by hundreds of children over a 5-10 year period, potentially making the intervention highly cost-effective.

When considering all these factors, further research into the effectiveness of this environmental restructuring strategy as a means to reduce sitting time in young people is warranted.

1.15. Objectives of the thesis

This introduction chapter has outlined that internationally, children spend most of the waking day sedentary, which tracks and continually increases from childhood through to adulthood, and this is when excessive sedentary time is associated with an increased risk of morbidity and mortality. Consequently, early intervention is essential before sedentary habits become entrenched and years of potentially harmful exposure are endured. Standing desks within the school classroom have emerged as one of the most promising strategies for reducing total sedentary time and therefore the aim of this thesis was to further explore the effectiveness of this method of classroom modification on reducing sedentary time.

The primary objectives of this thesis were to:

1) Systematically review the evidence of the effectiveness of standing desks within the school classroom
2) Outline and critique the data reduction methods and decisions when using objective measures of sedentary behaviour and physical activity, which provide the primary evidence for this thesis
3) Explore children's levels and patterns of sedentary time accumulation at and away from school
4) Evaluate the medium-term and longer-term impact of two different standing desk intervention systems as strategies to reduce classroom sitting time and increase PA in children. The impacts of the two interventions on secondary outcomes including adiposity, cognitive function, musculoskeletal discomfort and behaviour-related mental health will also be explored.
5) Conduct implementation evaluation of the pilot Stand Out in Class Intervention.

1.15.1. Thesis Overview

Table 1.4. provides an overview of the purpose of each objective and where and how they are addressed within this thesis.

Table 1.4. Thesis overview.

Objective	Location	The purpose	How the objective is addressed
1) Systematically review the evidence of the impact of standing desks within the school classroom	Chapter 2	To map all current evidence of standing desk studies implemented within schools. This will help identify what is currently known about these interventions and the gaps in the evidence that need addressing in future standing desk studies.	A systematic review was conducted using relevant database searchers to identify and comprehensively summaries all studies that have explored the impact of standing desks within the school classroom. Studies with samples of any school age and with any outcome measure were included in the review.
2) To outline the data reduction methods and decisions when using activPAL and ActiGraph devices in this thesis	Chapter 3	To fully disclose and critically evaluate all data reduction processes for objectively-measured sedentary behaviour and physical activity data presented in Chapters 4 and 5.	All data reduction methods for activPAL and ActiGraph data presented in Chapters 4 and 5 were fully detailed. A critical review of the key decisions are also presented, evaluating the impact that these decisions will have had on the results presented in Chapters 4 and 5.
3) Explore children's levels and patterns of sedentary time and physical activity accumulation at and away from school	Chapter 4	To better understand the SB and PA profiles of UK children using a valid objective measurement. The evidence will identify the extent to which a SB intervention is needed in UK children	Levels and patterns of sitting, standing and stepping behaviour in 9-10 year old children from the city of Bradford, UK, are explored in a cross-sectional study. Baseline activPAL data

Objective	Location	The purpose	How the objective is addressed
		overall and in specific domains and settings.	from the intervention study outlined in Chapter 4 and a previous pilot study (91) are examined.
4) Evaluate the medium-term and longer-term impact of two different standing desk intervention systems as strategies to reduce classroom sitting time and increase PA in children. The impacts of the two interventions on secondary outcomes including adiposity, cognitive function, musculoskeletal discomfort and behaviour-related mental health are also explored.	Chapter 5	To pilot two standing desk intervention systems over the longer term, both designed to reduce SB in UK children. These systems were a partial desk allocation and a full desk allocation system implemented in two separate classrooms. Aspects of the intervention design and evaluation process are informed by findings from chapters 2 and 4.	A pilot sit-stand desk controlled-trial named *Stand Out in Class,* implemented with 9-10 year old children in primary school classrooms in the city of Bradford, UK, is evaluated in this chapter. Outcomes include changes in sitting time (activPAL data) and PA (activPAL and ActiGraph data), adiposity, cognitive function, musculoskeletal discomfort and behaviour-related mental health during class time after 4 and 8 months of desk exposure. Data comparing the full desk and partial desk allocation classes to a control class are presented.
5) Implementation evaluation of the pilot Stand Out in Class Intervention	Chapter 6	To explore the extent to which the full desk allocation and partial desk allocation system were implemented by teaching staff. What were the impacts of this and the intervention in general	Focus groups and interviews with pupils and teachers from the full desk and partial desk allocation systems were conducted. Summaries of this qualitative data is presented and evaluated. Findings from the two

Objective	Location	The purpose	How the objective is addressed
		on the classroom environment and child behaviour	intervention systems are compared and suggestions for future research are provided.
6) Conclusions	Chapter 7	Why is this thesis and the evidence within it important or meaningful for SB research and public health?	The studies and evidence presented in chapters 2 to 6 are synthesised and critiqued. Key findings, potential future directions and implications for research and policy are discussed.

CHAPTER 2 - The effects of standing desks within the school classroom: a systematic review

The research outlined in this chapter has been published in Preventive Medicine Reports: *Sherry AP, Pearson N, Clemes SA, (2016), The effects of standing desks within the school classroom: a systematic review, Preventive Medicine Reports, 3:338–347*

2.1. Introduction

Due to advances in technology and environmental changes over the last few decades, particularly in more developed countries, many people spend the majority of their waking day sedentary (243). SB (SB) has been defined as "any waking behaviour characterised by an energy expenditure ≤ 1.5 METs while in a sitting, reclining or lying posture" (16). Adverse associations between high levels of SB and cardio-metabolic health risk markers (for example, obesity, blood pressure, cholesterol, insulin, and reduced cardiorespiratory fitness) have been reported in children (35,129,244). Furthermore, high levels of sedentary time have also been associated with reduced self-esteem and academic performance (35). These effects are largely independent of moderate-to-vigorous-physical activity (129).

While children are the most active age group, SB is increasingly prevalent in this population; data suggest that Canadian and US children spend around 60% (6-8 hrs) of waking hours sedentary, while studies suggest that UK children spend more than 65% of waking hours sedentary (76,81,245). SB has been found to track from childhood into adolescence and adulthood (139). Therefore, the development of effective strategies to reduce SB is imperative for the current and future health of young people.

While children function in multiple environments including the home, community and school, evidence suggests that children sit for longer during school hours compared to non-school hours (87). School pupils typically spend the majority of their school day in a classroom where the environment dictates prolonged periods of sitting. The classroom is therefore an important and opportune environment for the implementation of interventions aiming to reduce sitting (246).

Environmental changes in the workplace such as the implementation of adjustable sit-to-stand desks, which enable the user to alternate between sitting and standing, have led to significant reductions in sitting time (247,248) and increases in energy expenditure (249,250) in adults. In these studies, sit-to-stand desk use was associated with a number of health benefits, including reductions in blood pressure (249), back and neck pain (248), increases in HDL cholesterol (247), and improved mood states

(248). As employed within the workplace, making environmental changes to the classroom could be an effective way of reducing children's sitting time. Such interventions could provide the opportunity to reduce total sedentary time, as well as the ability to break up prolonged bouts of sitting, both of which have been shown to be beneficial to health in children (35,251). Classroom-based interventions may also help target health inequalities by being accessible to all children. The question of whether standing desks are beneficial in the classroom is an important public health topic; however, a review of the current evidence has not been conducted to date. The term 'standing desk' is used differentially across studies and can encompass sit-to-stand desks, standing workstations, stand-sit workstations, stand-biased desks and adjustable furniture. For simplicity the term standing desk is used herein to incorporate all of these terms. The purpose of this systematic review was to examine the effects of interventions that have implemented standing desks within the school classroom.

2.2. **Method**

2.2.1 Search strategy

Search strategies were built around four groups of keywords: Standing desk (sit-to-stand desk, standing desk, standing workstation, stand-sit workstation, stand-biased desks, adjustable furniture); school classroom (elementary, school, classroom, high school, classroom environment, secondary, primary, middle, academic); study type (intervention, trial, controlled trial, randomised controlled trial (RCT), quasi-intervention, feasibility, pilot); and sample type (young people, children, adolescents, girls, boys, youth). Science Direct, PubMed, Web of Science, Cochrane Library, Cochrane Library central register of controlled trials, APA Psych NET and EPPI Centre databases were searched using the key terms. In addition, manual searches of personal files were conducted along with screening of reference lists of relevant articles.

2.2.2. Inclusion criteria

For inclusion, studies were required to 1) be an intervention with either a comparison (control) measure or pre and post intervention measures; 2) include a standing desk as the experiment/treatment within a school classroom setting with its impact independently measured; 3) include children aged 5-11 years, and/or adolescents aged 12–18 years (or a mean within these ranges) as study participants. Studies that did not state the mean age of participants were classified as pre-school children, school-aged children or adolescents depending on the ages of the majority of the sample; 4) be published in a peer-reviewed journal in the English language; and 5) be published up to and including June 2015.

2.2.3. Identification of relevant articles

One reviewer (Aron Sherry (AS)) conducted all stages of the article identification process. AS selected potentially relevant articles and subsequently 1) screened the titles; 2) screened the abstracts; and 3) if abstracts were not available or did not provide sufficient information, full articles were retrieved and screened using a standardised in/out form developed for this study to determine whether it met the inclusion criteria. At each stage a selection of papers were cross-checked by two other reviewers (Natalie Pearson (NP) and Stacy Clemes (SC)). Where there was uncertainty or disagreement regarding inclusion, a discussion was held between the authors to reach a decision.

2.2.4. Data extraction and coding

Detailed information was extracted from each article by AS using a standardised data extraction form developed for this systematic review (see appendix B). Data extraction was cross checked by NP and SC. Information extracted from each article included: study setting, sample characteristics, study design, intervention design and implementation, length of intervention, standing desk characteristics, outcome measures and assessments, and study quality criteria. In addition, information about the study outcomes (e.g. intervention effects) were extracted (Table 2.1). The impact of the standing desk intervention on each outcome measure was coded as: + = significant positive effect; - = significant negative effect; 0 = no significant effect; * = no statistical test performed (Table 2.2).

2.2.5. Study quality

Quality of included studies was assessed by AS and NP using the Delphi list (252) as used in previous systematic reviews of behavioural interventions with children (235,253,254). AS assessed the quality of the entire sample and NP assessed the quality of a subsample (30+%). Where there was disagreement (*N* = 1 paper) discussions were held to reach a consensus.

The Delphi List includes 8 assessment items: randomisation methods, treatment allocation, comparisons of main outcomes at baseline, eligibility criteria, blinding of assessor, blinding of participants, provision of point estimates and measures of variability, and if intention-to-treat analysis was used. Item 6 ('were the participants blinded?') was excluded from the list as it was deemed inappropriate for assessing the quality of standing desk interventions. Consequently, the final assessment list consisted of seven items. Studies were given a 0 or 1 fulfilment score for each item, resulting in a final score out of 7, and then categorised as either low (0-2), medium (3-5) or high (6-7) quality. This categorisation system is based on a system used in previous research (255).

2.3. Results

The literature searches yielded 2131 titles of potentially relevant articles and 11 papers were eligible for inclusion. Two papers reported different outcomes for the same study (256,257) while another paper reported the findings of two independent pilot studies (91). Therefore, the findings from 11 studies with 11 independent samples are reported herein.

All studies were conducted within primary/elementary schools, predominantly in the USA (256,258–262), with ages ranging from 6-12 years (see Table 2.1). Sample sizes varied from 8 to 326, and intervention durations ranged from a single time point to five months. Two studies were RCTs (256,259), six studies were non-randomised controlled trials (237,238,258,260,262,263), one study had a pre-post design without a control group (261), one paper described two independent studies (91), within which, one used a non-randomised control design and one used a RCT design. Ten studies were scored low quality (78 (UK study),155,156,175,177–182) and one scored medium quality ((91) (Australian study)); scores ranged from 1-3 out of 7.

2.3.1. Standing desk implementation

Methods of standing desk implementation varied across studies (Table 2.2). Six provided a standing desk per participant (78 (Australian study),175,178–180,182). In two studies pupils of a similar height shared a workstation (237,238), one study reported rotating children in a class between sit-to-stand desks and traditional seated desks (78 UK study) and two studies did not report how pupils were allocated to a standing desk (258,262). Seven studies reported exposing all children in the class (78 (Australian study),156,175,177,180,181) to the standing desk intervention (with only those with consent participating in the evaluation), while four studies did not describe whether the whole class or participants only were exposed to the standing desks (237,259,260,263).

Table 2.1. Overview of studies

Study	Location	School	Design	Intervention Duration	Sample (n)	Age, years. Mean (SD)	Total study groups	Intervention groups	Control groups	Standing desk	Extra equipment	Adjusted for user?	Standing desk per participant?	Main outcome	Secondary outcomes	Study quality
Benden et al., 2011	Texas, USA	P	RCT pilot	5 months	58	6-7	5	2 (+1 WGC)	2 (+1 WGC)	Artco-bell, Temple, TX	Stool	Y	Y	EE	ST, FSD, CB	Low
Benden et al., 2012	Texas, USA	P	WST	5 months	9	6-8	1	1	1	Archetype, Artco-bell, Temple, TX	Stool	NS	Y	EE	S	Low
Benden et al., 2014	Texas, USA	P	CT	5 months	326	8.5 7-10	8	4	4	Stand2Learn LLC college station, TX, USA	Stool	NS	NS	EE	S	Low
Benden et al., 2013	Texas, USA	P	RCT	Single time point	42	7-9	4	2	2	Archetype, Artco-bell, Temple, TX	Stool	Y	Y	P	C	Low
Hinckson et al., 2013	Auckland, NZ	P	CT	4 weeks	30	10 (1)	3	2	1	Work station (Ghanghao Furniture Factory, China)	Exercise balls and mats	Y	N	ST, SG, S, SSC	PN, F, FSD	Low
Koepp et al., 2012	Idaho, USA	P	RMT, Pilot	5 months	8	11.3 (0.5) 11-12	1	1	0	VisualEd Tech, Wharton, NJ	Stool	Y	Y	S	CB, C	Low
Lanningham-Foster. 2008	Minesota, USA	P	WST	12 weeks	40	10 (1) 9-11	1	1	1	NS	Anti-fatigue mats	Y	N	PA	-	Low
Clemes et al., 2014	Bradford, UK / Victoria, AUZ	P	CT / RCT	9 / 10 weeks	40 / 44	9-10 10 (0.3) / 11-12 11.6 (0.5)	2 / 2	1/1	1/1	Ergotron WorkFit-PD	NS	NS	N/Y	SG	ST, S, SPT	Low / Medium
Aminian et al., 2015	Auckland, NZ	P	CT	5 months	26	9-11	2	1	1	Work station (Ghanghao Furniture Factory, China)	Exercise balls and mats	Y	Y	ST, SG	S, SSC, SPT, CB, PN, ADHD	Low
Dornhecker et al., 2015	NS	P	CT	5 months	282	7-10	NS	NS	NS. *N*=124	NS	Stools	Y	NS	CB	-	Low

P = primary; RCT = randomised control trial; WST = within-subject control trial; CT = control trial; RMT = repeated measures trial; NS = not stated; WGC = within group comparison; EE = energy expenditure; ST = standing time; FSD = feasibility of standing desks; CB = classroom behaviour; S = steps; P = posture; C = Comfort; SG = sitting; SSC = sit-to-stand counts; PN = pain; F = fatigue; PA = physical activity; SPT = stepping time; ADHD = Attention deficit hyperactivity disorder.

Table 2.2. Overview of standing desk implementation.

Study	Standing desk	Extra equipment	Standing desk implementation details	Desk adjusted for user?	study purpose explained to pupils, teachers or parents	Standing desk training provided	Methods to increase standing time promoted
Benden et al., 2011	Artco-bell, Temple, TX	Stool	All traditional desks replaced with sit-to-stand desks within the two intervention classrooms. One sit-to-stand desk per child, whether participating in the study or not. Not reported if pupils could adjust the desk freely.	Not reported	Sit-to-stand desks explained to pupils during the consent and assent process. No further details reported in the study.	Not reported	Participants were allowed to sit or stand at their discretion
Benden et al., 2012	Archetype, Artco-bell, Temple, TX	Stool	The entire class was switched to stand-biased desks. No details reported on the number of children per desk or if the desks were adjustable by the pupil freely.	Not reported	Not reported	Not reported	Participants were allowed to sit or stand at their discretion
Benden et al., 2014	Stand2Learn LLC college station, TX, USA	Stool	Every study participant received a stand-biased desk. No details reported regarding those who did not participant in the study, whether they received a stand-biased desk or if these desks were freely adjustable by the pupil.	Not reported	Teachers informed of the study purpose, protocol and financial incentive if they chose to take part. Parents informed of the study purpose in a meeting with researchers	Not reported	Not reported
Benden et al., 2013	Archetype, Artco-bell, Temple, TX	Stool	One stand-biased desk per intervention class participant. No details reported regarding desk allocation of pupils not participating in the study or traditional desk availability within the intervention class. Desks not adjustable by pupils freely.	Set at or slightly below standing elbow height	Not reported	Not reported	Not reported
Hinckson et al., 2013	Work station (Ghanghao Furniture Factory, China)	Exercise balls and mats	Eight standing workstations across two classes (five and three). Each class included a central circle workstation and semi-circle workstations placed around the room. No details of desk allocation for pupils not taking part in the study. Desks not adjustable by pupil freely.	Children in groups of fours and fives of similar height were assigned the same workstations (three different height settings)	Standing desks discussed with teachers and pupils. One of the two teachers was 'highly motivated' to trial the standing desks. The other teacher was 'less motivated.'	Not reported	Not reported

Study	Standing desk	Extra equipment	Standing desk implementation details	Desk adjusted for user?	study purpose explained to pupils, teachers or parents	Standing desk training provided	Methods to increase standing time promoted
Koepp et al., 2012	VisualEd Tech, Wharton, NJ	Stool	A standing desk was allocated to each study participant. This included every pupil in the class. Desk not adjustable by pupils freely.	Desk height set at each participants elbow height	Not reported	Not reported	Not reported
Lanningham -Foster. 2008	Not reported	Anti-fatigue mats to sit on the floor and stability balls to sit.	All traditional desks were replaced with standing desks but the number of pupils per desk not disclosed. These desks were not adjustable by pupils. 4-5 traditional tables and chairs were retained as an alternative option for participants.	Not reported	Pupils and parents were invited to attend preliminary information meetings about the study	Not reported	Not reported
Clemes et al., 2014	Ergotron WorkFit-PD	Stools	UK: Three standard desks replaced with six adjustable sit-to-stand desks, used by six pupils who could adjust the desks freely. The entire class was rotated between these six desks and traditional desks every day. Auz: All standard desks in the classroom replaced with sit-to-stand desks, one per pupil, which pupils could adjust freely.	Not reported	Not reported	Intervention class teachers within both the UK and AUZ study received training on desk adjustment	Intervention teachers from both countries received training in SB reduction strategies. Pupils initially encouraged to increase standing by 30 minutes a day and to gradually increase this time during the intervention period.
Aminian et al., 2015	Work station (Ghanghao Furniture Factory, China)	Exercise balls, beanbags, benches and mat spaces available for sitting.	All traditional desks replaced with five standing workstations: one circular desk in the centre of the class, three semi-circular desks and one for computers. Semi-circular desks shared by 4-5 children. These desks were not adjustable by pupils freely.	Pupils of similar floor to elbow height were grouped together to share the desks.	Not reported	Not reported	Not reported
Dornhecker et al., 2015	Stand biased desk (model not reported)	Stools	Stand-biased desks were installed in the intervention class. One desk per pupil. Desk allocation for pupils not taking part in the study and presence of standard desks in the classroom not reported. Desks could not be adjusted by pupils freely.	Adjusted to each student's height although the details of this procedure were not reported.	Parents were sent letters detailing the purpose of the study.	Not reported	Not reported

Seven studies reported adjusting the height of each desk to each user's requirements (237,238,256,259,261–263), while desk adjustment was not mentioned in four studies (77,177,179 (UK and Australian studies)). Three studies provided sit-to-stand desks where the user could adjust between sitting and standing freely (78,175 (UK and Australian studies)) whereas the remaining eight studies used standing desks or workstations that were not adjustable (237,238,258–263). Two studies reported the provision of training for pupils on standing desk use and the same two studies were the only ones to report the use of SB reduction strategies provided to teachers ((91) (UK and Australian study)).

2.3.2. Impact of standing desks

An overview of outcome measures can be seen in Table 2.3. From the 11 studies, the most common outcome measures were step counts (n=7), sitting time, standing time, stepping time (all n=4) and energy expenditure (n=3). Most outcome measures were quantitative (n=30 out of a possible 37 outcome measures) with qualitative assessments consisting of interviews with teachers (n=4), principles (n=1) parents (n=1) or pupils (n=1) and focus groups with students and parents (n=2).

2.3.2.1. Steps

The impact of standing desks on step counts was reported in seven studies with mixed results. The time periods used to measure step counts varied between studies, ranging from 2 hours to total daily waking hours (Table 2.3). Four studies compared step counts between intervention and control groups; two of these reported no effect (237,238), one showed a positive effect at mid-intervention but no effect at post-intervention (260) and the other reported an increase in steps without using statistical tests (258). In the remaining three studies, one paper reporting two independent studies (located in the UK and Australia) had control groups within each setting but did not compare step counts between control and intervention groups (91). Using pre-post analyses, a significant increase in step counts during class time was seen in the

UK intervention group, while no changes were seen in the Australian intervention group (91). The remaining study, which used a pre-post design, showed no effect on step counts during class time over the intervention period (261). In terms of stepping time, four studies found no change in intervention groups compared to control groups (78 (UK and AUZ studies),155,156).

2.3.2.2. Standing

Four studies measured standing time with mixed results. All four compared intervention group data with control group data (78 (UK and Australian studies),155,156). One study reported an increase in standing time (237) and another found no effect on standing during school time or across the whole day (238). One paper reported significant increases in the proportion of time spent standing during class time in the Australian study, while no changes in the proportion of time spent standing were observed in the UK study (91).

2.3.2.3. Sitting

Four studies measured sitting time and all compared intervention group data with control group data. One study reported a decrease in total daily sitting time among the intervention group (237), and another reported no effect on sitting time (238). One paper reporting two studies found a decrease in time spent sitting during class time in the Australian intervention group, relative to the control group, while no significant differences in sitting time during class time were observed between the UK intervention and control groups (91).

2.3.2.4. Energy expenditure

Three studies found an increase in energy expenditure in intervention groups using standing desks compared to controls (256,258,260).

2.3.2.5. Other outcome measures

One study reported a significant reduction in the number of transitions recorded between sitting and standing relative to a control group (238), while another study reported no significant differences in postural transitions relative to controls (237). Two studies measured comfort and neither found a change. One compared the intervention group to controls without using statistical tests (259) while the second used a pre-post analysis (261). Two studies measured classroom behaviour. One found an improvement in child behaviour through academic engagement (measured by the teacher using the Behaviour Observations of Students in Schools (BOSS) tool (264)) at an intervention mid-point but no effect thereafter compared to the control group (263). Another study, without a comparison group, found no change in classroom behaviour (based on teacher observations of disruptive behaviour) over the intervention period (261). One study reported no change in pain in an intervention group compared to baseline measures without using statistical tests or a comparison group (238). One study reported no change in physical activity (measured using speed of movement (expressed as meters per second) with an accelerometer) in an intervention group compared to a control group without using any statistical tests (262). One study reported an improvement in posture in an intervention group compared to a control group, also without using statistical tests (259). One study, without a control group, found no effect of standing desks on concentration compared to baseline (261) and another found no effect in attention deficit hyperactivity disorder (ADHD) scores when compared to a control group (238).

Table 2.3. Overview of outcome measures across studies. Data presented as mean (SD) unless otherwise stated.

Outcome	Study	Measure	Intervention duration and number of measurement time points	Occasions and duration of measure	Findings	Compared to a control group	A controlled study but without a comparison made to a control	No control group in study
Steps	Benden et al., (2012)	Body Bug Armband	5 months; 2	2 hrs per day (8.30-10.30am) over 5-day period in fall and spring semester	17.6% (836) step increase at follow up in IG compared to CG.	$+^{*}$		
	Benden et al., (2014)	SenseWear ® activity monitor	5 months; 2	2 hrs per day (9-11am) over 5-day period in fall and spring semester	Fall: IG 1.61 step/min (*P* = 0.0002) greater than CG. Spring: IG group 0.12 step/min (*P* = 0.8193) greater than CG.	+ / 0		
	Hinckson et al., (2013)	Accelerometer (ActivPAL)	4 weeks; 2	Week 1 and 4, 0500-2400 hrs	IG v CG = 0.01 effect size (90% CL = 0.94) - unclear magnitude of effect.	0		
	Koepp et al., (2012)	Pedometer (W4L Classic)	5 months; daily	Only 'class time' stated	363 more steps at follow up in IG but not significant (*P* = 0.1127).			0
	Clemes et al., (2015)	ActivPAL3	UK - 9 Weeks; 2	UK - Week 1 and 9. Seven days, 24hrs	UK - Class time: increase in IG and CG groups (IG +1370, *P* =0.013; CG +1163, no statistic reported) at follow up. Total time: IG and CG increased at follow up (IG +81 (4223); CG + 1321 (4712))		$+ / +^{*}$	
			AUZ -10 weeks; 2	AUZ - Week 1 and 10. Seven days, waking hours	AUZ - Class time: IG and CG decreased (-143, NS; -109, NS) at follow up. Total time: Both IG and CG decreased in steps at follow up (IG -1908 (3268), *P* <0.01; CG -2165 (4238), *P* <0.03)		$-^{*} / -$	
	Aminian et al., (2015)	ActivPAL	5 months; 3	Baseline, week 4 and week 8; 7 days	School time: 675 greater steps over 8 weeks in IG. CL too wide for effect, values not reported. Total time: 1859 greater steps over 8 weeks in IG. CL too wide for effect, values not reported.	0 / 0		
Stepping time	Hinckson et al., (2015)	Accelerometer (ActivPAL)	4 weeks; 2	Week 1 and 4, 0500-2400 hrs	IG v CG = 0.29 effect size (90% CL = 0.82) - unclear magnitude of change.	0		

Outcome	Study	Measure	Intervention duration and number of measurement time points	Occasions and duration of measure	Findings	Compared to a control group	A controlled study but without a comparison made to a control	No control group in study
	Clemes et al., (2015)	ActivPAL3	UK - 9 Weeks; 2	UK - Week 1 and 9. Seven days, 24hrs	UK - Class time: No difference in IG v CG at follow up (*P* >0.05). Total time: No change in IG and CG in B v follow up (*P* >0.05).	0	0	
			AUZ -10 weeks; 2	AUZ - Week 1 and 10. Seven days, waking hours	AUZ - Class time: No difference in IG and CG in B v follow up (no statistic reported). Total time: IG and CG reduced at follow up (IG -20.9 (40.2) mins, no statistic reported; CG -24.2 (50.3); no statistics reported)		0^{*} / 0^{*}	
	Aminian et al., (2015)	ActivPAL	5 months; 3	Baseline, week 4 and week 8; 7 days	School time: 11 mins/day greater stepping time IG v CG over 8 weeks. CL too wide for effect, values not reported. Total time: 26 mins/day greater stepping time in IG v CG over 8 weeks. CL too wide for effect, values not reported.	0 / 0		
Standing time	Hinckson et al., (2013)	Accelerometer (ActivPAL)	4 weeks; 2	Week 1 and 4, 0500-2400 hrs	IG v CG = 0.71 effect size (90% CL = 0.48); very likely large increase in standing time in IG.	+		
	Clemes et al., (2015)	ActivPAL3	UK - 9 Weeks; 2	UK - Week 1 and 9. Seven days, 24hrs	UK - Class time: No difference of IG v CG at B or follow up (*P* >0.05). Total time: No difference of IG and CG at B v follow up (*P* >0.05).	0	0	
			AUZ -10 weeks; 2	AUZ - Week 1 and 10. Seven days, waking hours	AUZ - Class time: IG had greater standing time v CG (*P* <0.01) at follow up. Both IG and CG increased at follow up v B (*P* <0.001). Total time: IG increased at follow up (+13 (53.1); *P* <0.01). No change in CG at follow up.	+	+	
	Aminian et al., (2015)	ActivPAL	5 months; 3	Baseline, week 4 and week 8; 7 days	School time: 24 min/day increase in IG v CG over 8 weeks. CL too wide for effect, values not reported. Total time: 55min/day increase in IG v CG over 8 weeks. CL too wide for effect (±129).	0 / 0		

Outcome	Study	Measure	Intervention duration and number of measurement time points	Occasions and duration of measure	Findings	Compared to a control group	A controlled study but without a comparison made to a control	No control group in study
Sitting time	Hinckson et al., (2013)	Accelerometer (ActivPAL)	4 weeks; 2	Week 1 and 4, 0500-2400 hrs	IG v CG = -0.49 effect size (90% CL = 0.64) - very likely large decrease in sitting.	+		
	Clemes et al., (2015)	ActivPAL3	UK - 9 Weeks; 2	UK - Week 1 and 9. Seven days, 24hrs	UK - Class time: no difference of IG v CG at follow up (*P* >0.05). Decrease in IG at follow up (-52.4 (66.6) mins; *P* = 0.03). Total time: No difference of IG or CG for B v follow up (*P* >0.05).	0	0	
			AUZ -10 weeks; 2	AUZ - Week 1 and 10. Seven days, waking hours	AUZ - Class time: IG had less sitting time v CG (*P* =0.03) at follow up. Both IG and CG increased at follow up v B (IG -9.8 (16.5) %, *P* = <0.001; CG -5.9 (11.6) %, *P* = 0.004). Total time: No difference of IG and CG for B v follow up (*P* >0.05).	+	0	
	Aminian et al., (2015)	ActivPAL	5 months; 3	Baseline, week 4 and week 8; 7 days	During school: -24 min/day in IG v CG over 8 weeks. CL too wide for effect, values not reported. Total time: 45min/day decrease in IG v CG over 8 weeks. CL too wide for effect (±122).	0 / 0		
Energy expenditure	Benden et al., (2011)	Body Bug Armband	5 months; 4	2 hours per day (8-10am) over 5 consecutive school days.	IG 0.18kcal.min (*P* = 0.022, 17%) greater EE than CG group at follow up	+		
	Benden et al., (2012)	Body Bug Armband	5 months; 2	2 hrs per day (8.30-10.30am) over 5-day period in fall and spring semester	IG 25.7% increase in mean EE at follow up. Mean EE 0.29 kcal.min higher v CG (*P* <0.0001) After adjusting for covariates.	+		
	Benden et al., (2014)	Sensewear ® activity monitor	5 months; 2	2 hrs per day (9-11am) over 5-day period in fall and spring semester	Fall: IG 0.16 kcal.min (*P* <0.0001) greater than CG group. Spring: 0.08 kcal.min (*P* = 0.0092) greater than CG group	+		
Sit-to-stand counts	Hinckson et al., (2013)	Accelerometer (ActivPAL)	4 weeks; 2	Week 1 and 4, 0500-2400 hrs	IG v CG = -0.96 effect size (90% CL = 0.54) - very likely large decrease in sit-to-stand counts.	-		
	Aminian et al., (2015)	ActivPAL	5 months; 3	Baseline, week 4 and week 8; 7 days	School time: -6 transitions in IG v CG over 8 weeks. CL too wide for effect, values not reported. Total time: IG -34 transitions at 8wks v B (-28.8%). CG -38 transitions at 8wks v B (-34.0%).	0	0*	

Outcome	Study	Measure	Intervention duration and number of measurement time points	Occasions and duration of measure	Findings	Compared to a control group	A controlled study but without a comparison made to a control	No control group in study
Comfort	Benden et al., (2013)	discomfort survey developed by the researchers	1	Baseline self-assessment	Greater comfort in neck, arms, and legs in IG. Greater comfort in the back, wrists, hands, ankles and feet in CG. CG reported greater discomfort in all areas of the body when combining data, except for arms. No statistical tests performed.	0*		
	Koepp et al., (2012)	Teacher observations - discomfort/fatigue	5 months; Daily	"Class periods" but total observation time not stated	No significant difference at follow up in IG (*P* = 0.6; z test) v B.			0
Classroom behaviour	Koepp et al., (2012)	Teacher observations – pupil behaviour that is disruptive to the class	5 months; Daily	Class periods – total observation time not stated	No significant difference at follow up in IG of disruptive behaviour (*P* <0.5, z test).			0
	Dornhecker et al., (2015)	Academic engagement (AE) – behaviour observations of students in schools (BOSS) tool	5 Months; 2	Fall and Spring; 12-minute observations in 15 second epochs, once per child	Fall: IG greater AE than CG (+4.21 score, *P* = 0.003). Spring: IG had small increase (0.72 AE) but no change from CG (*P* >0.05)	+ / 0		
Physical activity	Lanningham-Foster et al., (2008)	Triaxial accelerometer Biaxial inclinometer	12 weeks; 4	Week 1, 2, 3, 12 – full school days over 4, 1, 2-3 and 4 days respectively.	No difference between CG (71 (0.4) m/s^2) and standing desk IG (71 (0.7) m/s^2) in average movement (p value not reported).	0		
Pain and fatigue	Aminian et al., (2015)	Nordic musculoskeletal questionnaire	5 months; 3	Baseline, week 5 and week 9	Little or no pain reported, and similar values reported from baseline to follow up across body parts in IG. No CG data reported.		0*	
Posture	Benden et al., (2013)	Portable Ergonomic Observations – time in different postures	1	3 x 10 min observations.	A greater proportion of the standing students portrayed more time in preferred postures and less time in non- preferred postures overall.		+*	
Concentration	Koepp et al., (2012)	Teacher observations	5 months; Daily	Class periods but total time not stated	No significant difference at follow up in IG (*P* = 0.81, z test) v B.			0
ADHD	Aminian et al., (2015)	Strengths and weaknesses of ADHD-symptoms and normal behaviour (SWAN)	5 months; 3	Baseline, week 5 and week 9	No significant difference between IG and CG at final measure (IG t =1.59, *P* = 0.16; C t = 1.58, *P* = 0.13).	0		

IG = intervention group; CG = control group; ES = difference in mean as effect size; CL = confidence limit; EE = energy expenditure; B = baseline

+ Significant positive effect (P <0.05)

- Significant negative effect (P <0.05)

0 No effect (P >0.05)

* No statistical test performed

2.4. Discussion

The purpose of this review was to assess the impact of standing desks within the school classroom setting. While this area of research is very much in its infancy, the studies included in this review addressed diverse outcomes. Furthermore, this area of research is rapidly evolving and new studies are emerging at a fast pace. This review is therefore very timely as it provides a summary of the current evidence and enables the identification of future research directions for standing desk interventions conducted within the school environment. The current evidence base is relatively small (11 primary studies) and consists of mostly pilot studies that lack a robust study design. Furthermore, most studies had small samples which lacked the statistical power required to detect differences between control and intervention groups. Consequently, it is difficult to make strong conclusions on the effectiveness of standing desks in schools at present.

From the findings so far, standing desk interventions in the school classroom consistently showed positive effects on energy expenditure, but in only three studies. Evidence for an effect on step counts, standing time, sitting time, and stepping appears to be mixed which could be due to the diverse assessments and measurements and low statistical power within most studies.

Energy expenditure, measured with body monitors, increased in the intervention groups relative to controls in all three studies over a five-month period. This suggests that standing desks are beneficial for energy balance in children. However, measurements only took place for two hours within each study and so it is unknown if the standing desk intervention maintained this energy increase throughout the entire school day or waking day. If the increases in energy expenditure, all found within measures only conducted during school mornings, were consistent across an entire primary/elementary school day (e.g. 5 hours of class time) it would equate to an approximate elevation of 24-87 calories, which are modest but potentially meaningful improvements (see Chapter 5 section 5.1) during school hours. However, it is unknown how much additional standing time, if any, influenced these changes as this behaviour was not measured.

Step count was the most commonly assessed outcome. Across the 11 studies within this review, a variety of devices were used (e.g. the activPAL, ActiGraph, Pedometers, SenseWear armband) for various outcome measures. A common feature of these tools is a step count function which would suggest why this was the most common outcome measure. Although not a primary outcome in any study, an increase in steps would suggest the participant is standing more and being more active. Consequently, this data is meaningful for determining the effectiveness of standing desks. The current evidence demonstrated mixed results across seven studies; only three studies reported any increase in steps with just one demonstrating a significant increase compared to a control group for the full intervention duration. Consequently, based on these findings, it is unclear whether standing desks increase steps in children. It should be noted that the differences in measurement durations implemented between studies (from 2 hours per day, to class time only, to waking hours) do make comparisons of the findings between studies difficult. For example, increased steps during school hours may be compensated for by reductions during evenings or children may be more active during morning periods at school compared to afternoons. Consequently, these variations somewhat limit the generalizability of the evidence.

Studies that did report an increase in steps did not measure standing or sitting time. Furthermore, studies that demonstrated an increase in standing time also reported reductions in sitting time but no change in step counts or stepping time. Consequently, there was not a clear relationship between stepping and standing or sitting behaviour. All studies that measured standing and sitting time did report improvements in all mean intervention group values at follow up but only around half reported significant increases compared to control groups. On the balance of this evidence, and because of the lack of quality, it is inconclusive whether standing desks increase standing and reduce sitting during classroom time.

It is important that standing desks are practical within the classroom and are not detrimental to classroom behaviour or learning if they are to become a permanent infrastructure within schools. Most of the positive findings reported for the variables of feasibility, classroom behaviour and learning came from qualitative interviews and focus group data not reported in the results of this review (including an additional paper (257) based on a study in this review (256), where teachers, parents and pupils reported mostly positive opinions of the desks. Across all quantitative and qualitative evidence no negative results were found in any feasibility or learning related outcome including feasibility of standing desks, pain and fatigue, comfort, posture, concentration, ADHD, or classroom behaviour, except from an interview with one teacher (the desks were described as a distraction for the class as only some students took part in the study and had standing desks) (237). On the whole these findings suggest that standing desks within the classroom are practical and not detrimental to a child's ability to learn, with the balance of qualitative data suggesting they are facilitative. However, it is very important that academic achievement is captured as an outcome measure in further standing desk research to provide direct evidence on the impact of learning. It would not be viable for these desks to be part of school infrastructure if they are detrimental to academic performance, even if there are gains in other key outcomes.

2.4.1. Limitations and future directions

Standing desks are a novel intervention, particularly within the school classroom environment. While a diverse set of outcomes have been measured, there is a distinct lack of depth of evidence for most, further compounded by insufficient and inconsistent statistical comparisons to control groups. Consequently, conclusions for several outcomes are not possible due to a lack of evidence. As standing desks first and foremost are designed to increase standing and reduce sitting, more studies are needed to assess these key behavioural components. If these behaviours are not measured, there is no direct evidence to link improvements in standing or sitting time to positive changes in other outcome measures such as steps, energy expenditure, markers of health or classroom behaviour. Furthermore, it would be beneficial to determine whether these desks influence reductions in total daily sedentary time and their effectiveness in promoting regular breaks in prolonged sitting and how these changes influence other outcomes. Encouragingly, the more recent papers in this review used posture monitors, such as the activPAL, as the outcome measure and it is likely that as the field progresses we will see more papers with sitting and standing time as primary outcomes.

The standing desk interventions within this review were implemented in several different ways (e.g. full class allocation versus participant only desk allocation, freely adjustable versus fixed standing desks, one desk per participant versus shared standing workstations). It is difficult to decipher the most effective design as positive changes were found across differently implemented interventions (e.g. increased standing time with multi-user workstations ((237) and with freely adjustable sit-to-stand desks, one per pupil (91); Australian study). Some papers lacked key details regarding intervention implementation, thus limiting the ability to compare findings across studies. Future research should seek to directly compare different interventions to determine the most successful or cost-effective standing desk implementation strategy for reducing SB and impacting other key outcomes.

This study did not include a comprehensive set of qualitative search terms for database searchers but did identify two studies that included qualitative evidence (237,257). While this data has not been presented within the results of the present study, this evidence has been used to further understand and interpret the quantitative data identified within this systematic review. Without a comprehensive list of qualitative search terms, it is possible that some qualitative studies and evidence may have been missed. This should be considered when interpreting the results and conclusions within the present study. However, since the search terms for standing desks were comprehensive, it is unlikely that many, if any, qualitative studies or evidence related to standing desks was missed during database searchers.

Finally, standing desks have a potential risk of having a novelty effect due to their innovative design, which has been found in a workplace standing desk intervention (265). Within our sample of studies, no study reported the presence or absence of any novelty effects in children therefore no conclusion can be made at this stage. Future research should aim to explore differences between short term (i.e. 2-4 weeks) mid-point and long term (i.e. 6-9 months) measures to fully examine the sustainability of this intervention.

There are some strengths within the current evidence. The intervention setting of a primary/elementary school classroom provided very similar characteristics between studies, such as demographics (i.e. class size, ages) and learning conditions (e.g.

class duration, number of classes a pupil has per day), despite being across four countries (USA, UK, New Zealand and Australia). This is beneficial as it allows for more direct comparisons of the findings and for more conclusions of the impact of standing desks in schools to be made. However, it would be beneficial to diversify the country setting in future studies as the majority were conducted in the US. All studies that measured SB and physical activity used objective measures over five to seven days which provided more valid and reliable habitual data as well as further facilitation of study comparisons. However, data measured over the entire day, instead of just class time, should have been reported in more studies to reflect any changes in behaviour over the full day and determine any compensatory effects (265).

Almost all studies within this review implemented standing desks as a single component intervention design. It may be beneficial for more studies to include further supplementary methods to enhance the impact of the desks, such as SB reduction strategies utilised in two studies ((78) (UK and Australian studies)). A study that did not meet the inclusion criteria (218), described a multi-component intervention including educational and practical components such as information on health and posture, the creation of a classroom that encouraged movement, along with a standing workstation area. Future research should consider multifaceted intervention 'packages' such as these to potentially engage a wider set of needs and interests within the school classroom.

In conclusion, standing desk interventions in the classroom setting, have, to date, showed some positive effects. A positive impact on energy expenditure was the only consistent outcome reported from the limited evidence. The effect of standing desks in the classroom on standing, sitting and stepping time is unclear and future studies are needed to examine the impact of standing desks on these fundamental outcomes. Standing desk interventions would appear to be practical and do not demonstrate a detrimental effect on classroom behaviour or learning from the current evidence. Further research should seek to implement standing desks with larger samples, over a full academic year and within schools of lower socio-economic position as this is a key demographic for improving health inequalities and academic achievement. All studies within this review implemented standing desks within the primary/elementary school setting and therefore further intervention studies should assess this intervention in secondary/high schools. Although logistically this may be more challenging, due to pupils moving to different classrooms throughout the day compared to a single classroom in primary/elementary schools. However, it will be important to determine the impact of these interventions within the next phase of the education system, as reducing SB is needed throughout the life course.

Chapter 3: activPAL and ActiGraph data collection and reduction methods

3.i. Preface

activPAL data are presented in Chapters 4 and 5 and ActiGraph data in Chapter 5. The data collection and reduction methods for those studies are detailed within this chapter.

3.1. ActivPAL

Participants wore an activPAL inclinometer (PAL Technologies Ltd, Glasgow, UK) on the anterior aspect of the right thigh, placed within a nitrile sleeve and attached using hypoallergenic medical dressing (Hypafix, BSN Medical), for 7 days, sampling at 20 Hz and providing triaxial accelerometer data. The device was waterproofed and a 24 h wear protocol was adopted. The activPAL is a valid measure of free living sitting and standing in children in a classroom setting and during daily free-living activities when compared to direct observation (sitting time Rho (mean difference) = 0.86 (-5.6%)) (see Chapter 1 section 1.4.2.2. for more details of these study findings) (52,60). activPAL data explored in Chapters 4 and 5 included minutes spent sitting, standing and stepping, steps, and sit-to-stand transitions, all accumulated at school, after school and during total waking hours on week days and weekend days (Chapter 4 only). Participants were requested to record when they woke up, went to bed and when either of the devices (the activPAL and ActiGraph) were removed (or fell off) in a daily monitor log.

3.1.1. Data management

ActivPAL data were downloaded (PAL files) using standard manufacturer software (activPAL Professional v.7.2.29 and v.7.2.32). The PAL files were visually inspected once downloaded within the Activity Summary feature of the software as a basic compliance check; files that included less than 2 days of data with <500 steps/day (61) were not included in any later analysis. Files with sufficient data were converted to 15-second epochs (epoch.csv files) and then processed with a customised Microsoft Excel macro. The customised macro provided the frequency of and accumulated minutes spent sitting and standing in bouts of 5-10min, 10+min and 30+min (Chapter

4 only), comparable to bout lengths applied in a recent observational study in children (266). During school days, several periods of interests were isolated using the Excel macros (see section 3.1.1.1). In scenarios where a bout of sitting or standing spanned across two periods of interest, the bout was only included within the period of interest it began. For example, if a child engaged in a 15-minute siting bout that began during lesson 2 of the school day (e.g. 12:10pm) and continued into the lunch period (12:21 onwards), the bout would be included within lesson 2 data, and the macro would terminate the bout at the start of the next period of interest (12:21pm). While this will not capture the bout in its entirety in this instance, it is highly likely that children will change location and therefore posture between different school periods. Consequently, the example above is unlikely to be a frequent occurrence. Proportions of wear time spent sitting, standing and stepping and sit-to-stand transitions per hour of wear time were also calculated using the Excel macro. In Chapter 4, as an indicator of a sufficient level of physically activity, the recommendations of Tudor-Locke et al. (267) of ≥ 13,000 steps/day for 6–11 year-old boys; ≥ 11,000 steps/day for 6–11 year-old girls were applied to the step count data.

3.1.1.1. Wear time

In Chapter 4, wear time compliance was set at ≥10h/day on ≥3 school days and ≥1 weekend day to align with a similar cross-sectional study (87). Due to the exploratory nature of the pilot study in Chapter 5, participants were included in the analyses if they provided at least 8 hours of activPAL data per day on at least 2 weekdays, as applied elsewhere (268). The hours of 11pm-6am were set as sleep time and thus removed from the data (90). A non-wear time of 20 minutes was also applied using the accelerometer function of the device, determining additional sleep periods (between 6am and 11pm) or when the device was not being worn during waking hours. To identify periods of sleep during the designated waking hours (6am-11pm), the 3-axis acceleration data in Chapters 4 and 5 will have detected periods of no movement. If these periods exceed 20 mins then this period will have been excluded as non-wear. The effect of the non-wear criteria on sleep removal and waking hour data is discussed in Chapter 4 section 4.4.2. The use of non-wear methods (e.g. Troiano (65)) to identify sleep periods is a strategy currently recommended within activPAL research (61). The

Excel macros did not include a tolerance or interruption allowance for non-wear time (or wear time), in contrast to the ActiGraph criteria (see section 3.2.1.1. below). The non-wear time and epoch parameters are consistent with previous activPAL research (90), and are recommended (58). School hours were based on each school's timetable (intervention school 08:50-15:10, control school 08:41-15:15).

Nine different periods of interest were applied to the time stamped epoch file data on school days (morning, lesson 1, lesson 2, morning break, lunch, afternoon lessons, after school (until 6pm), evening (until 11pm), full waking day) using each schools timetable (Chapters 4 and 5). It was decided not necessary to include a minimum wear time of compliance for each of these periods of interest. No periods of interest were applied to weekend data (full waking day only).

3.2. ActiGraph

ActiGraph data are presented in Chapter 5. To determine time spent in different intensities of PA during class time, school break times, after school and during full week days, participants wore an ActiGraph GT3X triaxial accelerometer (ActiGraph LLC, Pensacola, FL, USA) on the waist above the right hip on a belt (sampling at 100 Hz) during the same seven days as the activPAL. Sampling at 100hz is common practice and generally recommended for physical activity research in children (62). This device has been found to be a valid measure of different PA intensities in children (Moderate-to-vigorous PA ROC-AUC = 0.90, excellent accuracy) (53). The ActiGraph device is an established measurement of PA in children (62). Participants were requested to remove the device during sleep, when bathing or during anytime in water.

3.2.1. Data management

ActiGraph data were downloaded using standard manufacturing software (ActiLife v.6.11.9) also at 15-second epochs as recommended in PA research in children (269,270). Only data from the vertical axis were used during data processing to replicate a key validation study (53). Trost et al. (2011) (53) compared and validated different accelerometer cut points based on vertical axis data only, generated from the GT1M ActiGraph model. The present study used a more recent ActiGraph model (the GT3X), however, Hänggi et al. (2013) (271) compared GT1M and GT3X models using vertical axis outputs and found that both devices categorised a range of activities within the same activity intensity (sedentary, Light intensity PA (LPA), MVPA). This is important because it demonstrates that the GT3X, used in the present study, is comparable to an older version of ActiGaph that has been validated in identifying different intensities of PA in children (271).

3.2.1.1. Wear time

The same non-wear time (20 mins) and minimum wear time criteria (8 hrs/day on at least 2 weekdays) applied to the activPAL data in Chapter 5 were applied to the ActiGraph data within the ActiLife software. While non-wear time was customised to 20 minutes, the default parameters within the Troiano (2007) (65) criteria were applied.

Specifically, *Activity Threshold* and *Use Max Counts* were set at zero counts/min, *Spike Tolerance* was set at 2 spikes/min, *Spike Level to Stop* was set at 100 counts/min and the *Required Consecutive Epochs Outside of the Activity Threshold* was selected.

School hours were based on each school's timetable as follows: Intervention school 08:50-15:10, control school 08:41-15:15. The timetables were used to determine school break periods, class time and outside of school time (the remaining wear time of a waking week day following the recognised school hours).

3.2.1.2. Cut points

After wear time validation was calculated, the time spent in different activity thresholds (sedentary, LPA, MVPA) were determined using the Freedson age-adjusted cut points (see equation below) within ActiLife (272,273). These cut points were selected because they have been recently implemented within a standing desk study of the same 8 month duration, using the same sit-stand desks and evaluated using the same GT3X ActiGraph model (268). Consequently, using the same cut points improves the comparability of study findings. The Freedson age-adjusted cut points have demonstrated excellent accuracy (area under the receiver operating characteristic curve (ROC–AUC) = 0.90) in categorising MVPA in 6-18 year olds (272). While these cut points were less accurate for determining LPA than the most accurate cut points (274) within the (272) validation study, the difference was negligible (ROC–AUC = 0.69 (Freedson) vs 0.70 (Evenson). A single mean age across all three study groups (two intervention, one control) during the baseline 7-day wear period were used for all data sets (baseline, 4 months and 8 months) to determine the age-adjusted cut points. This mean age (9.8 years) was entered into the below equation:

METs = 2.757 + (0.0015 * counts per minute) – (0.08957 * age (yr))

- (0.000038 * counts per minute * age (yr))

R^2 = 0.74 SEE = 1.1 METs (Freedson)

The MET values for sedentary, light, moderate and vigorous physical activity were based on those used within the Trost et al. (53) validation study. Applying the mean sample age to the equation provided the below cut point thresholds, which were applied to all ActiGraph data.

Table 3.1. Thresholds for MET intensities and resulting accelerometer cut point thresholds.

Intensity	**Cut point threshold (counts per minute)**
Sedentary, <1.5 METs	≤100
Light, ≥1.5 and <4 METs	101-1880
Moderate, ≥4 and <6 METs	1881-3654
Vigorous, ≥6 METs	>3655

Within accelerometer research in children a wide range of cut points have been applied (64) and one of the drivers of this is the varied MET values applied to intensities of PA (light, moderate and vigorous). With this in mind, when calculating the age-adjusted cut point thresholds for Chapter 5, the same MET value thresholds applied within the key Trost validation study (53) were utilised.

Once ActiGraph wear time and cut point parameters were applied, data were exported to Microsoft Excel to further organise the minutes and proportions of wear time spent in different activity intensities (LPA, MVPA) during different domains (class time, school break times, after school, full school day, full weekend day).

CHAPTER 4 - Inclinometer measured sitting and physical activity patterns in 9-10 year old children from a UK city

The research reported in this chapter has been published in the Journal of Public Health: *Sherry AP, Pearson N, Ridgers ND, Barber SE, Bingham DD, Nagy LC, Clemes SA. activPAL-measured sitting levels and patterns in 9–10 years old children from a UK city. Journal of Public Health. 2018 Oct. doi: 10.1093/pubmed/fdy181*

4.1. Introduction

Sedentary behaviour (SB) is defined as "any waking behaviour characterised by an energy expenditure ≤1.5 METs while in a sitting, reclining or lying posture"(16). Early research into SB has predominantly explored screen-based pursuits (TV viewing and computer use) using self-report measures. In children (ages 6-12 years), these types of SB are unfavourably associated with important cardio-metabolic health outcomes, self-esteem, pro-social behaviour, academic achievement (42) and cognitive function (3).

Recently, total waking sedentary time has been explored using accelerometry. This international evidence has consistently reported that children spend the majority of their time stationary, both during (88) and outside school hours (39,81,83). For example, in 1,862 English children (9-10 years), 64% (7.5 hours) of an average day was spent stationary (81). Unlike screen time, the relationship between total sedentary time and health outcomes in children is unclear (42). However, high sedentary time in children is a public health concern for several reasons. Firstly, sedentary/stationary time not only tracks from childhood into adolescence and adulthood (138,139), but also continually increases between these stages of life (138). There is a clear adverse association between high levels of sedentary time (i.e. >8h/day) and mortality in adults (106). Additionally, the emergence of an increased cardio-metabolic health risk in some demographics is evident during childhood (133). For example, British South Asian children (aged 9 – 10 years) have demonstrated higher levels of glycated haemoglobin, fasting insulin, triglycerides, and C-reactive protein and lower HDL-cholesterol compared to white British children (133). Therefore, these populations may be more vulnerable to the adverse affects of excessive sedentary time from an early stage. Consequently, it is important to develop strategies to reduce sedentary time during childhood before these behaviours become more established and difficult to change.

Like total sedentary time, there is currently growing interest into how sedentary time is accumulated. Time spent sedentary in bouts (a period of uninterrupted sitting (16)) that are prolonged (30+ min) is associated with increased risk of the metabolic syndrome in adults (275). Evidence using isotemporal substitution of prolonged bouts of sitting time with shorter sitting bouts has demonstrated favourable cardio-metabolic outcomes in UK adults (276). In European children, it would appear that sedentary time is rarely spent in prolonged bouts (i.e. 30+ min) (94,266) which may partly explain the weaker association betwen total sedentary time and health outcomes (22) compared to adults. However, Australian data have demonstrated that children spend Up to 20% of waking hours in such bouts during different times of the week (87). While an association between sedentary bouts and health indicators in children is inconsistent (42), evidence has shown that a higher frequency (up to 3.1/day) of 30+ min bouts of sedentary time is associated with reduced HDL cholesterol in children, independent of total sitting time, moderate-to-vigorous physical activity (MVPA), saturated fat intake and body composition (95). Consequently, the manner in which sedentary time is accumulated needs to be further explored to better understand when and how to target interruptions in sustained sedentary periods. It is worth noting that these studies are based on accelerometer data and are therefore patterns of stationary time (which in turn encompass sedentary time).

To date, the vast majority of objectively-measured sedentary data is from accelerometry. Accelerometers, which are typically worn on the waist, cannot accurately distinguish between sitting and standing postures (23). This is important because standing is not a SB (16). Consequently, there is a need to differentiate between time spent sitting and standing using inclinometers (42). The activPAL inclinometer has been implemented in a handful of studies in children (8-12 years) which confirm that the majority of time at school (70-71%) (91), on school days (53-69%) and weekend days (60-73%) is spent sitting (90–93). Furthermore, there was evidence of less time spent standing and stepping (90,93) fewer step counts and sedentary breaks and longer average sedentary bout lengths on weekends compared to weekdays (93). More studies need to build on these findings for a better understanding of sitting patterns. Such studies should include the exploration of sitting time in demographics that are typically more sedentary/stationary compared to other populations, from accelerometry. In the UK, British Pakistani children have demonstrated higher total stationary time than white British children on school days and weekend days (83,277). This is particularly important when considering the higher cardio-metabolic health risks that British South Asian children have (133). In the present cross-sectional study, using activPAL inclinometers, we explored total sitting time and sitting bouts of different lengths, during and outside of school hours in a sample of children of mostly British South Asian ethnicity.

4.2. Methods

4.2.1. Participants

Sitting and physical activity (PA) patterns during school days and weekend days were explored in Year 5 primary school children (aged 9-10 years) during term time. Participating children were from two schools, located within the city of Bradford, England. All children were originally approached and recruited for two classroom-based controlled intervention trial pilots conducted in 2014 and 2015. The 2015/6 intervention study is described in Chapters 5 and 6. Figure 4.1 details the number of schools, classes and children approached, the number of children with parental consent and provided assent, activPAL monitors worn, activPAL data provided and the final number of children with valid data for this study. In total, five separate classes consisting of 27-31 children per class (147 children in total) were approached (see Figure 4.1). The 2014 study included a single school (two classes) which also provided two of the three classes within the study in Chapters 5 and 6 but from the 2015 cohort of pupils. This school is located within a neighbourhood ranked in the top 30% of the most deprived in the UK (278). The second school included within the Chapter 5/6 study, located within 3km of the first school, provided one year 5 class of participants for this study. This school is located within a neighbourhood ranked in the top 10% of the most deprived in the UK (278).

Baseline assessments from each study, which employed identical measurement protocols and were conducted during the autumn (November, 2015 study) and winter (December/January, 2014 study) seasons, were included in this study.

Parental written consent and child assent were required for study participation. Children were not included in baseline assessments if they had any disability that prevented them from standing or an illness or injury that prevented them from performing normal daily tasks. Both studies were approved by Loughborough University's Ethical Advisory Committee.

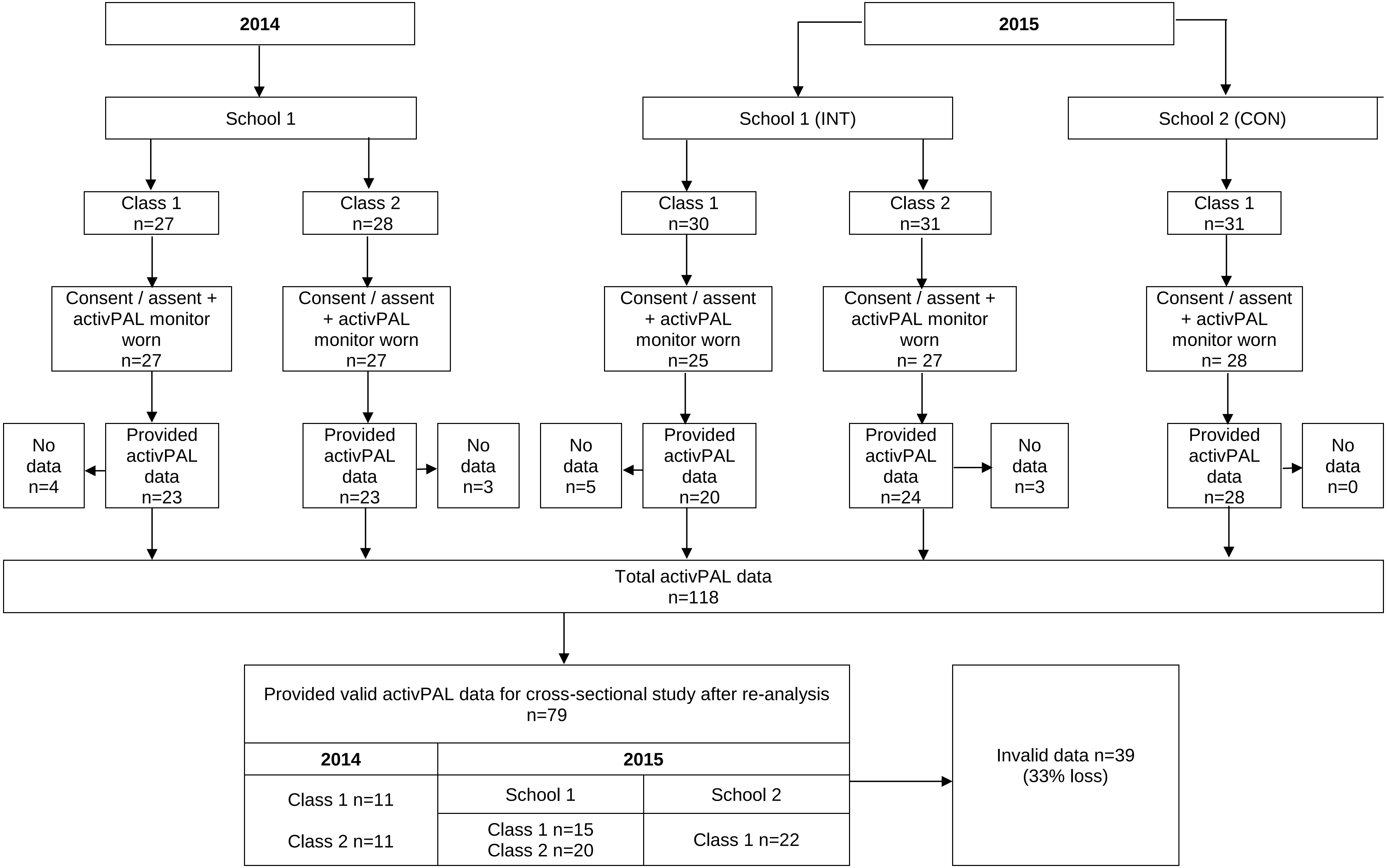

Figure 4.1. Flow diagram of participant recruitment and activPAL data compliance.

4.2.2. Measurements

Participants self-reported their age and ethnicity (after ethnicity was explained and a subsequent selection was made from a list of different options i.e. white British, Murpuri Pakistani). Research team members measured participant's height (wall mounted stadiometer: Seca UK, Birmingham, UK), weight (electronic weighing scales: Seca model 887), and waist circumference. Height and weight were recorded to the nearest 0.1cm and 0.1kg respectively, with shoes removed. BMI values were calculated (weight (kg)/height(m)^2) and Z-scores assigned to each participant using the British 1990 growth reference (279). Weight categories (underweight, normal, overweight and obese) were determined from BMI percentiles using the recommendations of Freeman et al. (1995) (279). Waist circumference was measured using a flexible steel tape at the narrowest point between the bottom rib and the iliac crest.

Participants wore an activPAL inclinometer (PAL Technologies Ltd, Glasgow, UK) on the anterior aspect of the right thigh, placed within a nitrile sleeve and attached using hypoallergenic medical dressing, for 7 days. Details of monitor deployment and data management within this study are discussed in Chapter 3.

4.2.3. Statistical analysis

Statistical analyses were conducted using SPSS v.23 (SPSS Inc., Chicago, IL, USA). activPAL-determined outcome variables were compared between school days and weekend days, and between school time and after school time. Wear time (minutes), time and proportion of wear time spent sitting standing and stepping, step counts, sit-to-stand transitions, and minutes accumulated in and frequency of time spent in bouts lasting 5-10 min, 10+ min and 30+ min when sitting and standing were first tested for normality using the Kolmogorov-Smirnov test. The Kolmogorov-Smirnov test found both normally distributed and skewed data. Normally distributed data sets were compared between school days and weekend days and during school and after school time using paired sample t-tests. For skewed data, a natural-log transformation was applied. Transformed data were then compared between time periods using paired t-tests. Mean transformed values and confidence intervals were then back transformed and reported in the results. Data that were still skewed following transformations were compared across periods using the Wilcoxon signed-rank test, and the median and inter-quartile range reported. Significant differences were detected (*P* <0.05) for wear time between school days and weekend days and school time and after school; minute and frequency data are therefore reported as descriptives only. To account for differences in wear time, the proportion of wear time spent sitting, standing and stepping as well as steps-per-minute and sit-to-stand transitions per hour of wear time were compared between the different time periods. Cohens d was used to calculate effect sizes using mean and standard deviation values (280) for outcome variables for each time period that were compared. Effect sizes were interpreted as small effect (*d* = 0.2-0.4); intermediate effect (d = 0.5-0.7); and large effect (*d* ≥0.8) (280). Sitting data between boys and girls and white British and British South Asian ethnicities were compared using independent t-tests. To account for gender as a potential confounder on the relationship between different time points across outcome variables, a two-by-two Factorial ANOVA (gender as the factor) was conducted in normally distributed outcome variables. To explore potential associations between adiposity indicators (BMI, BMI z-score and waist circumference) and sitting, standing and stepping variables (proportion of wear time spent sitting, standing and stepping, steps-per-minute of wear time and sit-to-stand transitions per hour of wear time, all during week days, weekend days, school time and after school), Pearson correlation coefficients were calculated. To account for multiple testing within the same data, a Bonferroni correction was applied. Comparisons between week days and weekend days and between school time and after school across nine dependent variables were conducted. Consequently, a significance level of *P* <0.006 (0.05/9) was calculated for these comparisons. For all other analysis, a significance level of *P* <0.05 was set.

4.3. Results

Table 4.1. details the characteristics of the study sample. One hundred and thirty-four children provided parental consent to participate in the study (see Figure 4.1), of which, 79 (59%) provided valid activPAL data (9.8 (SD 0.3) years old, 53% boys, 70% South Asian, 23% White, 7% mixed ethnicity).

Table 4.1. Characteristics of sample (n=79).

	Mean (SD)		**Range**
Age, years	9.8	(0.3)	9.0 – 10.4
Girls, n *(%)*	37	(47)	
Stature, m	1.38	(0.07)	1.26 – 1.53
Body mass, kg	35.1	(7.3)	22.3 – 52.3
Waist circumference, cm	64.2	(8.4)	39.6 – 87.0
BMI, kg/m^2	18.3	(3.0)	13.2 – 28.0
BMI z-scores	0.7	(1.3)	-2.4 – 3.6
Underweight, %	5		
Normal weight, %	57		
Overweight, %	16		
Obese, %	22		
South Asian (self-reported), %	70		
White, %	23		
Mixed ethnicity, %	7		

There were no significant differences between those who provided valid activPAL data and those who did not in terms of sex, ethnicity, BMI, BMI z-score or waist circumference (P >0.05). No significant differences (P >0.05) were observed between white British and British South Asian children for any sitting behaviour. There were significant differences (P ≥0.017) in just 3/64 sitting variables between boys and girls, with just one variable considered a primary outcome that was of marginal significance (school time sitting minutes; boys +21.1mins, P =0.042). Consequently, data hereafter are presented for the sample as a whole. In total, 410 valid weekdays and 151 valid weekend days of activPAL data were provided by the sample. On weekdays, 100%, 86.1%, 81.0%, 34.2% and 17.7% of participants provided 3, 4, 5, 6, and 7 days of valid data, respectively. On weekend days, 100% of participants provided 1 valid day and 8.9% of participants provided 2 days of valid data, respectively. For combined week days and weekend days, 100%, 97.5%, 84.9%, 76.0%, 34.2% and 17.7% of participants provided at least 4, 5, 6, 7, 8 and 9 days of valid data, respectively.

The mean time spent sitting on school days and on weekend days totalled more than 10 and 11 hours/day, respectively (Table 4.2). Participants spent a significantly greater mean proportion of time sitting (+6.3%, P <0.001, intermediate effect size) and spent a smaller mean proportion of time standing (-2.6%, P =0.002, small effect size) and median time stepping (-3.5%, P <0.001) on weekend days compared to school days. There were also significantly less mean sit-to-stand transitions per hour (-0.8, P <0.001, intermediate effect size) and median steps per minute of wear time (-3.6, P <0.001) during weekend days compared to school days (Table 4.2). Just one boy and seven girls achieved the daily step count recommendations for being classified as sufficiently active on school days but no boy or girl achieved the recommendations on weekends (Table 4.2).

On school day, 38% (3.8h) of total mean daily sitting time was accumulated at school, 48% (4.8h) was accumulated after school, with the remainder (14%,1.4h) accumulated before school. Participants spent a significantly lower mean proportion of time sitting at school (-6.7%, P =0.001, intermediate effect size) compared to time spent sitting after school (Table 4.2). Participants spent a significantly lower mean proportion of time standing (-3.7%, P <0.001, intermediate effect size), and median time stepping (-3.1%, P <0.001), had less mean sit-to-stand transitions per hour (-1.0%, P <0.001, intermediate effect size) and median steps-per-minute of wear time (-2.6%, P <0.001) after school compared to time spent at school (Table 4.2).

Just over 3h of total median sitting time was accumulated in prolonged bouts of 30+ min on school days (3.8 bouts), which increased to over 4.5h on weekend days (5.2 bouts) (Table 4.3). Similarly, a significantly greater mean proportion of time spent sitting in prolonged bouts was observed after school compared to at school on school days (+7.9%, P <0.001) (Table 4.4). These comparisons were also observed in the median proportion of time spent sitting in bouts of at least 10 minutes, with more than half of a weekend day (mean (SD) 51.5% (11.5)) and almost half of the time after school on school days (42.8% (6.9)) being spent sitting in bouts of this length (Table 4.4).

The highest median frequency, accumulated median minutes (Table 4.4) and mean proportion of wear time (Table 4.4) was in bouts of 10+ min at every period (except 5-10min at school; a 0.1 higher frequency). Higher median frequencies of 5-10min bouts were observed compared to 30+ min bouts at every period but a greater number of minutes were accumulated in 30+ min bouts (Table 4.3).

Two-by-two factorial ANOVAs with gender as the factor were conducted when comparing different times of the week in the proportion of wear time spent sitting and standing, steps-per-minute of wear time, and the proportion of wear time spent sitting in bouts of 5-10 mins and 30+ mins (see Tables 4.2 and 4.4). Day of week-by-gender and time of school day-by-gender interactions demonstrated one significant main effect; proportion of wear time spent sitting during school time compared to after school time at a $P < 0.05$ level of significance (P=0.15). Girls recorded 3.7% more time spent sitting after school compared to school time (68.2% vs 64.5%) whereas boys recorded 9.5% more time spent sitting after school compared to school time (71.1% vs 61.6%). Hence after school sitting was higher in both genders but this difference was greater in boys compared to girls. No other time point-by-gender interactions were observed in factorial ANOVA analysis ($P > 0.05$).

Table 4.2. Sitting, standing and stepping outcomes and comparisons during different times of the school week. Data presented as mean (SD) unless stated otherwise.

Sample n=79	**School day**	**Weekend day**	**Difference ¥ P (Effect size d)**	**At school**	**After school**	**Difference ¥ P (Effect size d)**
Number of valid days ‡	5.2 (1.2)	1.9 (0.3)		5.2 (1.2)	5.2 (1.2)	
Wear time, mins/d †	910.7 (82.9)	956.2 (51.0)	0.001	372.3 (29.7)	419.7 (48.2)	<0.001
Sitting, % WT [a]	67.7 (7.9)	74.0 (9.9)	<0.001 (0.7 IE) Gender: P=0.880	63.0 (11.6)	69.7 (8.4)	<0.001 (0.7 IE) **Gender: P=0.015**
Sitting, mins/d	† 605.9 (102.8)	† 686.3 (125.3)		227.8 (46.4)	290.2 (38.6)	
Standing, % WT [a]	19.7 (5.6)	17.1 (7.5)	0.002 (0.4 SE) Gender: P=0.672	22.3 (4.3)	18.6 (6.3)	<0.001 (0.7 IE) Gender: P=0.057
Time spent standing, mins/d	179.2 (53.5)	154.9 (68.0)		80.7 (31.1)	77.9 (28.3)	
Sit-to-stand transitions	93.9 (26.3)	84.0 (31.9)		43.1 (14.7)	42.3 (13.0)	
Sit-to-stand transitions p/hr [a]	6.2 (1.6)	5.4 (1.9)	<0.001 (0.5 IE) Gender: P=0.424	7.1 (2.2)	6.1 (1.8)	<0.001 (0.5 IE) Gender: P=0.839
Stepping, % WT †	13.2 (3.9)	9.7 (5.6)	<0.001	15.3 (4.5)	12.2 (3.7)	<0.001
Time spent stepping, mins/d †	116.5 (41.9)	83.9 (53.2)		55.8 (16.9)	47.7 (18.9)	
Total steps	8840 (2599)	6029 (2725)		4115 (1284)	3665 (1311)	
Steps p/min WT †	10.2 (2.8)	6.6 (3.9)	<0.001	11.6 (3.3)	9.0 (3.1)	<0.001

¥ A significant difference (Wilcoxon-signed rank test) was observed in activPAL wear time between school days and weekend days and school hours and after school. Comparisons were therefore made between proportions of wear time in sitting, standing and stepping. Minutes and frequencies in each behaviour are reported for descriptive purposes.

‡ Number of valid days (wear time ≥10 hrs/d) included in the analysis.

† Data represent the median and interquartile ranges due to skewed distributions. The Wilcoxon-signed rank test was used if values were compared (see 'Difference' column) and log transformation did not normalise the distributions.

[a] Comparisons made between times of the school week using two-by-two factorial ANOVA. Gender has been included as the factor and the main effect interaction statistic (gender) has also been reported.

WT, wear time; % WT, percentage of wear time; p/min, per minute; IE, intermediate effect size; SE, small effect size.

Significance level set at $P < 0.006$.

Table 4.3. Bout frequencies and accumulated minutes spent sitting and standing during different times of the school week (Mean (SD)).

Sample n=79	**School day**		**Weekend day**		**At school**		**After school**	
Sitting								
Frequency								
5-10 minutes	† 12.6	(4.5)	† 11.0	(5.5)	5.8	(2.0)	5.5	(1.7)
10+ minutes	† 15.3	(2.8)	† 17.5	(6.0)	5.7	(1.6)	7.6	(1.3)
30+ minutes	3.8	(1.0)	5.2	(1.8)	† 1.0	(0.7)	† 1.7	(0.9)
Total accumulated minutes								
5-10 minutes	87.6	(23.5)	75.3	(28.8)	40.9	(14.3)	38.9	(11.8)
10+ minutes	388.0	(62.7)	473.4	(121.1)	122.6	(36.2)	187.6	(40.9)
30+ minutes †	186.9	(79.6)	281.6	(138.2)	43.5	(33.7)	83.4	(51.6)
Standing								
Frequency								
5-10 minutes	3.5	(2.1)	3.7	(3.0)	1.3	(1.2)	1.6	(1.2)
10+ minutes	1.0	(0.9)	1.2	(1.5)	0.4	(0.4)	0.5	0.6)
30+ minutes	0.1	(0.1)	0.04	(0.2)	0.02	(0.01)	0.02	(0.1)
Total accumulated minutes								
5-10 minutes	23.3	(14.0)	24.5	(20.6)	8.4	(8.0)	10.5	(7.9)
10+ minutes	16.4	(14.6)	18.3	(26.4)	6.2	(7.2)	7.7	(10.2)
30+ minutes	2.1	(4.5)	1.2	(5.6)	0.7	(2.2)	0.9	(3.6)

† Values represent the median and interquartile ranges due to skewed data.

Table 4.4. Proportion of wear time spent sitting in different bout lengths and comparisons between different times of the school week (Mean (SD)).

Sample n=79	**School day**		**Weekend day**		**Difference, P (effect size, d)**	**At school**		**After school**		**Difference, P (effect size, d)**
Wear time, mins	908.8		919.8			361.7		417.2		
5-10 minutes, %	9.6	(2.5)	8.2	(3.0)	<0.001 (0.5 IE) Gender: P=0.869	11.3	(3.7)	9.3	(2.8)	<0.001 (0.6 IE) Gender: P=0.890
10+ minutes, %[b]	42.8	(6.9)	51.5	(11.5)	<0.001	34.1	(10.2)	45.1	(9.8)	<0.001
30+ minutes, % [a] *	20.4	19.5 – 22.0	28.3	27.1 - 33.1	<0.001 Gender: P=0.414	11.3	10.0 - 13.5	19.0	16.4 – 22.2	<0.001 Gender: P=0.969

*Mean value and confidence intervals taken from log transformed data which were then back transformed. Data compared using paired t-tests.

[a] Comparisons made between times of the school week using two-by-two factorial ANOVA. Gender has been included as the factor and the main effect interaction statistic (gender) has also been reported.

[b] Effect sizes not calculated due to median and interquartile range reported for minute data.

IE, intermediate effect size; NS, not significant.

Significance level set at *P* <0.006.

Just one boy and seven girls (18.4%) achieved recommended daily step counts (boys ≥13,000 steps; girls ≥11,000 steps) on school days and not a single boy or girl achieved these recommendations on weekend days.

The proportion of wear time spent sitting on school days was positively associated with both BMI and BMI z-score (r = 0.22, *P* =0.047 and r = 0.23, *P* =0.045, respectively). Sit-to-stand transitions per-hour of wear time was negatively associated with waist circumference (r = -0.22, *P* =0.049) and BMI (r = -0.24, *P* =0.033) during school days and negatively associated with waist circumference (r = -0.27, *P* =0.015), BMI (r = 0.30, *P* = -0.007) and BMI z-scores (r = -0.26, *P* =0.021) during school time. The proportion of wear time spent stepping was negatively associated with waist circumference, BMI and BMI z-score during school days (WC: r = -0.23, *P* =0.042; BMI: r = -0.36, *P* =0.001; BMI z-score: r = -0.34, *P* =0.002) and after school (WC: r = -0.28, *P* =0.0013; BMI: r = -0.39, *P* <0.0005; BMI z-score: r = -0.38, *P* <0.0005). Steps-per-minute of wear time was negatively associated with WC (r = -0.23, *P* =0.043) BMI (r = -0.35, *P* =0.002) and BMI z-score (r = -0.34, *P* =0.002) during school days and after school (WC: r = -0.28, *P* =0.0013; BMI: r = -0.39, *P* <0.0005; BMI z-score: r = -0.39, *P* <0.0005). No other significant associations were observed between adiposity indicators and sitting, standing and stepping outcomes (*P* >0.05).

4.4. Discussion

4.4.1. Main findings of this study

This study explored inclinometer-determined sitting patterns during and outside of school hours in a sample of 9-10 year old UK children. This study observed large proportions of wear time spent sitting on school days and weekend days, not only in total but also in prolonged bouts, which has not been observed before in UK children. Sitting time was particularly high after school and on weekends. These findings are concerning for a sample of mostly British South Asian children who are more susceptible to cardio-metabolic risk factors than white British children (133).

This study found that children sat in excess of 10hrs/day (68% of wear time) on school days and 11hrs/day (74% of wear time) on weekend days which are high volumes of sitting for this age group. These proportions are almost identical to inclinometer data reported in obese Malaysian children (aged 9-11yrs) on school days (68%) and weekend days (73%) who still achieved higher daily step counts than those seen in the present sample (school days: 9189 vs 8840; weekend days:7797 vs 6029) (93). Compared to accelerometer data, these results are similar to the proportions of stationary time observed in British Pakistani and white British girls (65-70%) (aged 10 years) (83) and higher than that reported in other English children (64%) (81). Furthermore, very few children achieved the recommended daily step counts to be classified as sufficiently active (267), with the total sample recording daily step counts (school day 8840 steps/day, weekend day 6029 steps/day) that were considerably lower than the thresholds recommended for boys (≥13,000 steps/day) and girls (≥11,000 steps/day) (267). This therefore suggests that the sample were inactive as well as highly sedentary. These findings are not entirely surprising since the sample consisted predominantly of ethnic minorities (70% South Asian) and there is evidence that ethnic minority children are more likely to be sedentary at and away from school and perform less MVPA (Salmon et al. 2011; Owen et al. 2009; Hornby-turner et al. 2014). As outlined in chapter 1, sections 1.8.1 and 1.8.2, the continual increase in daily sedentary time (96) and decline in PA (147) evident during the life course first occurs during early childhood (i.e. seven years of age) in UK children. These unfavourable trends may have already developed in the current sample since they are already in mid-childhood (9-10 years of age). Consequently, these children are likely to become even more sedentary and less physically active as they transition towards secondary school. A recent review highlighted that sedentary time increases by approximately 10-20 mins/day across the primary-secondary school transition (138). If this yearly change were to hold constant, the current sample will be sitting 11-13hrs/day (73-85% of current wear time) by the age of sixteen. This could mean as little as 3hrs available for movement-based activities (assuming 8hrs of sleep), which would have major implications for energy expenditure and body composition. However, this is based on a small sample of data, collected at a single time point and during the winter season. Consequently, these trends, albeit concerning, may vary considerably during different periods of the year.

This is the first study to explore sitting time accumulated in prolonged bouts in a sample of UK children. Wear time accumulated in sitting bouts of 30+ min on school days (187mins / 20% of wear time) and weekend days (282mins / 28%) was considerably higher than that observed in Belgian (school days: 34mins / 4%; weekend days: 29mins / 4%) (266), European (all days ≤80mins / ≤10%) (18), and Australian children (school days: 132mins / 16%; weekend days: 129mins / 16%) (87). The present results are comparable to those observed in adult office workers (10-30%) (282) and demonstrate that some children do spend a considerable amount of time throughout a day sitting for prolonged periods, contrary to previous conclusions (266). The daily frequency of prolonged bouts were low (school day 3.8, weekend day 5.2) compared to bouts of 5-10min and 10+ min (11-17.5), however, the average duration of prolonged bouts were 49 minutes and 54 minutes on school days and weekend days. This demonstrates that children do not need to engage in a high frequency of such bouts to result in a large proportion of waking hours being composed of prolonged sitting. The frequency values observed in this study exceed the highest number of 30+ min bouts (≤3.1) previously reported in a sample of obese children, with these children exhibiting lower levels of HDL cholesterol compared to children who did not accumulate any sitting bouts of this duration (although this is the only study to demonstrate these health trends to date) (95). Future research should further examine potential differences of health indicators between children who accumulate high and low volumes in prolonged sitting bouts (frequencies and minutes), particularly in groups of higher health risk (i.e. South Asians, obese), as this is largely unexplored.

Children spent more time sitting on weekend days compared to school days in this study. These findings add to the inconsistent evidence from previous studies that either support this finding (90,92,93), have found no difference (87,283), or have found the opposite (83). Children were also the least sedentary at school. This is in contrast to Abbott et al. (87) who observed the highest proportion of wear time spent sedentary in total and in prolonged bouts at school compared to other times of the week in Australian children. In the present study, reduced daylight hours (284) during the autumn/winter as well as less favourable weather associated with these seasons, may have influenced more indoor sedentary pursuits away from school (39) compared to outdoor conditions in the Abbott et al. study (set in western Australia). The sample in this study were recruited from schools based in neighbourhoods of low socio-economic position (SEP) and therefore many of the sample will have been of this status. UK Children of low SEP have demonstrated higher screen time SB than children of higher SEP (285) and may have been a reason why sitting time was high during time away from school compared to the children in the Abbott et al. study. It is also likely that contrasting school environments between study locations played a role in the differences reported during school time. Despite this, we still observed almost 4 hours of sitting at school, highlighting that the school environment is an important setting to reduce this behaviour. Although in the early stages of evidence, standing desk interventions implemented within the school classroom are emerging as a promising solution for interrupting and reducing sitting time (228,236).

Sitting time in total and in prolonged bouts was particularly high during weekend days and after school periods. These trends corresponded with less time spent in all indicators of PA compared to school days and during school time. These reductions in PA included less time spent standing and stepping, less steps-per-minute of wear time and less sit-to-stand transitions per hour of wear time. For example, on a weekend day, when compared to a school day, children demonstrated 6.3% more wear time spent sitting which corresponded with 2.6% less wear time spent standing, 3.5% less time spent stepping, 0.8 less sit-to-stand transitions per hour of wear time and 3.6 less steps per minute of wear time (all $P < 0.005$, small to intermediate effect sizes). Furthermore, on a school day, while only eight children achieved the recommended total daily step counts for boys (≥13,000) or girls (≥ 11,000) (267), not a single boy or girl performed a sufficient number of steps on a weekend day. Consequently, this demonstrates that when children spend more time sitting, there is a volume reduction across a range of physical activities within the movement continuum and in PA overall. The intensity of PA is unknown from this data, however the standing and stepping data is likely to encompass many light intensity physical activities. As stated in chapter 1 section 1.2, light intensity PA is strongly associated with sedentary time (32), which is clearly reflected in these trends. Taken together, it would seem important in this sample to target a reduction in sitting time during weekend days and after school with the simultaneous objective of increasing light and total PA.

A recent systematic review into the effectiveness of interventions targeting sedentary time (163) identified just one study in children (7-12 years), a six-month intervention to reduce media use, that found a reduction in sedentary time outside of school hours (-37min/day of TV viewing) (192). Although screen-based pursuits will surely be common, it is not known which types of SBs were adopted in the present study. This highlights the need for the inclusion of self-report measures (i.e. diary logs and surveys) to provide information on the mode, dose, and setting of SB to better inform intervention design. Also, within the six-month intervention study (192) no effects were observed in other SBs following the reduction in daily TV viewing, which suggests an increase in PA occurred however PA was not measured and therefore there was no direct evidence of this change. An alternative to targeting screen time to reduce total sedentary time could be to break up prolonged sitting bouts with short periods of activity, such as standing or stepping. Unfortunately, intervention studies with this objective are limited to a six-week school-based educational program that demonstrated inconsistent intervention effects during out of school hours (286). Future intervention studies may benefit from including parents and children in the intervention design process, which has not been undertaken to date (163), to potentially increase child engagement (287) and the likelihood of tackling SBs effectively during leisure time.

This study demonstrated little evidence of an association between indicators of adiposity and sitting time outcomes. BMI and BMI z-scores were positively associated with the proportion of school days spent sedentary, but these were only marginally significant. Conversely, waist circumference, which is a better indicator of cardiovascular disease risk factors than BMI (288) and an independent clinical risk factor for type II diabetes (132), was not associated with any sitting time outcome. The current literature on the relationship between objectively determined sedentary time and adiposity, and wider health indicators, is almost exclusively drawn from hip-worn accelerometer data in children (43). The inability of this measurement method to accurately distinguish between sitting and standing postures (23) is a limitation of this collective evidence. Consequently, the use of inclinometer data in the present study for determining sitting time provides important evidence on the SB-health relationship (42). Despite this important aspect of the data, the inconsistent association observed in the present study agree with findings from previous accelerometer based studies (42,43).

It is worth noting that many children within this sample, particularly females, will have been experiencing varying stages of puberty (111,118,119). Puberty is a dynamic stage of development manifested in rapid change in body shape, size and composition (113). Any potential relationship between adiposity markers and sedentary or PA indices will most likely be confounded by these developments. During puberty there is an increase in fat accumulation (again particularly in girls) (113,124) and therefore the extent to which sitting time has an influence on this may be largely lost and difficult to account for compared to other stages of the life course. Added to this the fact that this is a cross sectional study, where sitting behaviour captured during a single time point will likely vary compared to other periods (e.g. different seasons), it is perhaps unsurprising that few associations were found. Standard growth charts were used when interpreting adiposity indicators (waist circumference and BMI Z-scores) to account for potential maturation associated with each child's respective age (113). However, this will not account for growth trajectories, which is important (113). A boy or girl may have been classified as overweight from their BMI z-score at the time of measurement, however if they were on the 90th percentile growth trajectory that year, they could soon enter a normal BMI classification and lower z-score soon after this point (a large increase in height could reduce the BMI value). Consequently, the relationship between adiposity and sitting could be largely influenced by the timing of growth trajectories, particularly in children experiencing a growth spurt (113). Nutrition, which was not assessed as part of this study, would likely have a greater influence on maturation compared with sitting behaviour (112,127). To better account for associated changes from puberty, children could have been provided with Tanner staging scales (111) to capture the development of secondary sexual characteristics.

Each Tanner stage is associated with specific rates of development in body shape, size and composition (111,123). Consequently, this data could be used to control for varying rates of development when analysing relationships between adiposity and sitting outcomes. However, there is considerable variation in the tempo of puberty, even within the same gender and ethnicity (113) so this would only partially account for this confounder.

Other reasons for a lack of a relationship found between adiposity and sitting outcomes could be due to the small sample in this study which lacks the statistical power to detect some relationships between variables. With very little evidence available to date, more research of higher quality is required before robust conclusions can be made on the relationship between inclinometer-determined sitting time and adiposity. Future research should use longitudinal or experimental study designs, and include larger sample sizes, to better investigate this relationship.

Standing time was not associated with BMI, BMI z-scores or waist circumference in this study. This suggests that time spent standing during different days of the week or different times of the day do not have an influence on a child's adiposity. Conversely, some negative associations were observed between sit-to-stand transitions (per hour of wear time) and stepping outcomes (proportion of wear time and steps per minute of wear time) with BMI, BMI z-scores and waist circumference. This suggests that a greater number of sit-to-stand transitions or steps performed during a day may result in lower adiposity in children. Caution is needed with these observations as associations between these movement behaviours and adiposity indicators were not consistent across all domains of the week. For example, sit-to-stand transitions were negatively associated with adiposity outcomes during school days and school hours but not weekend days or after school. In comparison, the proportion of wear time spent stepping and steps-per-minute of wear time were negatively associated with adiposity outcomes during school days and after school time but not weekend days or during school time. These inconsistencies may in part be due to a lack of statistical power and more consistency may have been observed in a larger sample of children. Previous studies have established the positive effect that daily steps can have on adiposity outcomes in children and adolescents (289,290). However, the potential influence of sit-to-stand transitions on adiposity is a more novel finding that warrants further investigation. This specific movement is a relatively new behaviour to be measured and reported within PA and SB research since posture monitors have only recently been utilised in these fields. It needs pointing out that the simple bivariate correlations used in this analysis did not control for important confounding factors that may have had mediating effects on these relationships. Like in the correlational analysis with sitting variables, these associations will probably be considerably confounded by pubertal maturation and therefore these relationships should be interpreted with caution. Nevertheless, if the impact on adiposity observed in this study can be replicated more consistently in larger scale studies, while controlling for puberty maturation, this could be beneficial for obesity prevention strategies since sit-to-stand transitions can be easily performed in a range of settings. For example, the school classroom dictates that children predominantly sit during lessons where the opportunity for walking or even light ambulation is limited. However, it is potentially feasible that sit-to-stand transitions could be integrated into a lesson by teaching staff since it is a brief action. Standing desks, particularly models that are freely adjustable between sitting and standing positions (i.e. the Ergotron LearnFit sit-stand desk) may facilitate this behaviour during lesson time. Consequently, sit-to-stand transitions could become an important outcome measure in future standing desk studies.

4.4.2. Strengths and limitations of this study

A strength of this study is the use of inclinometers to accurately measure sitting time. However, the cross-sectional design of this study prevents any conclusions about causality. The high non-compliance rate of the activPAL protocol resulted in a large proportion of lost data which may have influenced the outcome of key variables. This was surprising since a 24h wear protocol was implemented which is suggested to improve wear time compliance compared to other protocols (e.g. device removal for water-based activities) (61,63). Perhaps the criteria of ≥10h/day on ≥3 valid week days, instead of 8/9h/day or 2-week days, for example, was a factor in a reduced wear time compliance and sample size. However, these criteria have been implemented in a similar previous sedentary behaviour cross-sectional study (87). It was found that a lack of valid weekend day data (≥1day) was the primary reason for a reduction in wear time compliance in the present study. It is generally recommended that a range of wear time criteria are applied to get the best compromise between sample size and reliable data (62). It was felt that the wear time criteria applied in this study was optimal for achieving this balance. The small sample spread across just two schools within close proximity to one another, limits the generalizability of the findings. It should also be noted that the sitting levels and patterns observed in this study only reflect behaviour during the autumn/winter seasons. It is likely that these outcomes will be more favourable during the more activity-permissive seasons of spring and summer (284,291). The study data was mostly analysed and reported as a single sample despite consisting of both girls and boys and several ethnicities. This decision was dictated by the sample being relatively small, making statistical comparisons between sub groups less feasible. However, to account for potential differences between boys and girls when comparing sitting and PA variables between different times of the school week, Factorial ANOVAs were conducted, with gender as the factor. Across 10 different univariate analysis, only one model found a difference between girls and boys when comparing outcome variables across different times of the school week. Within this comparison (the proportion of wear time spent sitting during school time compared to after school time) the trend was still the same between sexes (greater sitting time after school time compared to during school), only the difference was greater in boys. No other differences were found between sexes. In fact, in eight of the ten comparisons, sitting and PA trends were very closely matched between boys and girls. Consequently, within this study it can be concluded that boys and girls generally demonstrated very similar sitting and PA behaviour during a school week.

This study applied a blanket sleep period to all data (11pm-6am), to identify all sleep periods, which has limitations if this is the only method used to remove sleep (61). This would result in 1020 mins of waking data per day, however, a child could go to sleep at 9pm and wake up at 7am, meaning 3h of data has been miss-classified as waking hours. To identify periods of sleep during the designated waking hours (6am-11pm), the 3-axis acceleration data in this chapter (and Chapter 5) will have detected periods of no movement. If these periods exceed 20 mins then this period will have been excluded as non-wear. This is reflected in the wear times for this chapter and Chapter 5 being below 1020 mins; e.g. a mean of 911 mins for weekdays in Chapter 4 and 800-900 mins for week days in chapter 5. Wear time data for all 79 participants in this Chapter were inspected and every participant provided wear time below the wear time application of 1020 mins. While this could be due to the device being removed during brief periods of the day, it is highly improbable that every participant removed the device during the 7-day wear when a 24 h wear protocol was implemented and only some children reported issues with wearing (and removing) the monitors. Consequently, it would appear that sleep time was successfully removed from the dataset. Despite the limitations in this study, the findings provide novel information on the composition of accumulated sitting time in a sample of UK children, predominantly of South Asian ethnicity.

4.4.3. Conclusions

In conclusion, this sample of mostly British South Asian children demonstrated very high proportions of time spent sitting in total and in prolonged bouts and low levels of PA during school days and weekend days. These trends are likely to increase into adolescence which is concerning for an ethnic population at higher cardio-metabolic health risk. To inform effective interventions, further longitudinal research is required, with larger sample sizes spread across multiple UK areas, to better understand the levels and patterns of sitting accumulated at and away from school in children.

CHAPTER 5 – The impact of the Stand Out in Class intervention on sitting time, physical activity, adiposity, musculoskeletal health, cognitive function and behaviour related mental health

The research reported in this chapter was presented as an oral presentation at the 2017 ISBNPA annual meeting, and an abstract from this work was published in the conference proceedings: *Sherry AP, Pearson N, Ridgers ND, Barber SE, Bingham DD, Nagy LC, Dunstan D, Clemes S: The effectiveness of sit-to-stand desks to reduce sitting time within a primary school classroom: an 8 month controlled trial. In the proceedings of the International Society of Behavioral Nutrition and Physical Activity (ISBNPA) Annual Meeting: 2017; Victoria, Canada*

5.1. Introduction

The school environment has been identified as an important setting for promoting healthy lifestyle behaviours (157), partly because children spend the majority of their time during weekdays at school (235). The school setting provides the ability to reach a large number of children of diverse socio-economic backgrounds (84) and there are examples of school-based interventions successfully reducing health inequalities (292,293).

There is consistent evidence that children are predominately sedentary while at school. Objective data from England suggest that children spend 65-70% of school time stationary (81), and international data show a similar pattern (39,88). Australian Actical data suggests that children are more stationary at school compared to time outside of school (87), spend a greater proportion of time in prolonged bouts of stationary time (30+ mins), and report less sit-to-stand transitions during school time (87). Sitting trends outlined in Chapter 4 from activPAL data demonstated that 9-10 year old children from a northern UK city were the most active and least sedentary during school time compared to other periods of the school day and week. For example, children spent 63% of school time sitting compared to 70% of sitting time after school. However, children still spent almost 4h sitting in total while at school. Class time may be a domain where children are the most sedentary during a school week. A recent study demonstrated that children and adolescents are stationary for 70-90% of the time during different school subjects, with total stationary time and mean stationary bout lengths increasing from grade-to-grade (84). It may therefore be opportune to target the classroom setting, a highly structured and controlled environment, to potentially influence positive sedentary behaviour (SB) across a large population of children during a critical stage of development towards adolescents.

The use of standing desks has received considerable attention within primary/elementary school classrooms in recent years (228,294). These environmental interventions, found to be effective in the work place with adults (234) have emmerged as one of the more promising solutions for reducing total sedentary time in children (22,236,242). These interventions have compared favourably in reducing sedentary time to multi-component interventions (e.g. targeting a reduction in sedentary time as well as increase physical activity (PA) and reducing food intake) (236) which overall may be more challenging to implement and evaluate. The high potential exposure time (i.e. approximately 5 hours of class time per school day) and simple self-service design of sit-to-stand desks are major strengths compared to other common strategies (i.e. educational classes) that may have a greater dependence on teachers and therefore carry a higher risk of insufficient implementation previously seen in school based PA programmes (228). The autonomous, subconscious nature of using standing desks may also play a part in their relative success (236). Furthermore, the user has the ability to not only reduce total sedentary time but also frequently interupt prolonged bouts of sitting with standing or light PA.

Despite some encouraging findings from a few early studies, recent reviews show that overall the evidence for the effectiveness of these interventions in children across a diverse range of postural, PA, health and development-related outcomes is mixed (228,294,295). This may be partly due to the majority of studies being short-term pilots of low quality (228,294,295). Many studies have not included measures of sitting and standing time which are essential for determining first and foremost whether these interventions are effective in achieving their fundamental purpose (294). In studies that have included such outcomes during class time (all of which used accelerometers or inclinometers), there is a consistent reduction in sedentary/stationary time of approximately 20-60mins during daily class time within intervention classes over short (<9 weeks) (91,237), medium (5 months) (238), and longer periods (8 months) (268). These are noteworthy preliminary findings when considering a recent review reporting that sedentary/stationary time increases by approximately 10-20 mins/day per year across the primary-secondary school transition (138).

More standing desk studies are needed to build on these findings while simultaneously addressing the fundamental gaps that remain within the literature. For example, current evidence is unable to determine whether standing desk interventions are effective in reducing sedentary time during total waking hours (294). There is evidence that adults compensate for a reduction in sitting time during working hours with an increase in sitting time after work hours from an office-based standing desk intervention (265); this reaction to classroom standing desks has not been explicitly examined to date. With only one longer-term study conducted to date (268), more studies spanning a full academic year are also required to appropriately examine changes in classroom SB. Also, the study by Ayala et al. (2016) (268) is the only to our knowldege to have explored time spent sedentary in more prolonged bout lengths (i.e. 10+ mins) and any subsequent changes in such outcomes. Interrupting prolonged bouts of sedentary time may be a more attainable and beneficial behaviour change than replacing sedentary time with prolonged periods of static standing that can carry health risks of its own (228,295). As highlighted in the Introduction Chapter, standing desk studies in children (and adults) as yet have not utilised a behaviour change framework (173,236). While the standing desk interventions in these studies have successfully demonstrated reductions in class time sitting (91,237) it would be prudent for future studies to utilise a theoretical framework to enhance the likelihood of intervention effectiveness (175) and to shed light on the reasons for this success or ineffectiveness.

Standing desks certainly carry the risk of a novelty effect that may cause challenges to sustainability. Children become acustomed to traditional seated classroom furniture from the first year of primary school. By the age of mid-childhood (e.g. 8-10 years old), a stage in which standing desk interventions have been typically implemented, standing desks may feel like a substantial alteration to a normally consistent and standard table classroom environment. The opportunity to sit or stand during lessons when typically the only option previously was to sit, will at first be a novelty that may result in early engagement in classroom standing behaviour. Once familiarisation and normalisation sets in, it is very possible that usual sitting patterns resume. To date, only one study has included more than one follow up measurement which provided the opportunity to explore changes in intervention engagement (238). While a reduction in sitting behaviour (measured using activPAL inclinometers) was not observed in 9-11 year old children in New Zealand, follow ups were only after 4 and 8 weeks (238). Focus groups and interviews were conducted at 5 months of exposure and there was no apparent sign of a novelty effect, however this outcome was not directly examined. Future studies need to explicitly explore any potential evidence of a novelty effect from standing as this threatens the long-term effectiveness of these interventions.

Nearly all studies evaluating standing desks within the classroom are limited to the USA, Australia and New Zealand. The school systems, infrastructure and pupil demographics within these settings may be very different to European schools and therefore inference to UK schools is limited. Within the one UK based study (91), the school was located in a neighborhood with a high proportion of ethnic minorities. This is important because there is evidence that ethnic minorities are more likely to be sedentary at and away from school and perform less moderate to vigorous PA (MVPA) (83,246,277). Furthermore, South Asian children, which made up the largest part of the study sample in the UK trial of the Clemes et al. study (91), are known to have a higher body fat percentage at a given BMI and reduced insulin sensitivity compared to several other ethnicities (132). These health markers signify an increased risk of type 2 diabetes and cardiovascular disease, which have been directly observed in British South Asian children (133). Consequently, high risk populations such as these should be targeted when implementing interventions to reduce sedentary time for there to be the greatest effect on important health outcomes such as body composition.

Standing desk interventions implemented within the school classroom may have the potential to play an important role in childhood obesity prevention. To date, standing desk studies have consistently lead to, in US samples, increases in class time energy expenditure compared to control classes (256,258,260), with potential net gains in expenditure of 24-87kcal/day if expanded to a full day of lessons (see Chapter 2 section 2.4). It has been estimated that a calorie deficit of 77kcal/day in children of the United States aged 6-11 years (296) and 100kcal/day in Australian children aged between 4.5 and 15 years (297) are required for meaningful population level changes in weight status in the defence against rising obesity levels. Furthermore, assuming dietary intake is unchanged, common physical activity (PA) interventions, such as 10-30 mins of jogging per day which results in an increase in total daily PA, have been calculated to influenced energy expenditures of between 9-186kcal/day (298). Screen-based interventions, including reduced TV viewing or computer use of 60 mins, have been estimated to produce reductions in energy expenditure of 92-106kcal/day (298). When considering these calorie deficits and gains, it would appear that standing desks could provide a meaningful contribution to child weight loss or maintenance over time. This was evidenced in a two year study in Texas, USA, with third and fourth grade pupils (8-10 years old) (299). Children who were exposed to standing desks for the full study duration demonstrated a signifiant reduction in BMI percentile of 5.24% compared to a control group only exposed to traditonal classroom furniture (299). From an ecological perspective, it is important that standing desk studies based within the school classroom measure both sitting behaviour and adiposity outcomes over the longer-term to better understand the effect that a reduction in sitting time may have on child adiposity. This would help determine whether standing desks can play an important part in childhood obesity prevention strategies and population health.

While health outcomes in children are important, it is critical that the impact of standing desk on aspects of classroom behaviour and development are explored at such a key stage of life (50,242) as these outcomes are likely to be fundamental for intervention acceptance (228). Like the association between total sedentary time and important health outcomes, the effect of excessive sedentary time on outcomes such as cognitive function, academic achievement and prosocial behaviour is unclear (43) from a currently small evidence base (see Chapter 1, section 1.8). Within the emmerging evidence of classroom-based standing desk interventions, development-related outcome measures have included classroom behaviour (261), academic engagement (263), concentration (261) and attention deficit hyperactivity disorder (ADHD) (238) in low quality studies. These studies demonstrated either no effect (238,261) or a positive effect at a mid-point of a five month intervention (academic engagement; (263)). Based on these findings, Sherry et al. (294) concluded that standing desks are not detrimental to behaviour or learning based outcomes, which is important. These results will need to be replicated or improved upon in longer term studies if standing desks are to be accepted as a permanent classroom fixture within an educational setting.

The purpose of this chapter is to evaluate the impact of two 8 month sit-stand desk interventions in reducing classroom sedentary time and increasing PA in Year 5 (9-10 years old) primary school children. This study is piloting the impact of two different implementation methods: 1) providing a sit-stand desk for every child in a classroom (full desk allocation (FDA)) and 2) replacing a small number of traditional desks with sit-stand desks with the teacher rotating the children between traditional and standing desks (partial desk allocation (PDA)). These conditions are compared to a control group which is based within a classroom in a nearby school. The two intervention conditions were included due to a previous pilot study demonstrating comparable reductions in total sedentary time between these different designs (91). The second method therefore has the potential to be more cost-effective and needs to be further explored. No study to date has compared these two systems within a school setting. Comparing these PDA and FDA systems is therefore a novel application of a standing desk intervention. The term pilot is relevant to a study when an intervention is implemented in a novel way (165); In addition to the novelty of having two allocation approaches, this is the first study to implement a standing desk intervention throughout the majority of an academic year in the UK. Since the replacement of traditional desks with standing desks is a major alteration to a learning environment, it is important to first pilot this environmental restructuring approach over the longer term before time and resources are invested into a larger randomised controlled trial. This includes exploring whether the two systems show a positive direction of influence not only at 4 months but also at 8 months of exposure. Two follow-up measurements will provide evidence on potential novelty effects. Furthermore, different issues may arise over the longer-term during this pilot that may need to be addressed prior to a full trial.

5.2. Methods

5.2.1. School and participant recruitment

The Stand Out in Class study was a pilot non-randomised controlled trial implemented within two primary schools in the city of Bradford, UK. The intervention and control groups were initially selected for inclusion in the present study following consultation with head teachers and senior staff at the two schools. The two schools are located within 3km's of each other and are based in a neighbourhood highly ranked in England for deprivation (300). The city of Bradford itself is ethnically diverse, deprived and with high child morbidity (300). Half of all children born in Bradford are of South Asian ethnicity, with the majority born into the top 20% most deprived population in England (300). Year 5 children (aged 9-10 years) were targeted for this study due to their more active participation in learning (301) and to expand on a previous pilot study (91). Furthermore, children in northern England have demonstrated that the largest increase in the time spent sedentary (in total and in prolonged bouts) from childhood into adolescence occurs between the ages of 9 and 12 years of age (96), making children within this age group an important target for interventions.

Parents of the pupils within the intervention groups were sent letters to be informed of the changes to the classroom environment and to invite their child to participate in the evaluation of the study. Parents of children within the control group were sent letters to invite their child to participate in a standing desk study evaluation but that their classroom would be a control group with no alterations to the classroom furniture or teaching practices. The study was approved by Loughborough University Ethical Advisory Committee (project ID: R15-P086). Parents/guardians provided written informed consent for their child to take part in the evaluation of the intervention and children were required to provide written assent prior to the baseline measurements. Children were excluded from the study if they had a disability that prevented periods of standing or an injury or illness that precluded the ability to perform normal daily tasks.

5.2.2. The intervention

In one of the two schools, a single year 5 class functioned as a control group, continuing with traditional classroom furniture for the full study period. The control group was located in a separate school to avoid contamination, which has been a common issue in previous studies (228,268). In the other school, both year 5 classes received Ergotron LearnFit sit-stand desks (see Figure 5.2), but to different levels of allocation. In the FDA class, every pupil received their own sit-stand desk (see Figure 5.4). In the PDA class, six sit-stand desks replaced traditional desks and the teacher was requested to rotate the children to allow every child to have exposure to the intervention each week (see Figure 5.5section). The Ergotron LearnFit desk is an adjustable sit-stand desk that allows the user to adjust between sitting and standing and has been used within other standing desk studies recently (268,302).

5.2.2.1. Theoretical underpinning

Sit-stand desk interventions within each class (FDA and PDA) were designed using the Behaviour Change Wheel (BCW) (233) and the Behaviour Change Taxonomy (BCT) (v1) (303). As detailed in Chapter 1 (sections 1.12 and 1.12.2.5), there is limited understanding of the determinants of SB (161) and attempting to reduce sedentary time can potentially be a complex task. Consequently, it would seem suitable to utilise the Behaviour Change Wheel (BCW), a comprehensive framework, to underpin and guide this intervention. At the 'hub' of the BCW is the Capability, Opportunity and Motivation to perform a Behaviour (COM-B) model (233) which together determines the sources of behaviour and therefore provides targets for intervention. Each component can be split into two further domains; capability can be both the physical (e.g. skills, strength) and psychological (e.g. knowledge, stamina) capacity to change behaviour; opportunity can be physical (e.g. time, resources) or social (e.g. interpersonal influence, social cues); motivation can be reflective (plans and evaluations) or automatic (e.g. emotional reactions, desires). Around the COM-B model are nine intervention functions that can be used to influence behaviour change.

They are described as functions because an intervention may consist of more than one of these components (233). The BCT is a taxonomy of 93 consensually identified and unique behaviour change techniques (303). The step-by-step process for designing an intervention outlined by Michie et al. (2014) (233) was used in this study to develop both interventions.

The primary behaviour of interest in this study is to reduce class time sitting and is therefore the targeted outcome. In designing the two interventions, the BCW was used to identify potential mediators for intervention success (a reduction in class time sitting). Once mediators are identified, specific aspects of the COM-B model to enable behaviour change in the primary outcome were identified. Intervention functions to supplement the sit-stand desks were then selected to influence mediating factors and identified aspects of the COM-B model (233). The final stage of the intervention design process included identifying potential barriers to intervention effectiveness and selecting specific techniques from the Behaviour Change Taxonomy (based within BCW intervention functions) as possible solutions to intervention barriers (233). For both intervention groups, Tables 5.1 and 5.2 outline intervention components, Figure 5.1 outlines the underpinning theory, resources and activities, short term outputs/goals and longer-term output goals of both FDA and PDA interventions using a logic model, and Tables 5.3 and 5.4 detail potential barriers and solutions to barriers for intervention effectiveness.

Mediating processes of children reducing sitting time in intervention groups were identified as 1) the time children are exposed to sit-stand desks, and 2) children choosing to stand rather than sit during class time (see Tables 5.1 to 5.4 and Figures 5.3 and 5.4). The first mediator only applies to the PDA group since desk exposure is dependent on sufficient rotation in all children, whereas in the FA group, children have a desk each and therefore class time exposure is total. In both intervention groups, when the children were exposed to the sit-stand desks they were free to decide whether to sit or stand in both intervention groups. Consequently, the sit-stand desks themselves directly influenced the second mediator of children's decision to sit or stand during class time, since a choice between sitting and standing is provided.

Logic Model for the Stand Out In Class Intervention

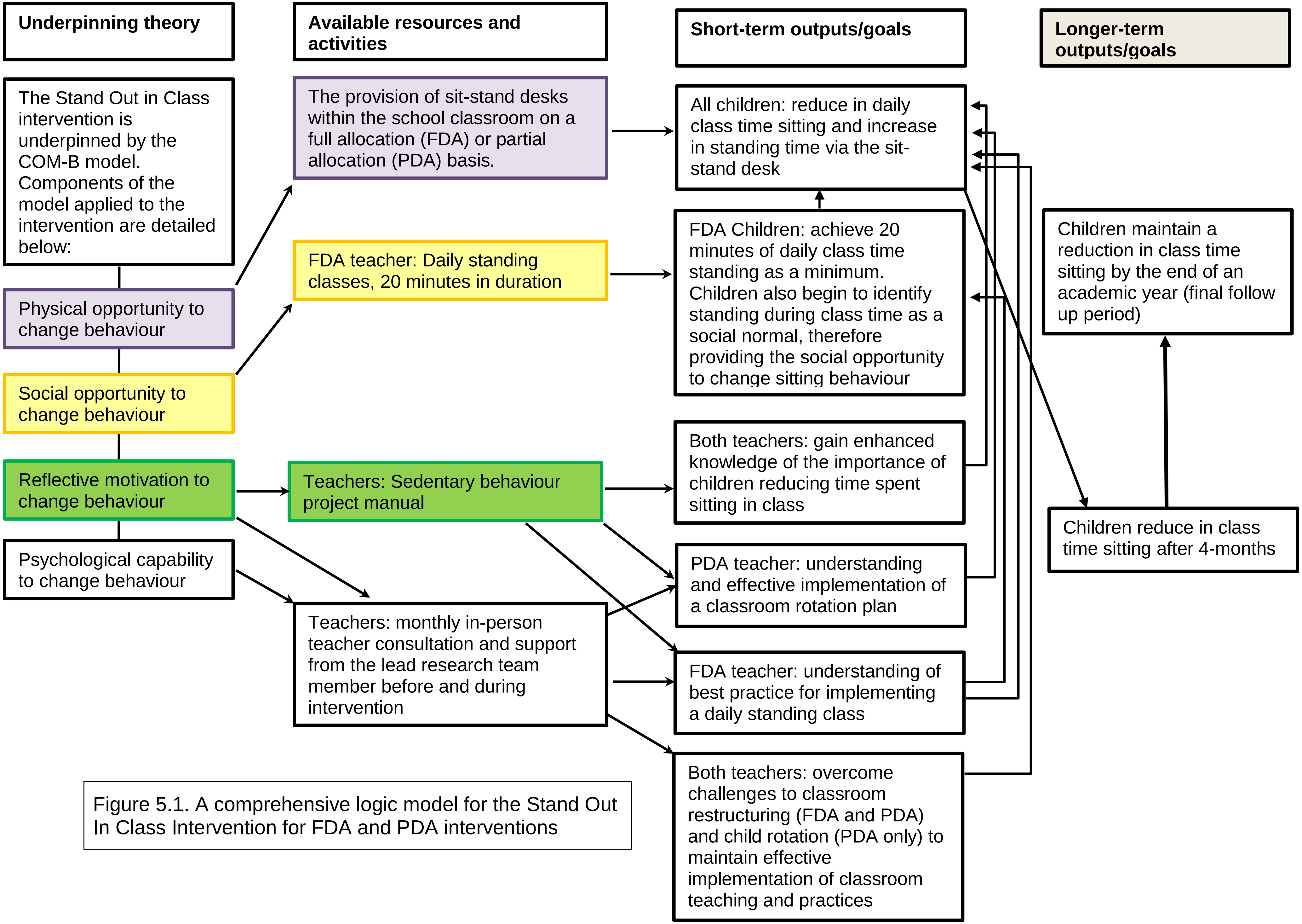

Figure 5.1. A comprehensive logic model for the Stand Out In Class Intervention for FDA and PDA interventions

Table 5.1. Components of the Stand Out in Class intervention within the full desk allocation intervention arm

Intervention component	Target domain	Meditating variable	Description
Adjustable sit-stand desks	Environment	Children choose to stand rather than sit when using desks	Full classroom of adjustable sit-stand desk are introduced into the class room (one per child)
Standing class	Teacher and children	Children choose to stand rather than sit when using desks	The teacher leads a daily standing class during the first 20 minutes of a Mathematics lesson. All children are requested to stand during the 20-minute standing class. If they sit down, they are requested to stand again
Professional development manual	Teacher	Exposure to desks	Cover topics such as: - Why it is important to increase standing - Safety – how to use desks - Standing classes
Monthly in person support from researcher	Teacher	Exposure to desks	Face to face meeting with researcher – discuss any issues around implementation of rotation plans

Table 5.2. Components of the Stand Out in Class intervention within the partial desk allocation intervention arm.

Intervention component	Target domain	Meditating variable	Description
Adjustable sit-stand desks	Environment	Children choose to stand rather than sit when using desks	6 adjustable sit-stand desks introduced into the classroom
Professional development manual	Teacher	Exposure to desks	Cover topics such as: - Why it is important to increase standing - Importance of exposure - Safety – how to use desk - Rotation plan and example and creation of a weekly rotation plan
Planned weekly rotation plan	Teacher	Exposure to desks	Teacher is provided with a predetermined rotation plan and will keep a record of whether this was met or not
Monthly in person support from researcher	Teacher	Exposure to desks	Face-to-face meeting with researcher – discuss any issues around implementation of rotation plans

Table 5.3. Potential intervention (full desk allocation) domain barriers and solutions to barriers using the Capability, Opportunity, Motivation to perform a Behaviour model (COM-B) and Behaviour Change Techniques (BCT) based on the Behaviour Change Taxonomy (v1).

Barriers	Affected meditating (M) variable	COM-B	Solution (What, Who, How, Where)	BCT
Teacher barriers				
Not understanding the importance of reducing children's sitting/sedentary time, therefore does not deliver standing class.	M1) Time children are exposed to sit-stand desks.	Reflective Motivation	**What:** 1) Training manual; 2) Monthly in person support from researcher **Who:** Researcher **Where/how:** School **When:** Before the desks are introduced into the classroom throughout the intervention.	5.1. Information about health consequences
Find it difficult to deliver standing class because of some of the needs of the children or because of challenging behaviour of children	M1) Time children are exposed to sit-stand desks.	Psychological capability	**What:** Monthly in person support from researcher **Who:** Researcher **Where/how:** School **When:** Before the desks are introduced into the classroom and throughout the intervention **Notes**: In person the researcher will ask the teacher to focus on past successes when	3.3. Social support (emotional) 15.3. Focus on past success

			standing classes are becoming challenging. The researcher will also provide emotional support and encouragement to continue with the standing classes.	
After a period of time the teacher does not have belief in the sit-stand desks and ceases to deliver standing classes.	M1) Time children are exposed to sit-stand desks.	Reflective motivation	**What:** Monthly in person support from researcher **Who:** Researcher **Where/how:** School **When:** Monthly **Notes**: Researcher will emphasise the importance of reducing sitting time in children. The researcher will also emphasise how successful the standing classes have been so FDA and how the teacher may later regret ending the practice.	5.1. Information about health consequences 5.5. Anticipated regret

Delivering the standing class is difficult and teacher stops these classes because of the added stress and consideration of enforcing a standing class with the children.	M1) Time children are exposed to sit-stand desks.	Psychological capability	**What:** Monthly in person support from researcher **Who:** Researcher **Where/how:** School **When:** Monthly **Notes**: Researcher will listen to the teachers issues related to the standing class practice. He will provide emotional support and encouragement to continue.	3.3. Social support (emotional)
Teacher is absent, so standing class does not take place. Or if there is a change in personnel (e.g. part-time teacher, trainee teacher, supply teacher or different teacher for certain classes), there may be inconsistent delivery of the standing class.	M1) Time children are exposed to sit-stand desks.	Psychological capability (of teacher replacement)	**What:** **Who:** Researcher ensures the timetable has been printed off, and ensure children and staff (teacher, assistant) know where the plan is kept and why. **Where/how:** School **When:** prior to the start of the intervention	7.1. Prompts/cues

Resistant to change - standing class requires a change in teaching practice	M1) Time children are exposed to sit-stand desks.	Reflective motivation and Psychological capability	**What:** consultation prior to desk installation **Who:** Researchers and teachers **Where/how:** school **When:** prior to and during the intervention **Notes:** The researcher and teacher will discuss in detail how the standing classes can work to help the teacher realise how the change in teaching practice can occur.	4.1. Instruction on how to perform the behaviour 8.1. Behavioural practice/rehearsal
Child barriers				
Children may think that standing is an unusual behaviour and choose not to stand to conform with social norms	M2) Children choosing to stand when using sit-stand desks.	Social opportunity	**What:** standing classes **Who:** Teacher **Where/how:** school **When:** During class time during the intervention **Notes:** The teacher leads daily standing classes which will demonstrate to the children that standing during lessons is a social norm and common practice.	6.1. demonstration of the behaviour

Table 5.4. Potential intervention (partial desk allocation) domain barriers and solutions to barriers using the Capability, Opportunity, Motivation to perform a Behaviour model (COM-B) and Behaviour Change Techniques (BCT) based on the Behaviour Change Taxonomy (v1).

Barriers	Affected meditating (M) variable	COM-B	Solution (What, Who, How, Where)	BCT
Teacher barriers				
Not understanding the importance of reducing children's sitting/sedentary time, therefore not rotating children.	M1) Time children are exposed to sit-stand desks.	Reflective Motivation	**What:** 1) Training manual; 2) Monthly in person support from researcher **Who:** Researcher **Where/how:** School **When:** Before the desks are introduced into the classroom throughout the intervention.	5.1. Information about health consequences
Find it difficult to rotate the children in groups because of some of the needs of the children or because of challenging behaviour of children	M1) Time children are exposed to sit-stand desks.	Psychological capability	**What:** 1) Training manual; 2) Monthly in person support from researcher **Who:** Researcher **Where/how:** School **When:** Before the desks are introduced into the classroom and throughout the intervention.	3.3. Social support (emotional) 15.3. Focus on past success

After a period of time the teacher does not have belief in the sit-stand desks and ceases to rotate the groups.	M1) Time children are exposed to sit-stand desks.	Reflective motivation	**What:** Monthly in person support from researcher **Who:** Researcher **Where/how:** School **When:** Monthly **Notes**: Researcher will emphasise the importance of reducing sitting time in children. The researcher will also emphasise how successful child rotation has been so FDA and how the teacher may later regret ending the practice.	5.1. Information about health consequences 5.5. Anticipated regret
Rotating the children is difficult and teacher stops rotating because of the added stress and consideration of how to rotate children.	M1) Time children are exposed to sit-stand desks.	Psychological capability	**What:** Monthly in person support from researcher **Who:** Researcher **Where/how:** School **When:** Monthly **Notes**: Researcher will listen to the teachers issues related to class rotation. The researcher	3.3. Social support (emotional)

			will provide emotional support and encouragement to continue with rotation practice.	
Teacher is absent, so rotation plan is not followed. Or if there is a change in personnel (e.g. part-time teacher, trainee teacher, supply teacher or different teacher for certain classes), there may be inconsistent delivery of the intervention and rotation policy	M1) Time children are exposed to sit-stand desks.	Psychological capability (of teacher replacement)	**What:** **Who:** Researcher ensures the timetable has been printed off, and ensure children and staff (teacher, assistant) know where the plan is kept and why. **Where/how:** School **When:** prior to the start of the intervention	7.1. Prompts/cues
Teacher does not have a clear understanding of the rotation plan	M1) Time children are exposed to sit-stand desks.	Psychological capability	**What:** 1) teacher's manual; 2) consulting **Who:** Researchers and teachers **Where/how:** school **When:** prior to and during the intervention	8.1. Behavioural practice/rehearsal
Resistant to change - may require a change in teaching practice	M1) Time children are exposed to sit-stand desks.	Reflective motivation and Psychological capability	**What:** 1) Consulting; 2) Monthly in person support from researcher **Who:** Researchers and teachers **Where/how:** school	4.1. Instruction on how to perform the behaviour

		When: prior to and during the intervention **Notes:** The researcher and teacher will discuss in detail how the rotation system can work to help the teacher realise how the change in teaching practice can occur.	8.1. Behavioural practice/rehearsal

In considering factors that would enable a child to change from sitting during class time to standing, two main variables were identified within the COM-B model; physical opportunity, and social opportunity (see Table 5.3 and 5.4). Sit-stand desks, an environmental restructuring intervention function (BCW), provide the physical opportunity for children to stand compared to traditional classroom furniture that dictates predominantly sitting. Social opportunity was identified because standing during class time is not a social norm within the classroom environment and therefore the children may feel inhibited to change (see Table 5.3). Consequently, for a shift from sitting to standing behaviour to occur, it may be important to attempt to normalise standing during lessons. To address this, within the FDA intervention, the teacher agreed to deliver a daily standing class whereby all children were instructed to stand for the first 20 minutes of a mathematics class. By demonstrating that standing during class time is a standard classroom practice, children would hopefully interpret this behaviour as a social norm and be more willing to engage in the behaviour. This intervention function is a modelling technique within the BCW (233) and is technique 6.1. 'Demonstration of the behaviour' within the Behaviour Change Taxonomy (303). Standing classes were not included in the PDA group arm of the study as this in addition to the responsibility of rotating children on a daily basis may be placing too much burden on the teaching staff.

Due to the reliance on teachers to deliver aspects of the intervention in both FDA and PDA intervention groups, the teachers were identified as important factors and potential barriers (see Tables 5.1 to 5.4 and Figures 5.3 and 5.4) to children reducing sitting time during class. For intervention success, it was important for the teachers to change their own teaching behaviour to comply with sufficient intervention implementation. Within the COM-B model, reflective motivation was identified as a key variable to this because it was critical for the teachers to believe that the intervention and their role within it were important and worthwhile. This specifically applies to the teacher's role within the daily standing classes within the FDA arm and the rotation of children between sit-stand desks and traditional desks within the PDA group arm. To support the teachers in their respective intervention roles, teachers were provided with Professional Development Manuals (see appendix C). These manuals were adapted from a resource used in a previous pilot study (91). Manuals for both teachers included details on the importance of reducing sitting time for child health and development. Within the FA manual, instructions of how to conduct a standing class were detailed for the teacher to refer to. Within the PDA group manual, instructions for child rotation were detailed as well as a weekly rotation schedule for the teacher to use. Both manuals also described how to correctly use the sit-stand desks. To further aid the teachers' reflective motivation, the lead researcher visited the school on a monthly basis to provide in-person support and re-enforce the importance of the intervention and the teachers' roles within it (see Tables 5.1 to 5.4 and Figures 5.1 and 5.2).

Figure 5.2. The Ergotron LearnFit sit-stand desks.

Figure 5.3. Intervention class with Ergotron LearnFit sit-stand desks provided for every child in the classroom.

Figure 5.4. Intervention class with six Ergotron LearnFit sit-stand desks and traditional desks.

The sit-stand desks (Ergotron LearnFit) were installed in the intervention classroom two weeks after baseline measurements (November 2015) and traditional classroom stools were retained for use with the new desks. Before the intervention began, pupils and teaching staff were trained by research team members in how to position the desk to the correct height whilst sitting and standing according to the manufacturer's guidelines. Instructional posters were also positioned around the classroom demonstrating correct posture. Within the control group, the teacher continued with normal lesson delivery with no changes to the classroom environment.

5.2.3. Measures

Baseline measures began in autumn (November) 2015 and the study concluded in summer (July) 2016. There were three measurement points during the study; baseline, 4 months (mid-intervention, undertaken in February 2016) and 8 months. The same measures were conducted at each time point by trained research staff in both the intervention and control schools. At baseline, children self-reported their age and ethnicity (after ethnicity was explained to the participant and a subsequent selection was made from a list of 19 different ethnic options i.e. white British, Indian, Mirpuri Pakistani). Self-reported Indian, Mirpuri Pakistani, Pakistani, Bangladeshi and other Asian ethnicities were combined into a South Asian category to be compared with White British children.

5.2.3.1. Sitting time and physical activity

Time spent in different postures (sitting, standing and stepping) during class time, after school and during full week days were measured using an activPAL inclinometer (PAL Technologies Ltd, Glasgow, UK) which was worn for seven consecutive days. To determine time spent in different intensities of PA during class time, school break times, after school and during full week days, participants wore an ActiGraph GT3X triaxial accelerometer (ActiGraph LLC, Pensacola, FL, USA) on the waist above the right hip on a belt (sampling at 100 Hz) during the same seven days as the activPAL. The full details of activPAL and ActiGraph methods used for this study are disclosed in Chapter 3.

5.2.3.2. Anthropometrics

Height (portable stadiometer: Seca UK, Birmingham, UK) and weight (portable electronic weighing scales: Seca model 887) were recorded to the nearest 0.1cm and 0.1kg, respectively, with shoes removed. Waist circumference was measured using flexible steel tape at the narrowest part between the iliac crest and bottom rib to the nearest 0.1cm.

5.2.3.3. Behaviour-related mental health

Mental health was measured using the Strength and Difficulties questionnaire (304), completed by the teachers (see appendix D). The questionnaire assesses five scales; emotional problems, conduct problems, hyperactivity, peer problems, and prosocial behaviour, all distributed randomly across 25 items. Each item includes a statement which is responded to by either selecting ‘not true’, ‘somewhat true’ or ‘certainly true,’ which are coded as 0, 1 and 2 respectively for all but five random items, which are reverse coded. Scores are totalled for each scale and overall (excluding the prosocial scale) and each score is categorised using standardised cut points based on a UK community cohort of 4-17 year olds (304). These cut point categories include ‘close to average’ (0-13), ‘slightly raised’ (14-16), ‘high’ (17-19) and ‘very high’ (20-40) risk of a behavioural disorder. Additionally, conduct and hyperactivity scales are condensed to determine an ‘externalising’ score, and emotional and peer problem scales are combined for an ‘internalising’ score, both out of 20. A higher score suggests a higher risk of a behavioural disorder in these combined scales. This questionnaire, when completed by teachers, has been shown to be a valid measure of children’s behaviour (convergent validity: Pearson correlation coefficient with the Rutter questionnaire = 0.92) (304).

5.2.3.4. Musculoskeletal discomfort

Musculoskeletal discomfort was measured using a seven-item survey, comprising different body parts (neck, back, arms, wrists/hands, hips, legs, ankles/feet) on a 5-point scale, ranging from ‘good’, to ‘OK’ to ‘bad’ feeling of comfort (see appendix E). Each point is represented by a face that reflects each description (e.g. a smiling face for ‘good’) and the participant circles the most representative. This survey has previously been used with children to assess discomfort when using standing desks within the primary school classroom environment (259). Mean discomfort scores for each scale were coded from 1-5 (good to bad) for each body part. Scales from the same region of the body were combined and scores totalled together to produced upper limb (arms and wrists/hands), neck and back, and lower limb (hips, legs and ankles/feet) discomfort scores. All seven scales were also combined to produce an overall mean discomfort score (a mean score across five scales; max score of 5).

5.2.3.5. Cognitive function

Cognitive function was assessed using a battery of two computer-based tests; the Stroop test and the Corsi-Block Tapping test. The Stroop test assesses executive function where participants must correctly select the font colour of a target word, ignoring the actual target colour spelled out. Within a baseline control test, participants correctly select the target colour spelled out, with no font colours included. Reaction time was the key outcome, with the mean baseline reaction time subtracted from the interference reaction time to determine sensitivity to interference. The Corsi-Block Tapping test measures visual spatial working memory capacity. Participants are presented with a 3 x 3 grid of squares and a sequence occurs by individual squares temporarily changing colour in which the participant must accurately repeat. The sequence increases or decreases by 1 with every correctly or incorrectly repeated sequence respectively, with a minimum (and starting sequence) length of 3 and maximum of 12. The key outcome is mean sequence length across 12 attempts. The battery was performed on each child's own school laptop without touch screen application, taking approximately 10 minutes to finish but at each participant's own pace. The battery was completed once per measurement point following a familiarisation attempt the previous day. The tests were completed in silence, in small groups during familiarisation and as an entire group within the classroom during the official data collection period, with support from two trained researchers. These tests have been used in PA-related research with children previously (305,306).

5.2.4. Data management

BMI was calculated (weight (kg) / height (m)^2) and z-scores and percentiles determined using the British 1990 growth references (279). Percentiles were then used to allocate individuals into either an underweight, normal, overweight or obese category, based on the Freeman et al. (1995) thresholds. Waist circumference z-scores were calculated using the NHANES III growth references (307).

5.2.5. Statistical analysis

Statistical analyses were conducted using Stata 15.0 (StataCorp LP., College station, TX, USA). Baseline comparisons were made between the control group and intervention groups (Control v FDA, control v PDA) across demographics (age, sex and ethnicity), activPAL and ActiGraph data, BMI, BMI z-cores, BMI categories, waist circumference z-scores, behaviour-related mental health scores (total score, externalising score and internalising score), musculoskeletal discomfort (full body score and subcategory scores of upper limb, neck and back, and lower limb) and cognitive function (Corsi-Block Tapping test mean sequence length and Stroop test mean reaction time). Categorical data (ethnicity, BMI categories) were compared using Pearson Chi-square tests. Continuous data (all other variables) were checked for normal distributions within baseline control group and intervention group data using Kolmogorov-Smirnov tests prior to baseline comparisons. The Kolmogorov-Smirnov test confirmed both normally distributed and skewed data. Normally distributed data sets were compared between intervention and control classes using independent t-tests. For skewed data, a natural log transformation was applied. Transformed data were then compared between intervention and control classes using independent t-tests. Mean transformed values and confidence intervals were then back transformed and reported in the results. Data that were still skewed following transformations were compared between intervention and control classes using the Wilcoxon signed-rank test, and the median and inter-quartile range reported. Significant differences were detected at baseline in activPAL wear time during class time and full week days between groups ($P < 0.05$). Consequently, minute and frequency data during class time, after school and full week days are reported for descriptive purposes only. To account for differences in wear time, the proportion of wear time spent in different sitting, standing and stepping variables were included in the subsequent analysis.

Due to the longitudinal study design (three measurements over an 8-month period), multi-level modelling was used to determine the influence of the intervention. This study is a pilot study which can be described as a miniature version of a larger scale main trial. Within a main trial, effectiveness of the intervention would be explored within the statistical analysis. Therefore, to mimic the analytical procedure of a full trial, multi-level modelling has been included to account for the longitudinal design of the study. Multi-level modelling would be a potential analytical procedure in a full trial should a longitudinal design be adopted. Multi-level modelling can account for the clustering of children within classrooms within schools (and potentially within geographical locations). This practice (mimicking the analysis of a main trial within a pilot) has recently been outlined within the Stand Out In Class pilot randomised controlled-trial (308).

Multi-level modelling is superior to repeated measures ANOVA analysis because it accounts for between individual variance. It also does not require balanced data (assuming data are missing at random), retaining all observations at each time point and providing greater statistical power. All models were univariate which were fitted to all outcome (dependent) variables of interest: activPAL data (the proportion of wear time spent sitting, standing and stepping, sit-to-stand transitions per hour of wear time and steps-per-minute of wear time during class time, school breaks, after school, and full week days); ActiGraph data (total minutes and the proportion of wear time spent in LPA and MVPA during class time, school breaks, after school and full weekdays); BMI and waist circumference z-scores; behaviour-related mental health (total score, externalising score and internalising score); musculoskeletal discomfort (full body score and upper limb, neck and back, and lower limb subcategory scores); and cognitive function (Corsi-Block Tapping test mean sequence length and Stroop test mean reaction time). The data are structured as occasions (level 1) nested within individuals (level 2).

The following equation was applied in the modelling:

$y^{it} = B^{oi} + B^{1}\text{time point}^{2} + B^{2}\text{time point}^{3} + B^{3}\text{condition} + B^{4}\text{Time point}^{2} \text{ X condition} + B^{5}\text{ Time}^{3} \text{ X condition} + E^{it}$

$B0i = B0 + U0i$

$U^{i} \sim N(0,\sigma_{u}^{2})$

$E^{it} \sim N(0,\sigma_{E}^{2})$

In this equation, y^{it} is the outcome in individual i at time point t, B^{oi} is an intercept comprising a sample-average fixed effect (B) and a level 2 (i.e., individual) random effect (U), B^{1} and B^{2} are binary dummy terms indicating the time point (0=no, 1=yes), B^{3} is a binary term indicating the intervention (0=control group, 1=intervention group) and B^{4} & B^{5} are the interaction between time point and intervention. E^{ij} is a level 1 (measurement occasion) random effect capturing residual error. The U^{i} and E^{ij} are assumed to be independent and normally distributed with zero means and variances ($U^{i} \sim N(0,\sigma_{u}^{2})$, $E^{it} \sim N(0,\sigma_{E}^{2})$)

Within each dependent variable of interest (e.g. proportion of wear time spent sitting during class time), visual data checks were performed in the frequency of observations at each time point in each condition to determine whether any missing data were systematic. If missing data were not interpreted as systematic, models were then built. Firstly, a variance component model (with no explanatory variables included) was built. The variance partitioning coefficient (VPC) statistic was used to determine how much variance is explained by each of the two levels (measurement occasion and individual). A second model was then built that included time points (4 months and 8 months), condition and time-point-by-condition interactions as explanatory variables (see full equation above). Covariates were not included in models due to CONSORT guidelines recommending the use of unadjusted models within trial studies (309). However, since randomisation was not carried out in this trial, where applicable, sensitivity analysis was conducted using variables that were different at baseline between groups as covariates (see appendix G).

Level 1 (measurement occasion) and level 2 (individual) residuals were generated and histograms plotted to explore distributions (normal distribution of residuals is an assumption of the model). Level 1 residuals were then further explored in an attempt to reduce model error; scatter plots were inspected to determine high residual values that suggest poor fitting trajectories of individuals. Participants with high residuals were identified and their original values (i.e. proportion of wear time spent sitting at baseline, 4 months and 8 months) were inspected to observe how these values compare. High residual values were then either deleted or remained within the analysis, depending on the nature of the outcome variable and previous research. For example, sitting and PA behaviour can be somewhat variable from day-to-day (90) and between different seasons of the year in children (291) and therefore considerable tolerance was allowed for high residuals in these outcomes. Other information within the data, if available, was also used to help inform the decision. For example, a low proportion of wear time spent sitting at baseline could be cross-checked with accumulated sitting minutes and standing and stepping data at baseline to determine whether the values combine coherently. If any observations were removed from the analysis, models were then re-fitted, and a comparison of model accuracy was made. These checks include the Wald statistic, the likelihood ratio test, level 1 variance, and the Bayesian Information Criterion (BIC). The Wald statistic should be significant ($P < 0.05$) and the latter three indicators should produce lower values if the new model is a better fit. The level of significance for determining an intervention effect was set at ($P < 0.05$).

5.3. Results

Eighty children (of the ninety-two children (74%) present across the three year 5 classes within the intervention and control schools) had parental consent to take part in the study; 28 in the control group, 27 in the FDA group and 25 in the PDA group. Sixty-eight of these participants (85%) provided valid activPAL data at baseline; 27 (96%) in the control group, 22 (81%) in the FDA group and 19 (76%) in the PDA group. All outcome variable data from these 68 participants were subsequently included in the analysis and are reported in the results.

5.3.1. ActivPAL and ActiGraph data

Outcome variable compliance of all 68 participants is detailed in Table 5.5. Overall, data compliance was highest at baseline, declined at 4 months and stabilised at 8 months across measurements in all three groups. Compliance was lowest for ActiGraph data (Control 68-71%, FDA 59-78%, PDA group 40-68%), followed by activPAL data (Control 75-96%, FDA 56-81%, PDA group 48-76%). The control group provided a higher proportion of valid data in all outcome variables at every time point compared to the intervention groups except for the ActiGraph data compared to the FDA group at baseline (-7%) and 4 months (-6%) and activPAL data at 4 months compared to the PDA group (-1%). activPAL data compliance was 15% and 20% higher at baseline, 12% higher and 1% lower at 4 months and 23% and 31% higher at 8 months in the control group compared to the FDA and PDA groups, respectively.

Table 5.5. Data compliance in outcome measures at the three-measurement time-points based on the proportion of participants who wore activPAL monitors at baseline. Data presented as % (n)

	Control [a]						FDA [b]						PDA [c]					
	B		4 Months		8 Months		B		4 Months		8 Months		B		4 Months		8 Months	
	%	*N*	%	*N*	%	*N*	%	*N*	%	*N*	%	*N*	%	*N*	%	*N*	%	*N*
activPAL	96	27	75	21	79	22	81	22	63	17	56	15	76	19	76	19	48	12
ActiGraph	71	20	68	19	75	21	78	21	74	20	59	16	68	17	64	16	40	10

FDA, full desk allocation; PDA, partial desk allocation

[a] 28 participants wore activPAL monitors at baseline

[b] 27 participants wore activPAL monitors at baseline

[c] 25 participants wore activPAL monitors at baseline

5.3.2. Anthropometrics, behaviour-related mental health, musculo-skeletal discomfort and cognitive function

Table 5.6 details data compliance for secondary outcomes. These are based on the total sample of children that wore activPAL monitors at baseline (see Table 5.5); the measurement for the primary outcome of sitting time. Overall, data compliance in secondary outcomes was highest at baseline, declined at 4 months and stabilised at 8 months across secondary outcome measures in all three groups (Table 5.6). Compliance was higher in the control group compared to both intervention groups in anthropometrics, behaviour-related mental health and musculoskeletal discomfort outcomes at each time point (control 64-71%, FDA 63-74%, PDA 0-76%) but not in cognitive function compared to the FDA group (Table 5.6). The PDA group had the lowest compliance across all outcomes at every time point except in musculoskeletal discomfort at 4 months and cognitive function at baseline and 4 months. Across all three groups, compliance was lowest in cognitive function (control 64-71%, FDA 63-74%, PDA 52-76%), although no behaviour related mental health data was provided from the PDA group at 8 months, but this was due to the data being lost by the teacher rather than data compliance by the class. There was little difference between the remaining outcome measures (combined group data: anthropometrics 72-96%, behaviour-related mental health 76-96% (when data was provided), musculoskeletal discomfort 76-96%).

Table 5.6. Data compliance in secondary outcome measures, at the three measurement time-points, based on the proportion of participants who wore activPAL monitors at baseline. Data presented as % (n)

	Control [a]						**FDA [b]**						**PDA [c]**					
	Baseline		**4 Months**		**Baseline**		**Baseline**		**4 Months**		**8 Months**		**Baseline**		**4 Months**		**8 Months**	
	%	***N***	**%**	***N***	**%**	***N***	**%**	***N***	**%**	***N***	**%**	***N***	**%**	***N***	**%**	***N***	**%**	***N***
Anthropometrics	96	27	81	25	93	26	81	22	78	21	78	21	76	19	76	19	72	18
Behaviour-related mental health	96	27	81	26	89	25	81	22	74	20	81	22	76	19	76	19	0	0
Musculoskeletal discomfort	96	27	81	25	93	26	81	22	81	22	78	21	76	19	76	19	72	18
Cognitive function	71	20	74	18	68	19	74	20	63	17	63	17	76	19	64	16	52	13

FDA, full desk allocation; PDA, partial desk allocation

[a] 28 participants wore activPAL monitors at baseline

[b] 27 participants wore activPAL monitors at baseline

[c] 25 participants wore activPAL monitors at baseline

5.3.3. Baseline comparisons

5.3.3.1. ActivPAL and ActiGraph data

Baseline comparisons between control and intervention groups in activPAL and ActiGraph data are detailed in Table 5.7. The FDA group contained a significantly lower proportion of South Asian children (-43%, *P* <0.01), a higher proportion of White British children (+42.3%, *P* <0.01), higher activPAL wear time during class time (+4.9mins, *P* <0.05) and full weekdays (+49.9mins, *P* <0.01), higher total minutes (+5.9 mins, *P* <0.01) and proportion of ActiGraph wear time during school breaks spent in MVPA (10+.3%, *P* <0.05). No other significant differences were observed between groups.

Compared to the control group, the PDA group had significantly less class time wear time (-4.9%, P <0.01), a lower proportion of class time wear time spent sitting (-10.9%, P <0.01), a lower proportion of class time wear time spent standing (10+.6%, P <0.01) greater class time sit-to-stand transitions per hour (+2.2, P <0.01), higher after school wear time (+27.1 mins, P <0.05), higher full day wear time (+39.7%, P <0.05), a lower proportion of wear time spent sitting during a full day (-9.3%, P <0.05) a higher proportion of wear time spent standing during a full day (+9.4%, P <0.05), less class time spent sedentary (ActiGraph) in minutes and as a proportion of wear time (-16.2 mins, P <0.05; -5.1%, P <0.05), greater class time LPA both as minutes and as a proportion of wear time (+20.2 mins, P <0.05; 7.3%, P <0.01), a lower proportion of wear time spent stationary (ActiGraph) during school break times (-13.0%, P <0.01), higher counts per minute (ActiGraph) during school break times (+285.7, P <0.05), lower full day stationary time (ActiGraph) as a proportion of wear time (-3.7%, P <0.05) and a higher proportion of full day wear time spent in LPA (+4.7%, P <0.05).

Table 5.7. Comparison of baseline characteristics between the control and intervention groups; full desk allocation (FDA) and partial desk allocation (PDA). Data presented as mean (SD) unless stated otherwise.

Descriptives	**Control**	**FDA mean**	***P*-Value vs control**	**PDA mean**	***P*-Value vs control**
N	27	22		19	
Age, years	9.7 (0.4)	9.8 (0.3)	0.66	9.8 (0.3)	0.63
Boys, %	46.2	50.0	0.79	42.1	0.69
Ethnicity					
South Asian, *N* (%)	88.5	45.5	**<0.01**	63.2	0.09
White British, *N* (%)	7.7	50	**<0.01**	31.6	0.33
Other, *N* (%)	3.8	4.5	0.90	5.3	0.77
activPAL data					
Valid week days, *N* †	6.0 (2.0)	5.0 (0.3)	0.23	5.0 (2.0)	0.56
Class time wear time, mins/day †	309.9 (21.3)	305.0 (5.5)	**<0.01**	305.0 (10.4)	**<0.01**
Class time sitting, % of wear time	73.9 (1.8)	70.4 (2.9)	0.28	63.0 (13.0)	**<0.01**
Class time standing, % of wear time	17.2 (7.6)	21.5 (10.9)	0.11	27.8 (11.0)	**<0.01**
Class time stepping, % of wear time †	9.0 (2.8)	8.8 (2.8)	0.57	9.0 (3.1)	0.80
Class time sitting 5-10 min bouts, % of wear time	11.6 (5.0)	14.0 (4.4)	0.09	12.1 (3.8)	0.73

Descriptives	Control	FDA mean	*P*-Value vs control	PDA mean	*P*-Value vs control
Class time sitting 10+ min bouts, % of wear time	38.8 (11.1)	35.5 (11.1)	0.33	32.8 (11.1)	0.08
Class time sit-to-stand transitions, p/h of wear time	7.1 (2.5)	8.4 (3.0)	0.09	9.3 (1.7)	**0.002**
Class time steps, per minute of wear time †	6.9 (2.0)	6.3 (1.4)	0.05	6.5 (2.0)	0.55
After school wear time, mins/day	394.6 (42.6)	424.2 (26.4)	0.07	421.7 (34.1)	**0.03**
After school sitting, % of wear time	69.7 (11.7)	70.6 (7.1)	0.74	66.3 (6.7)	0.27
Full day wear time, mins/day †	892.1 (59.2)	942.0 (40.9)	**<0.01**	931.8 (103.7)	**0.02**
Full day sitting, % of wear time	72.9 (3.8)	68.3 (1.9)	0.32	63.6 (6.3)	**0.03**
Full day standing, % of wear time	12.9 (4.6)	12.6 (4.4)	0.45	22.3 (5.3)	**0.02**
Full day stepping, % of wear time †	12.9 (4.2)	13.8 (5.0)	0.70	13.4 (5.1)	0.23
Full day sitting in 5-10 min bouts, % of wear time	9.4 (3.3)	10.3 (3.0)	0.31	9.7 (1.7)	0.73
Full day sitting in 10+ min bouts, % of wear time	42.3 (6.2)	41.8 (5.9)	0.76	39.2 (7.2)	0.13
Full day sit-to-stand transitions, p/h of wear time †	5.9 (2.0)	6.9 (1.5)	0.13	6.9 (1.0)	0.12
Full day steps, per minute of wear time †	10.3 (2.6)	10.6 (3.6)	0.93	10.3 (4.0)	1.00
ActiGraph data (8 observations missing; 7 control (n= 22), 1 FDA (n=21), PDA group (n=17))					
Class time wear time, mins/day †	310.0 (53.8)	288.0 (26.0)	0.08	301.0 (7.5)	0.13
Class time stationary time, mins/day	196.4 (21.2)	184.8 (21.5)	.091	180.2 (21.4)	0.02

Descriptives	Control	FDA mean	*P*-Value vs control	PDA mean	*P*-Value vs control
Class time stationary time, % wear time	66.2 (6.5)	64.4 (8.5)	.446	61.1 (8.5)	0.046
Class time LPA, mins/day	87.0 (5.4)	95.0 (6.0)	0.33	107.2 (25.3)	0.02
Class time LPA, % of wear time	28.8 (1.3)	32.7 (1.8)	0.09	36.1 (7.7)	<0.01
Break times stationary time, mins/day	24.3 (4.9)	22.2 (5.6)	.220	19.3 (6.3)	0.05
Break times stationary time, % wear time	42.1 (10.0)	28.0 (7.3)	**.000**	29.1 (5.8)	**<0.01**
Break times counts per minute †	875.3 (378.6)	1129.3 (943.0)	**.000**	1161.0 (463.5)	**0.03**
Break times at school MVPA, mins/day *	11.5 (9.9, 13.3)	17.4 (14.8, 20.6)	**<0.01**	16.0 (14.2, 19.5)	**0.08**
Break times at school MVPA, % of wear time †	36.2 (18.5)	46.5 (44.7)	**0.03**	22.0 (19.5, 26.7)	0.44
After school wear time, mins/day	329.1 (56.1)	283.0 (90.8)	0.06	315.0 (51.8)	0.44
After school stationary time, mins/day	175.1 (33.2)	162.0 (55.0)	.361	163.1 (37.7)	0.31
After school stationary time, % wear time	53.4 (7.0)	55.2 (8.6)	.481	51.5 (5.9)	0.38
After school counts per minute	576.1 (151.3)	583.5 (234.3)	.906	569.6 (132.0)	0.90
After school LPA, mins/day *	116.1 (104.0, 129.5)	94.4 (79.3, 112.4)	0.05	115.0 (108.3, 136.7)	0.88
After school LPA, % of wear time *	35.7 (33.6, 38.0)	34.1 (31.8, 36.6)	0.30	39.0 (36.0, 41.3)	0.42
After school MVPA, mins/day	34.9 (14.3)	28.4 (12.7)	0.13	29.7 (9.0)	0.20
After school MVPA, % of wear time *	2.30 (2.12, 2.47)	2.22 (2.00, 2.44)	0.58	9.0 (7.9, 11.4)	0.84

Descriptives	**Control**	**FDA mean**	***P*-Value vs control**	**PDA mean**	***P*-Value vs control**
Full day wear time, mins/day	744.4 (17.3)	709.5 (17.3)	0.16	737.0 (50.3)	0.74
Full day stationary time, mins/day	421.8 (45.1)	397.8 (65.1)	.180	391.9 (49.6)	0.06
Full day stationary time, % wear time	56.9 (5.8)	56.2 (7.0)	.696	53.2 (5.2)	**0.048**
Full day counts per minute	525.1 (107.5)	526.4 (131.5)	.972	512.9 (91.9)	0.72
Full day LPA, mins/day *	26.3 (223.9, 270.9)	243.4 (221.2, 267.8)	0.86	283.0 (262.1, 305.5)	0.42
Full day LPA, % of wear time *	33.3 (31.3, 35.3)	34.5 (32.1, 37.1)	0.41	38.0 (36.1, 41.1)	**0.03**
Full day MVPA, mins/day	71.4 (4.8)	62.9 (4.4)	0.20	61.5 (15.2)	0.12
Full day MVPA, % of wear time *	9.9 (8.4, 11.8)	9.2 (7.4, 11.5)	0.58	9.0 (7.3, 9.6)	0.39

P-values are obtained using two-sample t-tests or Pearson chi-square tests as appropriate.

† Data represent the median and interquartile ranges due to skewed distributions that were not corrected after transformations. The Wilcoxon-signed rank test was used to compare values.

* Mean value and confidence intervals taken from log transformed data which were then back transformed. Data compared using independent t-tests.

LPA, light intensity physical activity; MVPA, moderate-to-vigorous physical activity; p/h, per hour

5.3.3.2. Anthropometrics, behaviour-related mental health, musculoskeletal discomfort and cognitive function

The FDA group reported a significantly higher externalising mental health score compared to the control group at baseline (Table 5.8; +2.5, *P* <0.05). The PDA group contained a significantly higher proportion of overweight participants (30+.6%, *P* <0.05) and reported a significantly higher musculoskeletal discomfort score for the neck and back (+1.0, *P* <0.05) compared to the control group. No other significant differences were observed between groups in secondary outcomes at baseline (*P* >0.05).

Table 5.8. Comparison of baseline characteristics between the control and full desk allocation (FDA) and partial desk allocation (PDA) groups in secondary outcomes. Data presented as mean (SD) unless otherwise stated.

Outcomes	**Control**	**FDA**	***P*-value FDA vs Control**	**PAR**	***P*-value PDA vs Control**
N	27	22		19	
Age, years	9.7 (0.4)	9.8 (0.3)	0.66	9.8 (0.3)	0.63
Boys, %	46.2	50.0	0.79	42.1	0.69
Waist circumference z-score	0.28 (0.86)	0.32 (0.83)	0.87	0.6 (0.5)	0.15
BMI z-score (kg/m^2)	0.40 (1.35)	0.34 (1.42)	0.90	1.06 (0.67)	0.07
BMI categories (%)					
% Underweight	3.9	9.1	0.45	0.0	0.40
% Normal weight	61.5	63.6	0.88	47.4	0.43
% Overweight	11.5	13.6	0.83	42.1	**0.02**
% Obese	23.1	18.2	0.67	10.5	0.20
Behaviour-related mental health					
Total score, max score of 40	7.6 (5.1)	9.6 (5.9)	0.22	7.3 (5.0)	0.92
Externalising, max score of 20 †	3.0 (4.0)	5.5 (5.0)	**0.04**	3.0 (7.0)	0.77
Internalising, max score of 20 †	3.0 (2.0)	3.0 (5.3)	0.73	2.0 (2.0)	0.84
Musculoskeletal discomfort					

Outcomes	Control	FDA	*P*-value FDA vs Control	PAR	*P*-value PDA vs Control
Whole body, mean of all scales *	1.9 (1.8, 2.2)	1.8 (1.5, 2.1)	0.40	2.1 (1.8, 2.7)	0.27
Upper limb, sum score †	4.0 (2.0)	3.0 (2.0)	0.07	3.0 (4.0)	0.93
Neck and back, sum score †	4.0 (3.0)	3.0 (2.0)	0.43	5.0 (5.0)	**0.03**
Lower limb, sum score	6.5 (0.5)	6.3 (0.5)	0.76	6.8 (2.9)	0.65
Cognitive function					
Stroop test, reaction time (ms) † Control n=20, FDA n=20, PDA n=19	497.0 (239.0)	441.5 (235.0)	0.82	477.0 (228.0)	1.00
Corsi Block Tapping test, score out of 12 Control n=25, FDA n=22, PDA n=19	4.2 (1.4)	4.4 (1.3)	0.52	4.5 (0.8)	0.49

P-values are obtained using two-sample t-tests or Pearson chi-square tests as appropriate.

† Data represent the median and interquartile ranges due to skewed distributions that were not corrected after transformations. The Wilcoxon-signed rank test was used to compare values.

* Mean value and confidence intervals taken from log transformed data which were then back transformed. Data compared using independent t-tests.

BMI, body mass index

5.3.4. Intervention effects

5.3.4.1. Sitting time and physical activity

5.3.4.1.1. Class time

Full allocation group compared to control group

The FDA Intervention effects from multi-level models during class time from activPAL data are presented in Figure 5.5, panels A and B. The intervention group demonstrated a significantly lower proportion of wear time spent sitting than the control group at 4 months (β (95%CI) -25.3% (-32.3, -18.4), *P* <0.0005) which reduced marginally at 8 months but still remained highly significant (β (95% CI) -19.9% (-27.05, -12.9), *P* <0.0005). A highly significant reduction was also observed in the proportion of wear time spent sitting in 10+ minute bouts at 4 months (β (95% CI) -17.4% (-24.0, -10.7), *P* <0.0005) which then increased further at 8 months (-29.0% (-35.8, -22.1), *P* <0.0005) in the intervention group compared to the control group. The proportion of wear time spent sitting in bouts of 5-10 minutes also reduced significantly at 4 months (β (95% CI) -5.3% (-7.87, -2.7), *P* <0.0005) but this was not significant at the final measurement point in the intervention group compared to the control group (-0.6% (-3.6, 2.0), *P* >0.05).

Within the standing and stepping variables (Figure 5.5, panel C and D), at 4 months there were significant increases in the proportion of wear time spent standing (β (95% CI) +25.7% (19.9, 31.6), *P* <0.0005) and the number of sit-to-stand transitions per hour of wear time (+2.9 (1.3, 4.5), *P* <0.0005), in the intervention group compared to the control group during class time. Conversely, there was no difference in the proportion of wear time spent stepping (-0.3% (-2.3, 1.8), *P* >0.05), and a decrease in the number of steps per minute of wear time (-1.6 (-3.0, -0.2), *P* <0.05) in the intervention group compared to the control group. At 8 months, the intervention effect for the proportion of wear time spent standing reduced but remained highly significant (+17.8% (11.9, 23.8), *P* <0.0005). The number of sit-to-stand transitions per hour of wear time increased further at 8 months in the intervention group compared to the control group (+4.6 (3.0, 6.2), *P* <0.0005). The proportion of wear time spent stepping became significantly higher in the intervention group compared to the control group at the final follow up (+2.2% (0.2, 4.3), *P* <0.05). No intervention effect was observed in the number of steps per minute of wear time at 8 months (+0.9 (-0.6, 2.3), *P* >0.05).

Within the ActiGraph data (Table 5.18), the FDA group engaged in significantly less stationary minutes and proportion of wear time spent stationary at both 4 months and 8 months (minutes: 4 months -20.0 mins (-35.0, -5.1), *P* <0.05; 8 months -31.2 mins (-46.5, 16.0), *P* <0.0005; proportion of wear time spent stationary: 4 months -5.9% (-10.9, -0.9), *P* <0.05; 8 months -10.1% (-15.4, 5.0), *P* <0.0005). The total minutes and proportion of wear time spent in LPA during class time was significantly higher at 4 months (minutes β (95% CI) +23.9mins (7.7, 40.0), *P* <0.005; proportion of wear time +8.8% (4.4, 13.3), *P* <0.0005) and 8 months (minutes β (95%CI) +29.1mins (12.8, 45.5), *P* <0.0005; proportion of wear time +9.9% (5.3, 14.4), *P* <0.0005) in the intervention group compared to the control group. The total minutes and proportion of wear time spent in MVPA was significantly lower at baseline (minutes -6.60 (-9.67, -3.52) *P* <0.0005); proportion of wear time -2.07 (-3.00, -1.13) *P* <0.005) and at 4 months (minutes -6.86 (-9.98, -3.73) *P* <0.0005); proportion of wear time -2.18 (-3.14, -1.22) *P* <0.0005) but not at 8 months (both *P* >0.05) in the intervention group compared to the control group.

Partial allocation group compared to control group

The PDA group Intervention effects from multi-level models during class time from activPAL data are presented in Table 5.15. Wear time was significantly lower in the PDA group compared to the control group at baseline and 4 months but not at 8 months (β (95%CI) -25.3 mins (-15.7, -5.5), *P* <0.0005, 4 months; -30.4 mins (-41.7, -19.1), *P* <0.0005, 8 months; *P* >0.05). The proportion of wear time spent sitting was significantly lower in the PDA group at baseline (β (95%CI) -5.5% (-8.5, -2.4), *P* <0.0005) but not at 4 and 8 months compared to the control group (*P* >0.05). The proportion of wear time spent standing was significantly higher in the PDA group at baseline ((β (95%CI) 5.3% (2.8, 7.8), *P* <0.0005) and at 4 months (β (95%CI) 4.9% (0.7, 9.2), *P* <0.05) but not at 8 months (*P* >0.05). The proportion of wear time spent stepping was significantly lower at 4 months in the PDA group only compared to the control group (β (95%CI) -2.9% (-4.6, -1.2), *P* <0.001). The proportion of wear time spent sitting in bouts of 5-10 mins was also significantly lower at 4 months in the PDA group (β (95%CI) -3.2% (-5.7,

-0.8), *P* <0.01) but not at 8 months (*P* >0.05). The proportion of wear time spent sitting in bouts of 10+ mins was significantly lower at 8 months in the PDA group compared to the control group (β (95%CI) -13.0% (-21.1, -5.0), *P* <0.005) but not at 4 months (*P* >0.05). Steps per minute of wear time was significantly lower at 4 months (β (95%CI) -2.7% (-4.0, -1.4), *P* <0.0005) but not 8 months (*P* <0.05). Sit-to-stand transitions per hour of wear time was significantly higher in the PDA group at baseline compared to the control group (+1.1 (0.4, 1.7), *P* <0.005), with no difference between groups at 4 and 8 months (P >0.05).

Within the ActiGraph data (Table 5.19), stationary minutes and the proportion of wear time spent stationary were significantly lower in the PDA group compared to the control group at baseline (mins: β (95%CI) -7.8 mins (-14.8, -0.8), *P* <0.05; proportion of wear time: -2.4% (-4.7, -0.1), *P* <0.05), but not at 4 and 8 months (*P* >0.05). LPA mins and the proportion of wear time spent in LPA was significantly higher also at baseline in the PDA group compared to the control group (mins: 9.6 mins (2.0, 17.1), *P* <0.05; proportion of wear time: 3.5% (1.5, 5.5), *P* <0.05), with no difference at 4 and 8 months in both variables (*P* >0.05). MVPA mins during class time were significantly lower in the PDA group compared to the control group at baseline and 4 months (-3.2 mins (-4.79, -1.57), *P* <0.0005, 4 months; -9.5 mins (-12.2, -6.8), *P* <0.0005) but not at 8 months (P >0.05). The proportion of wear time spent in MVPA was also significantly lower at baseline and 4 months (-1.1% (-1.6, -0.6), *P* <0.0005, 4 months; -2.9% (-3.8, -2.0), *P* <0.0005) but not at 8 months follow up (*P* >0.05).

5.3.4.1.2. Break times at school

Full allocation group compared to control group

Within activPAL data, there were no differences between groups in the proportion of wear time spent sitting, standing, stepping or steps per minute of wear time at any time point during school break times (*P* >0.05). The only exceptions were at 8 months in the proportion of wear time spent stepping (β (95%CI); -9.25% (-17.53, -0.96), *P* <0.05) and steps per minute of wear time (-8.7% (-16.0, -1.50), *P* <0.05) where the intervention group reported significantly lower values in both outcomes compared to the control group.

Table 5.18 details multi-level model estimates in ActiGraph data during school break times. The FDA group engaged in significantly more sedentary minutes at 4 months follow up compared to the control group (+4.0 mins (0.8, 7.2) *P* <0.05) with no difference at 8 months (P >0.05). The proportion of wear time spent sitting was significantly lower in the FDA group at all 3 measurement phases (-14.1% (-18.7, -9.4); 4 months: -7.3 (-12.1, -2.6); 8 months: -7.9 (-12.7, -3.0); all *P* <0.0005). Counts per minute were significantly greater in the FDA group at baseline (+396.0 (196.1, 595.8), *P* <0.0005) compared to the control group, with no difference between groups at 4 and 8 months (P >0.05). The intervention group demonstrated a significantly higher proportion of wear time spent in LPA at baseline (+12.4% (6.1, 18.7) *P* <0.0005) and both follow ups compared to the control group (4 months: +11.0 (4.6, 17.4) *P* <0.01); 8 months: +7.7 (1.1, 14.3) *P* <0.05). At baseline, the intervention group demonstrated a significantly higher estimates for the proportion of wear time spent in MVPA compared to the control group during school break times (+6.9% (2.0, 11.8), *P* <0.01). At 4 months this variable was significantly lower in the intervention group compared to the control group (-6.2% (-11.2, -1.3), *P* <0.05) but not at 8 months (*P* >0.05).

Partial allocation group compared to control group

Within activPAL data, the PDA group engaged in a significantly lower proportion of wear time spent sitting at baseline (-5.7% (-10.1, -1.4), P <0.01), no difference at 4 months (P >0.05), and a significantly higher amount at 8 months follow up (20.9% (9.9, 31.9), P <0.0005) compared to the control group (Table 5.15). There was a significantly lower proportion of wear time spent standing at 8 months in the PDA group compared to the control group (-6.9% (-12.0, -1.9), P <0.01) but not at 4 months (P >0.05). The proportion of wear time spent stepping was significantly higher at baseline (4.7% (1.4, -8.0), P <0.01) and significantly lower at 4 and 8 months follow up (4 months: -7.0% (-14.9, -0.5), *P* <0.05; 8 months: -14.1% (-22.3, -5.9), *P* <0.005) in the PDA group compared to the control group. Similarly, steps-per-minute were significantly higher at baseline (4.4 (1.5, 7.3), P <0.005) but lower at both follow ups in the PDA group (4 months: -7.0 (-12.9, -0.5), *P* <0.05; 8 months: -12.5 (-19.5, -5.4), *P* <0.005).

Within ActiGraph data (Table 5.19), wear time was significantly higher in the PDA group compared to the control group at all three time points (β (95%CI) 6.6 mins (6.0, 7.3); 4 months: 2.9 mins (1.4, 4.4); 8 months: 4.0 (2.3, 5.60), all P <0.0005). Stationary minutes were significantly higher in the PDA group at both follow ups (4 months: 7.0 mins (3.8, 9.4), P <0.0005; 8 months: 5.2 (2.0, 8.3), P <0.005). Conversely, the proportion of wear time spent stationary, and counts per minute (cpm), were significantly lower and higher at baseline, respectively (stationary time -6.4% (-8.7, -4.10), P <0.0005; cpm 122.7 (37.6, 207.9), P <0.01) at baseline in the PDA group, yet no differences were observed between groups at both follow ups in both variables (P >0.05). The proportion of wear time spent in LPA was significantly lower in the PDA group compared to the control group across all three measurement points (-4.3% (-6.8, -1.9), P <0.005; 4 months: -11.4 mins (-16.5, -6.3), P <0.0005; 8 months: -11.3 (17.0, 5.6, P <0.0005). The proportion of wear time spent in MVPA was also significantly lower at both follow ups in the PDA group (4 months: -10.9 mins (-14.7, -7.0), P <0.0005; 8 months: -5.7 (-10.0, -1.4, P <0.05)

5.3.4.1.3. After school time

Full allocation group compared to control group

At all three measurement points the intervention group recorded a higher proportion of activPAL wear time spent sitting in comparison to the control group from multi-level model estimates but these differences were not significant (β (95% CI); baseline +1.0% (-4.7, 6.7); 4 months +3.7% (-2.5, 9.9); 8 months +1.3% (-5.2, 7.8), all *P* >0.05). There were no differences observed in the proportion of wear time spent standing or stepping between the intervention and control groups at each time point (*P* >0.05). The intervention group reported significantly lower steps-per-minute of wear time compared to the control group at 4 months (-3.1 (-6.0, -0.1) *P* <0.05) but not 8 months (*P* >0.05).

Within the ActiGraph data (Table 5.18), there was no intervention effect in stationary minutes (P >0.05) during the after-school period. The FDA group, however, engaged in a significantly greater proportion of wear time spent stationary at both 4 months and 8 months (4 months -7.1% (1.7, 12.4), *P* <0.01; 8 months 5.9% (0.5, 11.4), *P* <0.05). Counts per minute (cpm) were significantly lower in the FDA group compared to the control group at both 4 months and 8 months (4 months -133.6 (-261.4, -5.9), *P* <0.05; 8 months -142.0 (-273.4, -10.6), *P* <0.05). No intervention effects were observed in the proportion of wear time spent in LPA (*P* >0.05). Children in the intervention group spent a lower proportion of wear time in MVPA at all time points compared to the control group, but only significantly at 8 months (baseline -0.4% (-3.0, 2.2); 4 months -1.4% (-4.1, 1.3), both *P* >0.05; 8 months -3.5% (-6.3, -0.7), *P* <0.05).

Partial allocation group compared to control group

Within the activPAl data (Table 5.15), there was no difference between groups in the proportion of wear time spent sitting or standing (*P* >0.05) during the after school period. The PDA group demonstrated significantly less wear time spent stepping at 8 months -3.7% (-7.4, -0.03), *P* <0.05), with no difference between groups at 4 months (*P* >0.05). There were no differences between groups in steps-per-minute at all three time points (P >0.05).

Within the ActiGraph data (Table 5.19), there was no difference between groups in after school wear time and stationary minutes at all three measurement phases (*P* >0.05). The PDA group demonstrated a significantly greater proportion of wear time spent stationary, and significantly less counts per minute, at 8 months (proportion of wear time stationary 6.2% (0.8, 11.6), *P* <0.05; cpm -159.0 (-299.2, -119.1), *P* <0.05) but not at 4 months in either variable (*P* >0.05). There was no difference between groups in the proportion for wear time spent in LPA across measurement phases (*P* >0.05), However, the proportion of wear time spent in MVPA was significantly lower in the PDA group at both follow ups (4 months -2.5% (-1.5, 0.3), *P* <0.0005; 8 months -1.6% (-3.5, -0.1), *P* <0.05).

5.3.4.1.4. Full week day

Full allocation group compared to control group

Intervention effects from multi-level models during waking hours on an average week day from the activPAL data are presented in Figure 5.6. Within the sitting variables (panels A and B), at 4 months intervention effects were observed in the proportion of wear time spent sitting in total (β (95% CI); -7.7% (-12.8, -2.6) *P* <0.005) and in bouts of 5-10 minutes (-1.8% (-3.4, -0.15) *P* <0.05), but not in the proportion of wear time spent sitting in bouts of 10+ minutes (-4.0% (-8.6, 0.7) $P > 0.05$). At 8 months, the proportion of wear time spent sitting was still significantly lower in the intervention group but the difference between groups had reduced (-5.5% (-10.8, -0.2) $P < 0.05$). At 8 months no intervention effect was observed in sitting bouts of 5-10 minutes (-0.3% (-2.0, 1.4) $P > 0.05$) but significant effects were observed for wear time spent sitting in bouts of 10+ minutes at the final follow up (-7.4% (-12.3, 2.5) $P < 0.05$).

For the standing and stepping variables (Figure 5.6, panels C and D), at 4 months the intervention group spent a significantly greater proportion of wear time standing compared to the control group (β (95% CI); +8.8% (5.2, 12.4) $P < 0.0005$) and exhibited more sit-to-stand transitions per hour of wear time (+1.4 (0.4, 2.5) $P < 0.01$). At 8 months the intervention effect reduced in time spent standing but remained significant (+5.8% (2.0, 9.5) $P < 0.005$) and remained higher in the intervention group compared to the control group for sit-to-stand transitions per hour of wear time (+1.4% (0.3, 2.4) $P < 0.05$). No differences between groups were observed in the proportion of wear time spent stepping or in steps-per-minute of wear time at 4 months or 8 months (stepping: 4 months -0.9% (-3.4, 1.7); 8 months -0.2% (-2.8, 2.4); steps p/min wear time: 4 months -0.9% (-3.1, 1.3); 8 months -0.4% (-2.5, 1.8), all $P > 0.05$).

In multi-level model estimates for ActiGraph data (Table 5.18), no intervention effects were observed for stationary minutes and the proportion of wear time spent stationary ($P > 0.05$) during a full week day. Counts per minute were significantly lower in the FDA group compared to the control group at 4 months (-87.0 (-159.4, -14.1), $P < 0.05$) but no difference was observed at 8 months ($P > 0.05$). The intervention group recorded marginally higher total minutes and proportion of wear time spent in LPA at 4 months and 8 months during a full week day but these differences were not significant (total minutes: 4 months +15.6 mins (-14.6, 45.8); 8 months +5.8 mins (-24.9, 36.4); proportion of wear time: 4 months +2.8% (-0.2, 5.9); 8 months +2.8% (-0.2, 5.9), all $P > 0.05$). Total accumulated MVPA minutes were lower in the intervention group compared to the control group at baseline but not significantly (β (95% CI); -7.9 mins (-20.2, 4.4) $P > 0.05$). This difference between groups increased at 4 months to a significant difference (-17.6 mins (-30.1, -5.2) $P < 0.01$) and then reduced at 8 months but still remained significant (-14.8 mins (-27.4, -2.2) $P < 0.05$).

Within descriptive ActiGraph data (Table 5.16), both groups at each time point exceeded 60 (median) minutes a day of MVPA. The control group at baseline (n=20) recorded 71.1 mins (IQR 38.1), this increased by 9.9 minutes at 4 months (81.0 mins (32.3), n=19) and then increased further by 12.0 minutes at 8 months (93.0 mins (25.3), n=21). The intervention group at baseline (n=21) recorded 61.8 mins (IQR 24.4), this increased by 8.1 mins at 4 months (69.9 mins (28.7), n=20) and increased further by 4.6 mins at 8 months (74.5 mins (13.0), n=16).

Partial allocation group compared to control group

ActivPAL data for full waking hours is presented in Table 5.15. Wear time was significantly lower in the PDA group compared to the control group at 4 months (β (95% CI); -59.6mins (-105.7, -13.5) $P < 0.05$) but not at baseline or 8 months ($P > 0.05$). The proportion of wear time spent sitting was significantly lower at baseline in the PDA group (-2.9% (-5.3, -0.5) $P < 0.05$) but not at either follow-up point ($P > 0.05$). The proportion of wear time spent standing was significantly higher in the PDA group compared to the control group at baseline (2.2% (0.6, 3.9), $P < 0.01$). The proportion of wear time spent stepping was significantly lower in the PDA group (-2.7% (-4.9, -0.4), $P < 0.05$) at 4 months but not 8 months ($P > 0.05$). The proportion of wear time spent sitting in bouts of 5-10mins was significantly lower in the PDA group at 4 months (-3.2% (5.7, -0.8), $P < 0.005$) but not 8 months ($P < 0.05$). The proportion of wear time spent sitting in bouts of 10+ mins was significantly lower in the PDA group at 8 months (-13.0% (-21.1, -5.0), $P < 0.005$) but not at 4 months ($P < 0.005$). There were no differences between groups in Steps per minute of wear time sit-to-stand transitions per hour of wear time ($P > 0.05$).

Within the ActiGraph data (Table 5.19), there were no differences between groups in stationary minutes or the proportion of wear time spent stationary at 4 months or 8 months ($P > 0.05$). There was a significant difference in counts per minute at months in the PDA group compared to the control group (-133.9 CPM (-196.8, -70.9), $P < 0.0005$) but not at 4 or 8 months ($P > 0.05$). The PDA group had significantly higher minutes spent in LPA and the proportion of wear time spent in LPA at baseline (min: 17.2 mins (3.5, 30.9), $P < 0.05$; proportion of wear time: 2.5% (1.1, 3.8), $P < 0.0005$) but not at 4 and 8 months (P >0.05). The PDA group demonstrated significantly less MVPA minutes and a proportion of wear time spent in MVPA at both follow ups (minutes: 4 months -

20.1 mins (-30.7, -9.4), *P* <0.0005; 8 months -13.1 mins (-25.0, -1.3), *P* <0.05; proportion of wear time: 4 months -2.5% (-3.9, -1.2), *P* <0.0005; 8 months -1.6% (-3.2, -0.1), *P* <0.05).

Within descriptive ActiGraph MVPA data (Table 5.17), the PDA group at baseline (n=17) recorded 57.0 median minutes (IQR 24.5), which reduced by 1.0 mins at 4 months (56.0 mins (34.0), n=16) and then increased by 18.5 mins at 8 months (72.5 mins (26.0), n=10). At each time point, these values were lower than the control group by 14.1 mins (baseline), 25.0 mins (4 months) and 8.5 mins (8 months), respectively.

5.3.4.1.5. PDA class - within group comparisons

Within the PDA class, it was reported by the teacher and children that the same children provided with sit-stand desks at baseline may have remained at the same desks for most of the 8-month study. Table 5.20 details descriptive class time sitting data, comparing children with and without sit-stand desks within the PDA class during the three measurement phases. The five children with sit-stand desks reduced in sitting minutes at 4 months by 3.8 mins (136.8 mins) but increased by 37.3 minutes at 8 months (178.0 mins) compared to baseline. The proportion of wear time spent sitting increased by 0.6% at 4 months (46.7%) and by 12.3% at 8 months (58.4%) compared to baseline. In children located at traditional desks for most of the study, class time sitting time reduced by 17.5 mins at 4 months (180.5 mins) but increased by 12.2 mins at 8 months (203.2 mins) compared to baseline. The proportion of wear time spent sitting remained the same at 4 months (68.0%) compared to baseline and increased by 0.9% at 8 months (68.9%). Sitting minutes and the proportion of wear time spent sitting were higher in children with traditional desks compared to children with sit-stand desks at baseline (+57.4 minutes, +21.9%) 4 months (+43.7 minutes, +21.3%) and 8 months (+32.1 minutes, 10+.5%).

Table 5.9. Sitting, standing and stepping outcomes in control and full desk allocation groups during class time and school breaks at baseline, 4 months and 8 months. Data presented as median minutes (interquartile range), and the median (interquartile range) proportion of wear time spent in each behaviour during different domains.

	Control (n=27)								**Intervention (n=22)**							
	Baseline		**4 Months**		**▲ Vs B**	**8 Months**		**▲ Vs B**	**Baseline**		**4 Months**		**▲ Vs B**	**8 Months**		**▲ Vs B**
Class time																
WT, mins	309.9	(21.3)	330.0	(0.0)	20.1	308.2	(20.7)	-1.7	305.0	(5.5)	305.0	(0.0)	0.0	305.0	(2.6)	0.0
Sitting, mins	232.2	(40.9)	238.7	(54.0)	6.5	216.8	(41.9)	-15.4	218.5	(58.7)	122.6	(68.0)	-95.9	158.5	(73.2)	-60.0
Sitting, % WT	73.7	(10.2)	72.6	(13.4)	-1.1	72.1	(6.6)	-1.6	72.2	(19.3)	40.5	(23.3)	-31.7	52.4	(21.9)	-19.8
Standing, mins	51.5	(26.1)	51.2	(27.5)	-0.3	52.7	(26.0)	1.2	57.4	(51.4)	134.1	(59.5)	76.7	103.6	(52.6)	46.2
Standing, % WT	16.6	(8.4)	16.3	(8.5)	-0.3	17.6	(9.0)	1.0	19.2	(16.6)	43.5	(21.1)	24.3	35.6	(18.1)	16.4
Stepping, mins	28.3	(10.8)	37.0	(14.6)	8.7	35.1	(10.3)	6.8	26.7	(8.5)	33.6	(14.0)	6.9	36.4	(14.5)	9.7
Stepping, % WT	9.0	(2.8)	11.1	(4.6)	2.1	11.0	(2.7)	2.0	8.8	(2.8)	11.2	(5.1)	2.4	12.0	(4.0)	3.2
Steps	2119.0	(569.8)	2845.2	(1177.3)	726.2	2615.5	(871.2)	496.5	1886.4	(434.2)	2123.4	(853.6)	237.0	2654.7	(1137.8)	768.3
Steps p/min WT	6.9	(2.0)	8.6	(3.6)	1.7	8.5	(2.5)	1.6	6.3	(1.4)	7.0	(2.9)	0.7	8.8	(3.3)	2.5
SIT2STD Trans	38.4	(14.7)	39.8	(12.1)	1.4	29.3	(9.8)	-9.1	41.5	(17.1)	57.6	(24.6)	16.1	54.2	(17.6)	12.7
SIT2STD Trans p/h WT	7.1	(3.0)	7.8	(2.0)	0.7	5.6	(2.2)	-1.5	8.2	(3.6)	11.2	(5.4)	3.0	10.7	(2.3)	2.5
Bouts																

	Control (n=27)					Intervention (n=22)				
	Baseline	4 Months	▲ Vs B	8 Months	▲ Vs B	Baseline	4 Months	▲ Vs B	8 Months	▲ Vs B
5-10 minutes										
Sitting, frequency	4.9 (2.8)	4.8 (3.1)	-0.1	3.9 (1.8)	-1.0	5.7 (2.4)	2.3 (2.1)	-3.4	2.8 (2.7)	-2.9
Sitting, minutes	35.1 (21.0)	32.7 (18.8)	-2.4	28.3 (11.9)	-6.8	40.4 (19.1)	16.2 (15.2)	-24.2	18.7 (18.4)	-21.7
Sitting, % WT	11.5 (6.9)	10.1 (5.5)	-1.4	8.9 (4.0)	-2.6	13.6 (5.8)	5.2 (5.2)	-8.4	6.4 (5.6)	-7.2
Standing, frequency	0.7 (1.5)	0.6 (0.6)	-0.1	0.9 (0.9)	0.2	1.0 (2.2)	3.1 (3.4)	2.1	2.0 (2.2)	1.0
Standing, minutes	5.3 (9.9)	4.7 (4.9)	-0.6	5.1 (5.1)	-0.2	6.2 (14.7)	19.4 (25.9)	13.2	12.8 (13.3)	6.6
10+ minutes										
Sitting, frequency	5.6 (2.6)	6.0 (2.7)	0.4	5.9 (2.1)	0.3	4.6 (3.1)	1.9 (1.1)	-2.7	2.9 (1.9)	-1.7
Sitting, minutes	128.2 (42.3)	143.7 (74.6)	15.5	150.8 (50.4)	22.6	105.6 (122.8)	58.1 (23.7)	-47.5	18.7 (18.4)	-86.9
Sitting, % WT	40.9 (13.3)	43.5 (22.3)	2.6	49.4 (16.0)	8.5	35.5 (18.5)	19.3 (7.5)	-16.2	18.7 (12.7)	-16.8
Standing, frequency	0.0 (0.6)	0.0 (30.0)	0.0	0.1 (0.3)	0.1	0.2 (0.4)	0.6 (1.1)	0.4	0.6 (1.0)	0.4
Standing, minutes	0.0 (11.0)	0.0 (3.8)	0.0	1.6 (3.7)	1.6	2.2 (5.8)	7.7 (18.4)	5.5	6.4 (13.4)	4.2
School breaks										

	Control (n=27)								Intervention (n=22)							
	Baseline		4 Months		▲ Vs B	8 Months		▲ Vs B	Baseline		4 Months		▲ Vs B	8 Months		▲ Vs B
WT, mins	64.2	9.3	65.0	0.0	0.8	61.7	9.3	-2.5	75.0	0.0	75.0	0.0	0.0	75.0	0.0	0.0
Sitting, mins	20.1	(10.7)	16.7	(11.4)	-3.4	14.4	(10.0)	-5.7	18.5	(7.3)	16.5	(9.1)	-1.9	20.7	(10.6)	2.3
Sitting, % WT	30.8	(17.5)	26.1	(20.0)	-4.7	25.2	(12.7)	-5.7	24.5	(9.8)	22.0	(12.1)	-2.5	27.7	(14.2)	3.2
Stand, mins	16.2	(9.0)	16.5	(6.8)	0.3	16.8	(7.9)	0.6	21.0	(7.9)	20.5	(10.8)	-0.5	22.8	(6.3)	1.7
Stand, % WT	25.2	(16.2)	25.1	(10.4)	-0.1	27.5	(6.4)	2.3	28.1	(10.5)	27.3	(14.4)	-0.8	30.4	(8.4)	2.3
Stepping, mins	23.2	(7.3)	29.3	(8.2)	6.1	26.5	(9.4)	3.3	35.5	(11.7)	36.0	(15.2)	0.5	28.3	(8.3)	-7.3
Step, % wear	37.7	(10.4)	44.9	(16.8)	7.2	45.3	(16.2)	7.6	47.1	(14.0)	48.0	(19.7)	0.9	37.7	(11.1)	-9.5
Steps	1891.3	(549.1)	2363.2	(796.4)	471.9	2217.2	(870.7)	325.9	2813.6	(1228.8)	2755.0	(1376.7)	-58.6	2294.0	(781.4)	-519.6
Steps p/min WT	29.6	(9.6)	36.1	(12.3)	6.5	37.8	(15.9)	8.2	37.5	(16.4)	38.1	(18.9)	0.6	30.6	(10.4)	-6.9

▲ Change; B, baseline; SIT2STD Trans, sit-to-stand transitions; p/h, per hour; WT, wear time.

Table 5.10. Sitting, standing and stepping outcomes in control and partial desk allocation groups during class time and school breaks at baseline, 4 months and 8 months. Data presented as median minutes (interquartile range), and the median (interquartile range) proportion of wear time spent in each behaviour during different domains.

	Control (n=27)								**Intervention (n=19)**							
	Baseline		**4 Months**		**▲ Vs B**	**8 Months**		**▲ Vs B**	**Baseline**		**4 Months**		**▲ Vs B**	**8 Months**		**▲ Vs B**
Class time																
WT, mins	309.9	(21.3)	330.0	(0.0)	20.1	308.2	(20.7)	-1.7	305.0	10.4	292.0	19.0	-13.0	305.0	0.0	0.0
Sitting, mins	232.2	(40.9)	238.7	(54.0)	6.5	216.8	(41.9)	-15.4	196.4	65.1	173.2	49.0	-23.2	200.1	54.0	3.6
Sitting, % WT	73.7	(10.2)	72.6	(13.4)	-1.1	72.1	(6.6)	-1.6	65.4	15.4	61.2	20.0	-4.2	65.6	18.0	0.2
Standing, mins	51.5	(26.1)	51.2	(27.5)	-0.3	52.7	(26.0)	1.2	77.4	38.2	90.8	51.0	13.4	69.4	49.0	-8.0
Standing, % WT	16.6	(8.4)	16.3	(8.5)	-0.3	17.6	(9.0)	1.0	25.4	11.5	30.5	18.0	5.1	22.7	16.0	-2.7
Stepping, mins	28.3	(10.8)	37.0	(14.6)	8.7	35.1	(10.3)	6.8	26.9	10.3	24.1	13.0	-2.8	32.8	10.0	5.9
Stepping, % WT	9.0	(2.8)	11.1	(4.6)	2.1	11.0	(2.7)	2.0	9.0	3.1	8.4	4.0	-0.6	10.8	3.0	1.8
Steps	2119.0	(569.8)	2845.2	(1177.3)	726.2	2615.5	(871.2)	496.5	1974.0	754.2	1563.3	627.0	- 410.7	2426.0	879.0	452.0
Steps p/min WT	6.9	(2.0)	8.6	(3.6)	1.7	8.5	(2.5)	1.6	6.5	2.0	5.4	2.0	-1.1	8.0	3.0	1.5
SIT2STD Trans	38.4	(14.7)	39.8	(12.1)	1.4	29.3	(9.8)	-9.1	43.5	9.6	38.0	18.0	-5.5	42.9	16.0	-0.6
SIT2STD Trans p/h WT	7.1	(3.0)	7.8	(2.0)	0.7	5.6	(2.2)	-1.5	9.3	1.7	7.5	3.0	-1.8	8.4	2.9	-0.9

	Control (n=27)								Intervention (n=19)							
	Baseline		4 Months		▲ Vs B	8 Months		▲ Vs B	Baseline		4 Months		▲ Vs B	8 Months		▲ Vs B
Bouts																
5-10 minutes																
Sitting, frequency	4.9	(2.8)	4.8	(3.1)	-0.1	3.9	(1.8)	-1.0	5.0	2.3	3.3	3.0	-1.7	5.2	2.0	0.2
Sitting, minutes	35.1	(21.0)	32.7	(18.8)	-2.4	28.3	(11.9)	-6.8	35.0	15.5	23.0	24.0	-12.0	37.3	14.0	2.3
Sitting, % WT	11.5	(6.9)	10.1	(5.5)	-1.4	8.9	(4.0)	-2.6	12.0	5.2	8.7	7.0	-3.3	12.2	5.0	0.2
Standing, frequency	0.7	(1.5)	0.6	(0.6)	-0.1	0.9	(0.9)	0.2	1.3	2.2	1.4	6.0	0.1	1.5	2.0	0.2
Standing, minutes	5.3	(9.9)	4.7	(4.9)	-0.6	5.1	(5.1)	-0.2	9.0	14.0	8.0	11.0	-1.0	9.3	14.0	0.3
10+ minutes																
Sitting, frequency	5.6	(2.6)	6.0	(2.7)	0.4	5.9	(2.1)	0.3	4.8	2.1	4.0	2.0	-0.8	4.7	3.0	-0.1
Sitting, minutes	128.2	(42.3)	143.7	(74.6)	15.5	150.8	(50.4)	22.6	98.1	49.6	84.0	61.0	-14.1	102.9	55.0	4.8
Sitting, % WT	40.9	(13.3)	43.5	(22.3)	2.6	49.4	(16.0)	8.5	33.3	19.3	30.9	21.0	-2.4	33.8	18.0	0.5
Standing, frequency	0.0	(0.6)	0.0	(30.0)	0.0	0.1	(0.3)	0.1	0.3	0.4	0.8	1.0	0.5	1.9	8.0	1.6
Standing, minutes	0.0	(11.0)	0.0	(3.8)	0.0	1.6	(3.7)	1.6	3.8	7.0	12.0	26.0	8.2	5.2	2.0	1.4

	Control (n=27)								Intervention (n=19)							
	Baseline		4 Months		▲ Vs B	8 Months		▲ Vs B	Baseline		4 Months		▲ Vs B	8 Months		▲ Vs B
School breaks																
WT, mins	64.2	9.3	65.0	0.0	0.8	61.7	9.3	-2.5	75.0	5.0	72.5	11.0	-2.5	75.0	0.0	0.0
Sitting, mins	20.1	(10.7)	16.7	(11.4)	-3.4	14.4	(10.0)	-5.7	75.0	5.0	72.5	11.0	-2.5	75.0	0.0	0.0
Sitting, % WT	30.8	(17.5)	26.1	(20.0)	-4.7	25.2	(12.7)	-5.7	17.5	7.1	20.3	7.0	2.8	27.7	7.0	10.2
Stand, mins	16.2	(9.0)	16.5	(6.8)	0.3	16.8	(7.9)	0.6	25.2	11.2	31.4	15.0	6.2	36.9	10.0	11.7
Stand, % WT	25.2	(16.2)	25.1	(10.4)	-0.1	27.5	(6.4)	2.3	19.7	8.6	17.3	11.0	-2.4	17.0	6.0	-2.7
Stepping, mins	23.2	(7.3)	29.3	(8.2)	6.1	26.5	(9.4)	3.3	26.3	9.6	24.1	10.0	-2.2	22.7	8.0	-3.6
Step, % wear	37.7	(10.4)	44.9	(16.8)	7.2	45.3	(16.2)	7.6	35.0	10.8	29.2	12.0	-5.8	29.9	7.0	-5.1
Steps	1891.3	(549.1)	2363.2	(796.4)	471.9	2217.2	(870.7)	325.9	3011.2	1092.6	2378.3	895.0	-632.9	2523.4	674.0	-487.8
Steps p/min WT	29.6	(9.6)	36.1	(12.3)	6.5	37.8	(15.9)	8.2	47.6	16.8	41.7	13.0	-5.9	39.9	9.0	-7.7

▲ Change; B, baseline; SIT2STD Trans, sit-to-stand transitions; p/h, per hour; WT, wear time.

Table 5.11. Sitting, standing and stepping outcomes in control and full desk allocation groups after school at baseline, 4 months and 8 months. Data presented as median minutes (interquartile range), and the median (interquartile range) proportion of wear time spent in each behaviour during different domains.

	Control (n=27)								Intervention (n=22)							
	Baseline		**4 Months**		**▲ Vs B**	**8 Months**		**▲ Vs B**	**Baseline**		**4 Months**		**▲ Vs B**	**8 Months**		**▲ Vs B**
After School																
WT, mins	395.8	(52.0)	403.2	(99.6)	7.4	435.5	(52.6)	39.7	422.4	(34.3)	408.7	(66.8)	-13.7	424.4	(93.8)	2.0
Sitting, mins	276.0	(55.6)	237.5	(86.4)	-38.5	254.5	(83.5)	-21.5	293.9	(56.0)	270.9	(76.2)	-23.0	269.4	(90.2)	-24.5
Sitting, % WT	69.4	(11.8)	62.1	(14.1)	-7.3	59.1	(15.3)	-10.3	69.6	(12.2)	69.2	(14.2)	-0.4	64.4	(9.0)	-5.2
Standing, mins	72.9	(161.2)	76.1	(46.8)	3.2	82.0	(44.4)	9.1	75.1	(44.4)	77.0	(56.6)	1.9	72.5	(21.3)	-2.6
Standing, % WT	17.7	(8.2)	19.1	(9.1)	1.4	18.7	(5.8)	1.0	19.4	(8.4)	18.2	(13.8)	-1.2	17.1	(10.8)	-2.4
Stepping, mins	47.8	(-17.3)	62.1	(-48.7)	14.3	85.3	(-40.7)	37.5	50.9	(-21.4)	51.9	(-29.9)	1.0	62.5	(-28.2)	11.6
Stepping, % WT	12.2	(4.8)	15.0	(7.7)	2.8	20.3	(7.9)	8.1	12.7	(4.9)	11.9	(7.1)	-0.8	16.5	(6.8)	3.8
Steps	3673.4	(1162.6)	4776.2	(3778.0)	1102.8	6830.9	(2254.3)	3157.5	3713.6	(1984.5)	3954.7	(2148.0)	241.1	4821.4	(2466.3)	1107.8

	Control (n=27)					Intervention (n=22)				
	Baseline	**4 Months**	**▲ Vs B**	**8 Months**	**▲ Vs B**	**Baseline**	**4 Months**	**▲ Vs B**	**8 Months**	**▲ Vs B**
Steps p/min WT	9.3 (3.8)	12.2 (6.6)	2.9	16.1 (5.8)	6.8	9.2 (4.9)	8.8 (5.2)	-0.3	12.7 (5.2)	3.5

▲ Change; B, baseline; SIT2STD Trans, sit-to-stand transitions; p/h, per hour; WT, wear time

Table 5.12. Sitting, standing and stepping outcomes in control and the partial desk allocation group after school at baseline, 4 months and 8 months. Data presented as median minutes (interquartile range), and the median (interquartile range) proportion of wear time spent in each behaviour during different domains.

	Control (n=27)								Intervention (n=19)							
	Baseline		4 Months		▲ Vs B	8 Months		▲ Vs B	Baseline		4 Months		▲ Vs B	8 Months		▲ Vs B
After School																
WT, mins	395.8	(52.0)	403.2	(99.6)	7.4	435.5	(52.6)	39.7	424.2	33.3	408.3	60.9	-15.9	401.4	120.1	-22.8
Sitting, mins	276.0	(55.6)	237.5	(86.4)	-38.5	254.5	(83.5)	-21.5	276.1	53.5	258.7	47.2	-17.4	243.7	70.7	-32.4
Sitting, % WT	69.4	(11.8)	62.1	(14.1)	-7.3	59.1	(15.3)	-10.3	66.8	10.3	65.9	10.1	-0.9	58.3	16.3	-8.5
Standing, mins	72.9	(161.2)	76.1	(46.8)	3.2	82.0	(44.4)	9.1	83.9	41.4	76.5	43.8	-7.4	94.8	45.9	10.9
Standing, % WT	17.7	(8.2)	19.1	(9.1)	1.4	18.7	(5.8)	1.0	18.7	9.9	20.5	10.1	1.8	24.4	6.7	5.7
Stepping, mins	47.8	(-17.3)	62.1	(-48.7)	14.3	85.3	(-40.7)	37.5	55.4	26.3	49.8	37.9	-5.6	60.3	46.4	4.9
Stepping, % WT	12.2	(4.8)	15.0	(7.7)	2.8	20.3	(7.9)	8.1	13.7	6.6	12.4	10.7	-1.3	13.8	7.6	0.1
Steps	3673.4	(1162.6)	4776.2	(3778.0)	1102.8	6830.9	(2254.3)	3157.5	3801.4	1722.6	3825.7	3558.2	24.3	4585	3280.3	783.6

	Control (n=27)					Intervention (n=19)				
	Baseline	4 Months	▲ Vs B	8 Months	▲ Vs B	Baseline	4 Months	▲ Vs B	8 Months	▲ Vs B
Steps p/min WT	9.3 (3.8)	12.2 (6.6)	2.9	16.1 (5.8)	6.8	9.2 4.9	8.8 8.3	-0.4	10.8 7	1.6

▲ Change; B, baseline; SIT2STD Trans, sit-to-stand transitions; p/h, per hour; WT, wear time

Table 5.13. Sitting, standing and stepping outcomes in control and full desk allocation classes during a full weekday at baseline, 4 months and 8 months. Data presented as median minutes (interquartile range), and the median (interquartile range) proportion of wear time spent in each behaviour during different domains.

	Control (n=27)								Intervention (n=22)							
	Baseline		**4 Months**		**▲ Vs B**	**8 Months**		**▲ Vs B**	**Baseline**		**4 Months**		**▲ Vs B**	**8 Months**		**▲ Vs B**
Full week day																
WT, mins	892.1	(59.1)	948.8	(110.3)	56.7	924.6	(68.5)	32.5	942.0	(40.9)	933.8	(117.4)	-8.2	968.4	(114.6)	26.4
Sitting, mins	617.9	(105.2)	566.3	(123.0)	-51.6	599.4	(322.8)	-18.5	637.7	(80.9)	530.3	(140.1)	-107.4	570.5	(94.4)	-67.2
Sitting, % WT	69.5	(10.5)	65.4	(12.3)	-4.1	63.5	(9.7)	-6.0	68.1	(10.6)	57.4	(7.8)	-10.7	59.1	(10.3)	-9.0
Standing, mins	153.8	(71.9)	163.5	(75.4)	9.7	162.7	(94.7)	8.9	168.3	(84.0)	264.3	(98.1)	96.0	214.2	(93.0)	45.9
Standing, % WT	17.9	(7.8)	18.5	(8.6)	0.6	17.5	(10.3)	-0.4	18.0	(9.9)	27.1	(9.7)	9.1	23.6	(10.2)	5.6
Stepping, mins	114.8	(43.6)	137.5	(75.0)	22.7	160.0	(40.9)	45.2	131.2	(48.9)	141.4	(55.7)	10.2	141.4	(45.1)	10.2
Stepping, % WT	12.9	(4.2)	15.3	(5.8)	2.4	17.5	(3.8)	4.6	13.8	(5.0)	14.6	(6.1)	0.8	15.5	(4.5)	1.7
Steps	9278.7	(2625.3)	10903.1	(4823.5)	1624.4	13197.8	(2768.2)	3919.1	10038.9	(3454.4)	10594.3	(3420.0)	555.4	10959.7	(4150.3)	920.8

	Control (n=27)								Intervention (n=22)							
	Baseline		4 Months		▲ Vs B	8 Months		▲ Vs B	Baseline		4 Months		▲ Vs B	8 Months		▲ Vs B
Steps p/min of WT	10.3	(2.6)	11.5	(5.3)	1.2	14.1	(3.3)	3.8	10.6	(3.6)	11.0	(4.3)	0.4	11.8	(3.6)	1.2
SIT2STD Trans	88.0	(27.5)	94.8	(36.6)	6.8	83.5	(23.4)	-4.5	106.7	(25.4)	115.3	(47.7)	8.6	118.2	(38.1)	11.5
SIT2STD Trans p/h WT	5.9	(2.0)	6.4	(3.0)	0.5	5.4	(1.8)	-0.5	6.9	(1.5)	7.5	(2.7)	0.6	7.5	(1.5)	0.6
Bouts																
5-10 minutes																
Sitting, frequency	12.6	(4.9)	11.9	(5.9)	-0.7	10.0	(2.9)	-2.6	14.6	(2.8)	10.0	(4.0)	-4.6	9.7	(3.3)	-4.9
Sitting, minutes	90.3	(32.9)	83.9	(35.1)	-6.4	72.2	(24.7)	-18.1	103.8	(24.3)	67.4	(26.0)	-36.4	66.6	(27.5)	-37.2
Sitting, % WT	9.9	(4.2)	8.8	(2.9)	-1.1	8.1	(3.0)	-1.8	10.8	(3.1)	7.5	(3.4)	-3.3	7.6	(3.1)	-3.2
Standing, frequency	1.8	(3.5)	2.2	(2.5)	0.4	2.7	(1.7)	0.9	3.5	(2.5)	5.0	(5.6)	1.5	4.3	(3.0)	0.8
Standing, minutes	11.4	(24.5)	15.9	(16.1)	4.5	16.6	(11.8)	5.2	21.6	(15.1)	31.5	(37.8)	9.9	26.5	(18.2)	4.9
10+ minutes																

	Control (n=27)							Intervention (n=22)						
	Baseline		4 Months		▲ Vs B	8 Months		▲ Vs B	Baseline		4 Months		▲ Vs B	8 Months		▲ Vs B
Sitting, frequency	14.6	(3. 5)	15.5	(5.0)	0.9	15.7	(4.0)	1.1	15.3	(3.1)	12.0	(4.0)	-3.3	14.3	(3.6)	-1.0
Sitting, mins	381.4	(77.7)	359.7	(113.7)	-21.7	402.7	(140.5)	21.3	395.5	(81.3)	329.9	(117.8)	-65.6	358.8	(78.5)	-36.7
Sitting, % WT	43.1	(7.8)	38.5	(14.4)	-4.6	44.0	(11.9)	0.9	41.6	(9.3)	36.2	(10.5)	-5.4	37.6	(6.5)	-4.0
Standing, frequency	0.6	(1.1)	0.6	(0.6)	0.0	0.3	(0.7)	-0.3	0.6	(1.4)	1.0	(2.0)	0.4	1.0	(1.2)	0.4
Standing, mins	8.5	(19.7)	6.8	(7.2)	-1.7	5.2	(11.5)	-3.3	9.8	(20.9)	15.8	(31.6)	6.0	13.7	(18.4)	3.9

▲ Change; B, baseline; SIT2STD Trans, sit-to-stand transitions; p/h, per hour; WT, wear time

Table 5.14. Sitting, standing and stepping outcomes in control and partial desk allocation group classes during a full weekday at baseline, 4 months and 8 months. Data presented as median minutes (interquartile range), and the median (interquartile range) proportion of wear time spent in each behaviour during different domains.

	Control (n=27)								Intervention (n=19)							
	Baseline		4 Months		▲ Vs B	8 Months		▲ Vs B	Baseline		4 Months		▲ Vs B	8 Months		▲ Vs B
Full week day																
WT, mins	892.1	(59.1)	948.8	(110.3)	56.7	924.6	(68.5)	32.5	931.8	103.7	880.9	55.0	-50.9	934.8	109.0	3.0
Sitting, mins	617.9	(105.2)	566.3	(123.0)	-51.6	599.4	(322.8)	-18.5	570.3	98.3	534.8	54.0	-35.5	576.0	118.0	5.7
Sitting, % WT	69.5	(10.5)	65.4	(12.3)	-4.1	63.5	(9.7)	-6.0	63.2	11.0	63.0	9.0	-0.2	60.0	11.0	-3.2
Standing, mins	153.8	(71.9)	163.5	(75.4)	9.7	162.7	(94.7)	8.9	221.6	86.5	207.3	44.0	-14.3	204.9	98.0	-16.7
Standing, % WT	17.9	(7.8)	18.5	(8.6)	0.6	17.5	(10.3)	-0.4	22.8	8.5	24.0	6.0	1.2	21.3	11.0	-1.5
Stepping, mins	114.8	(43.6)	137.5	(75.0)	22.7	160.0	(40.9)	45.2	131.4	41.9	114.3	41.0	-17.1	139.9	52.0	8.5
Stepping, % WT	12.9	(4.2)	15.3	(5.8)	2.4	17.5	(3.8)	4.6	13.4	5.1	13.1	4.0	-0.3	14.6	6.0	1.2
Steps	9278.7	(2625.3)	10903.1	(4823.5)	1624.4	13197.8	(2768.2)	3919.1	9862.0	3323.7	8285.2	3593.0	-1576.8	11002.6	4681.0	1140.6

	Control (n=27)							Intervention (n=19)							
	Baseline		4 Months		▲ Vs B	8 Months		▲ Vs B	Baseline		4 Months		▲ Vs B	8 Months		▲ Vs B
Steps p/min of WT	10.3	(2.6)	11.5	(5.3)	1.2	14.1	(3.3)	3.8	10.3	4.0	9.7	4.0	-0.6	11.6	5.0	1.3
SIT2STD Trans	88.0	(27.5)	94.8	(36.6)	6.8	83.5	(23.4)	-4.5	106.6	32.9	96.8	40.0	-9.8	108.0	23.0	1.4
SIT2STD Trans p/h WT	5.9	(2.0)	6.4	(3.0)	0.5	5.4	(1.8)	-0.5	6.8	1.2	6.2	2.0	-0.8	7.0	2.0	0.2
Bouts																
5-10 minutes																
Sitting, frequency	12.6	(4.9)	11.9	(5.9)	-0.7	10.0	(2.9)	-2.6	12.3	4.0	10.5	5.0	-1.8	11.9	4.0	-0.4
Sitting, minutes	90.3	(32.9)	83.9	(35.1)	-6.4	72.2	(24.7)	-18.1	85.6	27.0	74.0	40.0	-11.6	84.9	27.0	-0.7
Sitting, % WT	9.9	(4.2)	8.8	(2.9)	-1.1	8.1	(3.0)	-1.8	9.4	2.1	8.3	5.0	-1.1	9.1	2.0	-0.3
Standing, frequency	1.8	(3.5)	2.2	(2.5)	0.4	2.7	(1.7)	0.9	4.8	3.0	3.5	3.0	-1.3	4.0	3.0	-0.8
Standing, minutes	11.4	(24.5)	15.9	(16.1)	4.5	16.6	(11.8)	5.2	31.2	21.0	22.1	19.0	-9.1	26.0	15.0	-5.2
10+ minutes																

	Control (n=27)							Intervention (n=19)							
	Baseline		**4 Months**		**▲ Vs B**	**8 Months**		**▲ Vs B**	**Baseline**		**4 Months**		**▲ Vs B**	**8 Months**		**▲ Vs B**
Sitting, frequency	14.6	(3. 5)	15.5	(5.0)	0.9	15.7	(4.0)	1.1	14.2	4.3	13.7	4.0	-0.5	15.5	6.0	1.3
Sitting, mins	381.4	(77.7)	359.7	(113.7)	-21.7	402.7	(140.5)	21.3	344.6	114.3	351.8	106.0	7.2	343.5	141.0	-1.1
Sitting, % WT	43.1	(7.8)	38.5	(14.4)	-4.6	44.0	(11.9)	0.9	36.8	11.7	39.0	12.0	2.2	35.4	12.0	-1.4
Standing, frequency	0.6	(1.1)	0.6	(0.6)	0.0	0.3	(0.7)	-0.3	0.8	1.0	1.3	1.0	0.5	1.0	2.0	0.2
Standing, mins	8.5	(19.7)	6.8	(7.2)	-1.7	5.2	(11.5)	-3.3	11.5	17.1	19.6	29.0	8.1	13.9	25.0	2.4

▲ Change; B, baseline; SIT2STD Trans, sit-to-stand transitions; p/h, per hour; WT, wear time

INTERVENTION EFFECTS

CLASSROOM TIME

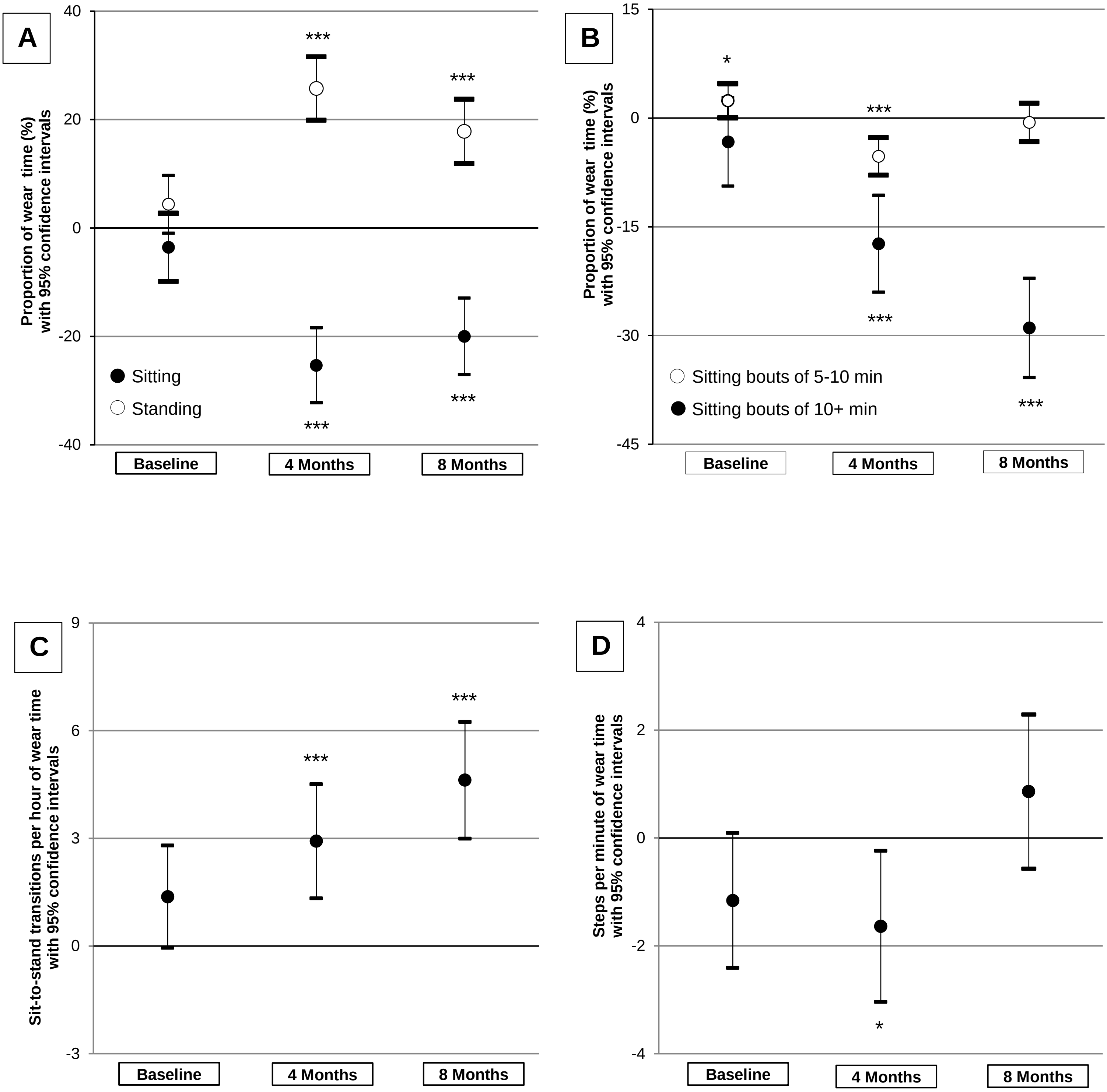

Figure 5.5. Estimated effect sizes of the full desk allocation group (compared to the control group) at baseline, 4 months and 8 months from multi-level models during class time. A: proportion of wear time spent sitting and standing; B; proportion of wear time spent sitting in bouts of 5-10 mins and 10+ mins; C: sit-to-stand transitions per hour of wear time; D: steps-per-minute of wear time. * *P* <0.05; ** *P* <0.01; *** *P* <0.0005

FULL WEEKDAY

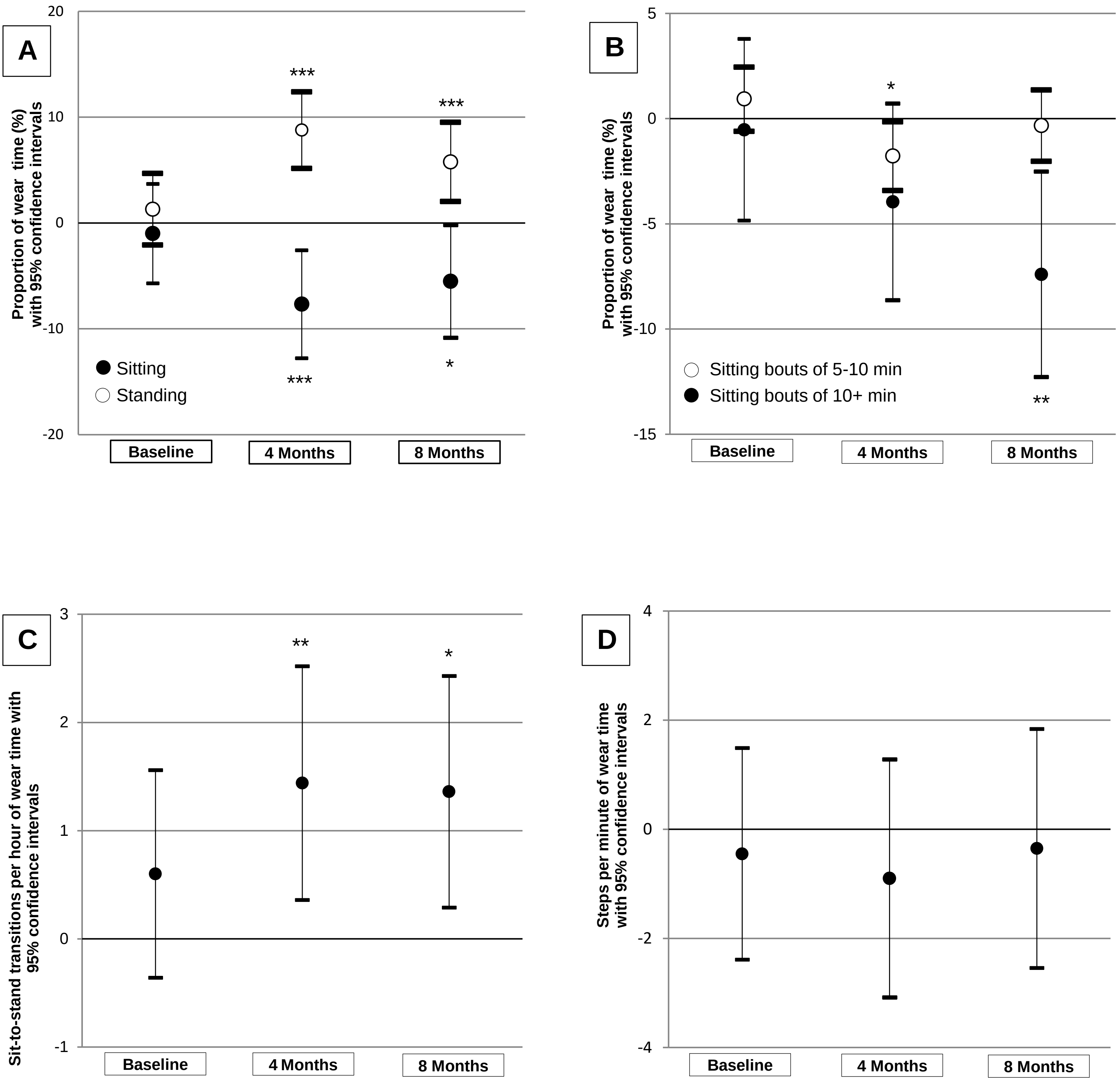

Figure 5.6. Estimated effect sizes of the full desk allocation group (compared to the control group) at baseline, 4 months and 8 months from multi-level models during a full weekday. A: proportion of wear time spent sitting and standing; B; proportion of wear time spent sitting in bouts of 5-10 mins and >10 mins; C: sit-to-stand transitions per hour of wear time; D: steps-per-minute of wear time. * *P* <0.05; ** *P* <0.01; *** *P* <0.0005

Table 5.15. Estimated effect sizes of the partial desk allocation group (compared to the control group) in ActivPAL-measured sitting, standing and stepping outcome variables during different times of a weekday at baseline, 4 months and 8 months from multi-level models. Control n=27, Intervention n=19.

	Time point											
	Baseline				**4 Months**				**8 Months**			
Outcome	**β**	**95% CI**		***P***	**β**	**95% CI**		***P***	**β**	**95% CI**		***P***
Class time												
Wear time, mins	-10.64	-15.74	-5.54	**0.000**	-30.38	-41.69	-19.06	**0.000**	4.44	-8.32	17.20	0.495
Sitting, % WT	-5.45	-8.51	-2.39	**0.000**	-1.94	-7.20	3.32	0.469	2.19	-3.68	8.06	0.464
Standing, % WT	5.30	2.77	7.83	**0.000**	4.92	0.69	9.15	**0.023**	-1.22	-5.94	3.49	0.612
Stepping, % WT	0.14	-0.73	1.01	0.748	-2.93	-4.62	-1.24	**0.001**	-1.00	-2.90	0.89	0.299
Sitting bouts, 5-10 mins, % WT	0.24	-0.91	1.39	0.688	-3.23	-5.65	-0.81	**0.009**	2.02	-0.70	4.74	0.145
Sitting bouts, 10+ mins, % WT	-2.99	-6.51	0.52	0.095	3.18	-4.00	10.36	0.385	-13.02	-21.08	-4.96	**0.002**
Steps p/min of WT	-0.15	-0.79	0.50	0.650	-2.70	-3.99	-1.42	**0.000**	-0.99	-2.43	0.45	0.179
SIT2STD Trans p/h WT	1.10	0.43	1.72	**0.001**	-0.70	-1.90	-0.50	0.25	1.07	-0.24	2.40	0.110
School break time												
Wear time, mins	5.55	3.89	7.21	**0.000**	-1.08	-4.52	2.36	0.538	9.44	5.51	13.38	**0.000**
Sitting, % WT	-5.74	-10.08	-1.41	**0.009**	8.19	-1.48	17.87	0.097	20.91	9.92	31.89	**0.000**
Standing, % WT	1.04	-1.36	3.45	0.394	-0.13	-4.55	4.30	0.956	-6.94	-12.00	-1.88	**0.007**

Outcome	Baseline β	Baseline 95% CI		Baseline *P*	4 Months β	4 Months 95% CI		4 Months *P*	8 Months β	8 Months 95% CI		8 Months *P*
Stepping, % WT	4.70	1.40	8.01	**0.005**	-7.69	-14.86	-0.53	**0.035**	-14.12	-22.28	-5.96	**0.001**
Steps p/min of WT	4.40	1.46	7.34	**0.003**	-6.70	-12.93	-0.46	**0.035**	-12.45	-19.50	-5.39	**0.001**
After School												
Wear time, mins	13.55	-2.72	29.81	0.103	12.71	-23.74	49.15	0.494	-49.42	-90.46	-8.37	**0.018**
Sitting, % WT	-1.68	-4.73	1.38	0.282	2.57	-2.86	8.00	0.354	0.22	-5.92	6.36	0.944
Standing, % WT	1.07	-0.88	3.02	0.283	-0.25	-3.72	3.22	0.887	3.55	-0.37	7.48	0.076
Stepping, % WT	0.61	-1.28	2.49	0.529	-2.30	-5.58	0.98	0.169	-3.73	-0.03	-7.43	**0.048**
Steps p/min of WT	0.36	-1.17	1.88	0.648	-1.69	-4.27	0.90	0.200	-2.77	-5.68	0.14	0.062
Full day												
Wear time, mins	17.48	-3.56	38.52	0.103	-59.56	-105.66	-13.46	0.011	-28.25	-80.32	23.81	0.287
Sitting, % WT	-2.87	-5.28	-0.46	**0.020**	0.96	-3.22	5.13	0.653	2.24	-2.47	6.95	0.351
Standing, % WT	2.23	0.55	3.91	**0.009**	1.79	-0.86	4.43	0.185	0.09	-2.87	3.05	0.951
Stepping, % WT	0.63	-0.63	1.89	0.329	-2.68	-4.93	-0.42	0.020	-2.39	-4.94	0.16	0.066
Sitting bouts, 5-10 mins, % WT	0.24	-0.91	1.39	0.688	-3.23	-5.65	-0.81	0.009	2.02	-0.70	4.74	0.145
Sitting bouts, 10+ mins, % WT	-2.99	-6.51	0.52	0.095	3.18	-4.00	10.36	0.385	-13.02	-21.08	-4.96	0.002

Outcome	Time point											
	Baseline				4 Months				8 Months			
	β	95% CI		*P*	β	95% CI		*P*	β	95% CI		*P*
Steps p/min of WT	0.40	-0.69	1.49	0.470	-1.95	-4.00	0.08	0.060	-1.80	-3.99	0.39	0.107
SIT2STD Trans p/h WT	0.39	-0.08	0.87	0.102	-0.22	-1.05	0.61	0.605	0.44	-0.46	1.33	0.960

▲ Change; B, baseline; SIT2STD Trans, sit-to-stand transitions; p/h, per hour; WT, wear time

Table 5.16. Light intensity physical activity and moderate-to-vigorous physical activity outcomes in control and full desk allocation classes during class time, after school and during a full weekday at baseline, 4 months and 8 months. Data presented as median minutes (interquartile range), and the median (interquartile range) proportion of wear time spent in each behaviour during different domains.

	Control (n=27)								Intervention (n=22)							
	Baseline		4 Months		▲ Vs B	8 Months		▲ Vs B	Baseline		4 Months		▲ Vs B	8 Months		▲ Vs B
Class time																
WT, mins	373.0	(51.0)	370.0	(65.0)	-3.0	362.0	(44.5)	-11.0	361.0	(26.5)	368.0	(30.8)	7.0	374.5	(15.8)	13.5
STA, mins	197.2	35.9	190.5	30.4	-6.7	195.6	32.4	-1.6	186.2	28.1	166.9	37.6	-19.3	170.6	18.8	-15.6
STA, % wear	66.2	6.8	66	12.1	-0.2	67.9	9.9	1.7	65.6	9.7	61.1	14.9	-4.5	59.5	8.2	-6.1
LPA, mins	81.6	(34.7)	75.1	(52.9)	-6.5	80.8	(27.6)	-0.8	91.0	(33.1)	107.5	(47.5)	16.5	108.5	(24.5)	17.5
LPA, % WT	27.2	(7.5)	27.5	(10.9)	0.3	27.0	(6.6)	-0.2	31.8	(9.7)	35.0	(14.7)	3.3	35.7	(5.9)	3.9
MVPA, mins	13.3	(7.0)	16.3	(9.2)	3.0	16.7	(9.0)	3.4	8.2	(3.5)	12.0	(7.9)	3.8	18.7	(7.4)	10.6
MVPA, % WT	4.5	(2.5)	6.1	(2.6)	1.6	5.3	(3.4)	0.8	2.9	(1.3)	4.0	(2.4)	1.1	6.1	(2.8)	3.2
School break time																
WT, mins	62.9	(7.1)	63.0	(0.0)	0.1	63.0	(1.1)	0.1	73.0	(0.0)	73.0	(0.0)	0.0	73.0	(0.0)	0.0
STA, mins	23.8	7.6	20	6.5	-3.8	23.1	7.9	-0.7	22.1	6.6	24	6.8	1.9	24.9	6.7	2.8
STA, % wear	38.7	15.4	38.1	9.4	-0.6	39.8	5.7	1.1	28.6	11.2	29.2	11.5	0.6	30.6	11	2
CPM	875.3	378.6	1093.5	329.8	218.2	977.7	330.2	102.4	1129.3	943.0	1262.8	483.5	133.5	1214.1	541.1	84.8
LPA, mins	23.8	(5.5)	24.6	(4.7)	0.8	24.6	(4.1)	0.8	32.0	(9.6)	32.3	(4.5)	0.3	32.9	(5.8)	0.9

	Control (n=27)								Intervention (n=22)							
	Baseline		4 Months		▲ Vs B	8 Months		▲ Vs B	Baseline		4 Months		▲ Vs B	8 Months		▲ Vs B
LPA, % WT	55.4	(17.6)	61.0	(15.3)	5.6	60.1	(12.3)	4.7	69.4	(20.6)	70.3	(15.4)	0.9	68.1	(11.2)	-1.3
MVPA, mins	11.2	(6.5)	17.6	(6.3)	6.4	15.2	(7.3)	4.1	16.2	(11.6)	17.3	(9.3)	1.1	15.9	(7.4)	-0.4
MVPA, % WT	18.1	(9.3)	27.9	(10.9)	9.9	24.4	(11.3)	6.4	23.3	(22.4)	23.7	(13.2)	0.3	21.7	(10.2)	-1.6
After school																
WT, mins	321.5	(55.8)	321.8	(104.8)	0.3	369.4	(106.8)	47.9	292.0	(149.0)	287.6	(117.7)	-4.4	296.1	(55.9)	4.1
STA, mins	175.1	54.6	151.5	73.1	-23.6	174.7	72.7	-0.4	168.1	80.7	148.2	68	-19.9	168.6	52.3	0.5
STA, % wear	54.7	12.1	49.1	11.2	-5.6	47	10.5	-7.7	56.6	13.7	53.7	11.9	-2.9	53.3	7.2	-3.3
CPM	554.2	201.2	681.7	411.5	127.5	722.0	240.5	167.8	534.2	287.2	616.5	254.6	82.3	597.1	191.0	62.9
LPA, mins	114.8	(40.1)	126.6	(56.3)	11.8	135.2	(42.2)	20.4	102.1	(48.8)	103.9	(49.8)	1.8	113.4	(23.1)	11.3
LPA, % WT	35.8	(7.4)	36.3	(10.0)	0.5	38.5	(6.1)	2.7	34.3	(6.1)	36.1	(9.4)	1.9	35.5	(4.9)	1.2
MVPA, mins	32.0	(19.7)	34.8	(23.8)	2.9	45.9	(24.6)	14.0	25.7	(15.5)	31.8	(18.2)	6.1	31.0	(13.9)	5.4
MVPA, % WT	10.1	(4.2)	10.6	(6.3)	0.5	14.4	(5.3)	4.4	9.2	(5.9)	10.2	(4.4)	1.0	10.5	(3.6)	1.4
Full day																
WT, mins	752.5	(111.8)	742.0	(120.0)	-10.5	778.0	(82.5)	25.5	711.0	(98.5)	721.0	(105.0)	10.0	725.5	(66.5)	14.5
STA, mins	418.9	71.3	397.9	83.4	-21	427.9	88.6	9	416.8	88.6	374	83.3	-42.8	385.9	71.6	-30.9
STA, % wear	58.1	8.1	53.6	9.3	-4.5	53.7	7.1	-4.4	55.7	8.8	53.9	11.1	-1.8	53.8	6.5	-1.9

	Control (n=27)								Intervention (n=22)							
	Baseline		4 Months		▲ Vs B	8 Months		▲ Vs B	Baseline		4 Months		▲ Vs B	8 Months		▲ Vs B
CPM	523.9	195.9	611.3	260.4	87.4	617.7	163.6	93.8	514.3	198.4	584.6	155.5	70.3	595.4	172.8	81.1
LPA, mins	248.4	(80.9)	251.4	(77.0)	3.0	268.5	(63.6)	20.1	233.6	(57.9)	256.5	(82.9)	22.9	260.8	(54.8)	27.2
LPA, % WT	32.3	(6.4)	34.3	(7.4)	2.0	33.1	(5.0)	0.8	34.4	(5.9)	37.6	(8.3)	3.3	36.8	(3.9)	2.5
MVPA, mins	71.1	(38.1)	81.0	(32.3)	9.9	93.0	(25.3)	21.9	60.2	(21.7)	69.9	(28.7)	9.7	74.5	(13.0)	14.4
MVPA, % WT	9.3	(4.0)	10.9	(4.4)	1.6	11.5	(4.6)	2.2	8.4	(4.1)	10.1	(3.5)	1.8	10.4	(2.8)	2.0

STA, stationary time; CPM, counts per minute; LPA, light physical activity; MVPA, moderate to vigorous physical activity; ▲ Change, WT, wear time

Table 5.17. Light intensity physical activity and moderate-to-vigorous physical activity outcomes in control and partial desk allocation group classes during class time, after school and during a full weekday at baseline, 4 months and 8 months. Data presented as median minutes (interquartile range), and the median (interquartile range) proportion of wear time spent in each behaviour during different domains.

	Control (n=27)								**Intervention (n=19)**							
	Baseline		**4 Months**		**▲ Vs B**	**8 Months**		**▲ Vs B**	**Baseline**		**4 Months**		**▲ Vs B**	**8 Months**		**▲ Vs B**
Class time																
WT, mins	373.0	(51.0)	370.0	(65.0)	-3.0	362.0	(44.5)	-11.0	301.0	7.5	280.0	36.0	-21.0	284.5	17.3	-16.5
STA, mins	197.2	35.9	190.5	30.4	-6.7	195.6	32.4	-1.6	182.0	26.0	178.5	19.0	-3.5	175.0	23.5	-7.0
STA, % wear	66.2	6.8	66	12.1	-0.2	67.9	9.9	1.7	61.0	9.0	65.5	8.0	4.5	63.0	12.3	2.0
LPA, mins	81.6	(34.7)	75.1	(52.9)	-6.5	80.8	(27.6)	-0.8	106.0	25.0	89.0	28.8	-17.0	93.0	39.8	-13.0
LPA, % WT	27.2	(7.5)	27.5	(10.9)	0.3	27.0	(6.6)	-0.2	35.0	7.5	32.0	8.5	-3.0	32.0	12.3	-3.0
MVPA, mins	13.3	(7.0)	16.3	(9.2)	3.0	16.7	(9.0)	3.4	7.0	5.0	5.7	3.6	-1.3	17.0	4.4	10.0
MVPA, % WT	4.5	(2.5)	6.1	(2.6)	1.6	5.3	(3.4)	0.8	2.0	2.0	2.0	1.0	0.0	5.0	1.3	3.0
School break time																
WT, mins	62.9	(7.1)	63.0	(0.0)	0.1	63.0	(1.1)	0.1	75.0	0.0	73.0	1.8	-2.0	73.0	0.0	-2.0
STA, mins	23.8	7.6	20	6.5	-3.8	23.1	7.9	-0.7	20.0	4.0	22.5	9.0	2.5	25.0	6.0	5.0
STA, % wear	38.7	15.4	38.1	9.4	-0.6	39.8	5.7	1.1	28.0	7.0	31.5	13.0	3.5	34.5	7.8	6.5
CPM	875.3	378.6	1093.5	329.8	218.2	977.7	330.2	102.4	1161.0	463.5	1184.5	406.8	23.5	1206.0	339.3	45.0
LPA, mins	23.8	(5.5)	24.6	(4.7)	0.8	24.6	(4.1)	0.8								
LPA, % WT	55.4	(17.6)	61.0	(15.3)	5.6	60.1	(12.3)	4.7	48.0	7.0	48.0	12.5	0.0	45.0	6.3	-3.0

	Control (n=27)								Intervention (n=19)							
	Baseline		**4 Months**		**▲ Vs B**	**8 Months**		**▲ Vs B**	**Baseline**		**4 Months**		**▲ Vs B**	**8 Months**		**▲ Vs B**
MVPA, mins	11.2	(6.5)	17.6	(6.3)	6.4	15.2	(7.3)	4.1	16.0	6.5	14.0	6.8	-2.0	15.0	5.8	-1.0
MVPA, % WT	18.1	(9.3)	27.9	(10.9)	9.9	24.4	(11.3)	6.4	22.0	9.5	19.5	9.0	-2.5	21.0	7.0	-1.0
After school																
WT, mins	321.5	(55.8)	321.8	(104.8)	0.3	369.4	(106.8)	47.9	298.0	76.0	311.0	63.8	13.0	348.5	69.3	50.5
STA, mins	175.1	54.6	151.5	73.1	-23.6	174.7	72.7	-0.4	155.0	37.0	147.5	62.0	-7.5	178.5	28.0	23.5
STA, % wear	54.7	12.1	49.1	11.2	-5.6	47	10.5	-7.7	51.0	9.0	50.0	14.0	-1.0	52.5	7.8	1.5
CPM	554.2	201.2	681.7	411.5	127.5	722.0	240.5	167.8	595.1	203.0	599.9	284.0	4.7	578.5	126.5	
LPA, mins	114.8	(40.1)	126.6	(56.3)	11.8	135.2	(42.2)	20.4	115.0	51.5	120.5	25.5	5.5	138.5	43.3	23.5
LPA, % WT	35.8	(7.4)	36.3	(10.0)	0.5	38.5	(6.1)	2.7	39.0	8.0	39.0	8.5	0.0	38.5	8.8	-0.5
MVPA, mins	32.0	(19.7)	34.8	(23.8)	2.9	45.9	(24.6)	14.0	28.0	14.5	27.5	20.3	-0.5	33.0	12.3	5.0
MVPA, % WT	10.1	(4.2)	10.6	(6.3)	0.5	14.4	(5.3)	4.4	9.0	5.0	10.5	6.0	1.5	10.0	3.8	1.0
Full day																
WT, mins	752.5	(111.8)	742.0	(120.0)	-10.5	778.0	(82.5)	25.5	727.0	65.5	683.0	52.3	-44.0	773.5	63.0	46.5
STA, mins	418.9	71.3	397.9	83.4	-21	427.9	88.6	9	379.0	57.0	371.5	62.0	-7.5	408.0	51.0	29.0
STA, % wear	58.1	8.1	53.6	9.3	-4.5	53.7	7.1	-4.4	53.0	7.0	54.5	9.0	1.5	52.5	5.8	-0.5
CPM	523.9	195.9	611.3	260.4	87.4	617.7	163.6	93.8	511.2	141.0	490.9	185.0	-20.3	544.6	111.7	33.3
LPA, mins	248.4	(80.9)	251.4	(77.0)	3.0	268.5	(63.6)	20.1	283.0	60.0	254.0	20.5	-29.0	275.5	63.5	-7.5

	Control (n=27)								Intervention (n=19)							
	Baseline		4 Months		▲ Vs B	8 Months		▲ Vs B	Baseline		4 Months		▲ Vs B	8 Months		▲ Vs B
LPA, % WT	32.3	(6.4)	34.3	(7.4)	2.0	33.1	(5.0)	0.8	38.0	8.0	38.0	3.8	0.0	37.0	6.3	-1.0
MVPA, mins	71.1	(38.1)	81.0	(32.3)	9.9	93.0	(25.3)	21.9	57.0	24.5	56.0	34.0	-1.0	72.5	26.0	15.5
MVPA, % WT	9.3	(4.0)	10.9	(4.4)	1.6	11.5	(4.6)	2.2	9.0	3.5	8.5	5.0	-0.5	9.0	3.0	0.0

STA, stationary; CMP, Counts per minute, LPA, light physical activity; MVPA, moderate to vigorous physical activity; ▲ Change, WT, wear time

Table 5.18. Estimated effect sizes of the full desk allocation group (compared to the control group) in ActiGraph-measured light intensity and moderate-to-vigorous physical activity outcome variables during different times of a weekday at baseline, 4 months and 8 months from multi-level models. Control n=27, Intervention n=22.

	Time point												
	Baseline				**4 Months**				**8 Months**				
Outcome	**β**	**95% CI**		***P***	**β**	**95% CI**		***P***	**β**	**95% CI**		***P***
Class Time												
Wear time, mins	-10.15	(-26.08,	5.78)	0.212	-3.88	(-20.17,	12.40)	0.640	-0.61	(-17.39,	16.16)	0.943
STA, mins	10.88	-25.29	3.53	0.14	-19.95	-34.78	-5.11	**0.01**	-31.23	-46.51	-15.95	**0.00**
STA, % wear	-1.55	-6.45	3.35	0.54	-5.90	-10.87	-0.93	**0.02**	-10.09	-15.14	-5.05	**0.00**
LPA, mins	8.44	(-7.51,	24.39)	0.300	23.85	(7.72,	39.98)	**0.004**	29.11	(12.76,	45.45)	**0.000**
LPA, % WT	4.03	(-0.40,	8.46)	0.075	8.84	(4.36,	13.31)	**0.000**	9.87	(5.33,	14.40)	**0.000**
MVPA, mins	-6.60	(-9.67	-3.52)	**0.000**	-6.86	(-9.98	-3.73)	**0.000**	1.25	(-1.95	4.44)	0.445
MVPA, % WT	-2.07	(-3.00	-1.13)	**0.000**	-2.18	(-3.14	-1.22)	**0.000**	0.42	(-0.56	1.41)	0.399
Full day												
Wear time, mins	-22.38	(-67.41,	22.65)	0.330	-11.88	(-57.61,	33.85)	0.611	-41.44	(-88.04,	5.17)	0.081
STA, mins	-16.55	-50.73	17.62	0.34	-9.76	-44.40	24.88	0.58	-32.91	-68.11	2.29	0.07
STA, % wear	-0.68	-4.36	3.01	0.720	-0.38	-4.1	3.35	0.840	-1.53	-5.3	2.24	0.430
CPM	-2.5	-74.16	69.15	0.950	-86.74	-159.36	-14.11	**0.020**	-20.61	-94.43	53.2	0.580

						Time point						
		Baseline				4 Months				8 Months		
Outcome	**β**	**95% CI**		***P***	**β**	**95% CI**		***P***	**β**	**95% CI**		***P***
LPA, mins	3.40	(-26.39,	33.19)	0.823	15.58	-(14.59,	45.76)	0.311	5.76	(-24.89,	36.40)	0.713
LPA, % WT	1.51	(-1.49,	4.51)	0.325	2.78	(-0.26,	5.82)	0.073	2.84	(-0.23,	5.92)	0.070
MVPA, mins	-7.89	(-20.16,	4.38)	0.208	-17.64	(-30.05,	-5.22)	**0.005**	-14.82	(-27.41,	-2.22)	**0.021**
MVPA, % WT	-0.82	(-2.39	0.76)	0.311	-1.52	(-2.84	-0.22)	**0.022**	-0.52	(-1.88	0.84)	0.456
School break times												
Wear time, mins	12.87	(11.72,	14.01)	**0.000**	10.07	(8.89,	11.25)	**0.000**	10.69	(9.47,	11.91)	**0.000**
STA, mins	-1.79	-4.91	1.32	0.260	3.99	0.83	7.15	**0.010**	2.56	-0.65	5.78	0.120
STA, % wear	-14.08	-18.74	-9.42	**0.000**	-7.31	-12.06	2.56	**0.000**	-7.85	-12.72	-2.98	**0.000**
CPM	395.95	196.07	595.83	**0.000**	102.73	-101.02	306.48	0.320	158.6	-50.23	367.43	0.140
LPA, % WT	12.41	(6.14	18.67)	**0.000**	10.99	(4.59	17.40)	**0.001**	7.73	(1.13	14.33)	**0.022**
MVPA, % WT	6.89	(1.99,	11.79)	**0.006**	-6.23	(-11.20,	-1.26)	**0.014**	-1.87	(-6.92,	3.19)	0.470
After school												
Wear time, mins	-39.17	(-80.54	2.20)	0.064	-19.5	(-61.0	23.0)	0.368	-47.5	(-91.0	-4.1)	**0.032**
STA, mins	-7.17	-34.23	19.88	0.603	6.01	-21.45	33.47	0.668	-3.86	31.84	-24.11	0.787
STA, % wear	1.86	-3.36	7.07	0.485	7.05	1.74	12.36	**0.009**	5.93	0.49	11.38	**0.033**

	Time point								
	Baseline			4 Months			8 Months		
Outcome	β	95% CI	*P*	β	95% CI	*P*	β	95% CI	*P*
CPM	2.65	-122.37 127.68	0.967	-133.63	-261.35 -5.90	**0.040**	-142.01	-273.40 -10.63	**0.034**
LPA, % WT	-1.51	(-5.05, 2.03)	0.404	-1.21	(-4.83, 2.41)	0.512	-2.57	(-6.30, 1.16)	0.177
MVPA, % WT	-0.43	(-3.09, 2.23)	0.751	-1.42	(-4.14, 1.30)	0.307	-3.47	(-6.26, -0.67)	**0.015**

STA, stationary time; CPM, counts per minute; LPA, light intensity physical activity; MVPA, moderate-to-vigorous physical activity; WT, wear time

Table 5.19. Estimated effect sizes of the partial desk allocation group (compared to the control group) in ActiGraph-measured light intensity and moderate-to-vigorous physical activity outcome variables during different times of a weekday at baseline, 4 months and 8 months from multi-level models. Control n=27, Intervention n=19.

	Time point											
	Baseline				4 Months				8 Months			
Outcome	**β**	**95% CI**		***P***	**β**	**95% CI**		***P***	**β**	**95% CI**		***P***
Class Time												
Wear time, mins	-1.32	-10.03	7.39	0.766	-17.07	-34.69	0.56	0.058	-10.84	-30.64	8.97	0.284
STA, mins	-7.82	-14.84	-0.81	**0.029**	-1.03	-15.21	13.14	0.887	-12.01	-27.94	3.92	0.140
STA, % wear	-2.42	-4.72	-0.11	**0.040**	3.37	-0.32	7.07	0.074	-1.10	-5.22	3.02	0.600
LPA, mins	9.59	2.04	17.14	**0.013**	-6.94	-19.50	5.62	0.279	1.44	-12.59	15.48	0.840
LPA, % WT	3.49	1.47	5.51	**0.001**	-0.06	-3.40	3.27	0.970	1.40	-2.33	5.12	0.463
MVPA, mins	-3.18	-4.79	-1.57	**0.000**	-9.48	-12.18	-6.78	**0.000**	-1.27	-4.29	1.75	0.410
MVPA, % WT	-1.10	-1.59	-0.61	**0.000**	-2.89	-3.78	-2.00	**0.000**	-0.03	-1.03	0.98	0.959
Full day												
Wear time, mins	-0.07	-21.42	21.28	0.995	-23.19	-60.68	14.29	0.225	-19.29	-61.35	22.76	0.369
STA, mins	-11.45	-27.85	4.94	0.171	7.02	-19.62	33.67	0.605	5.46	-24.27	35.19	0.719
STA, % wear	-1.69	-3.48	0.09	0.063	2.77	-0.02	5.55	0.051	2.55	-0.55	5.65	0.106
CPM	-9.05	-47.18	29.09	0.642	-133.86	-196.78	-70.94	**0.000**	-66.93	-137.22	3.36	0.062
LPA, mins	17.21	3.47	30.94	**0.014**	-11.03	-34.18	12.13	0.351	-13.04	-38.95	12.87	0.324

	Time point											
	Baseline				**4 Months**				**8 Months**			
Outcome	**β**	**95% CI**		***P***	**β**	**95% CI**		***P***	**β**	**95% CI**		***P***
LPA, % WT	2.46	1.13	3.79	**0.000**	-0.36	-2.56	1.84	0.749	-1.29	-3.75	1.16	0.302
MVPA, mins	-5.16	-11.97	1.66	0.138	-20.07	-30.72	-9.41	**0.000**	-13.14	-24.99	-1.29	0.030
MVPA, % WT	-0.64	-1.54	0.25	0.160	-2.53	-3.90	-1.16	**0.000**	-1.62	-3.15	-0.10	0.037
School breaks												
Wear time, mins	6.61	5.95	7.26	**0.000**	2.91	1.42	4.40	**0.000**	3.99	2.33	5.64	**0.000**
STA, mins	-1.30	-2.82	0.22	**0.095**	6.59	3.80	9.37	**0.000**	5.15	2.02	8.28	**0.001**
STA, % wear	-6.42	-8.74	-4.09	**0.000**	4.50	-0.09	9.08	0.055	1.98	-3.17	7.14	0.451
CPM	122.74	37.62	207.86	**0.005**	-147.96	-312.35	16.43	0.078	26.87	-158.01	211.74	0.776
LPA, % WT	-4.34	-6.82	-1.85	**0.001**	-11.41	-16.52	-6.30	**0.000**	-11.29	17.03	5.56	**0.000**
MVPA, % WT	1.39	-1.02	3.80	0.258	-10.85	-14.71	-6.98	**0.000**	-5.69	-10.00	-1.38	**0.010**
After school												
Wear time, mins	-3.39	-22.46	15.67	0.727	3.52	-30.36	37.41	0.839	-10.27	-48.31	27.76	0.597
STA, mins	-3.26	-16.32	-9.80	0.625	6.28	-14.64	27.19	0.556	13.38	-9.92	36.69	0.260
STA, % wear	-0.84	-3.56	1.89	0.546	3.48	-1.29	8.26	0.153	6.20	0.84	11.55	**0.023**
CPM	-6.08	-72.33	60.17	0.857	-115.61	-240.16	8.94	0.069	-159.13	-299.18	-19.08	**0.026**
LPA, % WT	1.30	-0.49	3.08	0.155	1.78	-1.78	5.34	0.327	-3.00	-7.01	1.00	0.141

	Time point								
	Baseline			4 Months			8 Months		
Outcome	**β**	**95% CI**	***P***	**β**	**95% CI**	***P***	**β**	**95% CI**	***P***
MVPA, % WT	-0.64	-1.54 0.25	0.160	-2.53	-3.90 -1.16	**0.000**	-1.62	-3.15 -0.10	**0.037**

STA, stationary time; CPM, counts per minute; LPA, light intensity physical activity; MVPA, moderate-to-vigorous physical activity; WT, wear time

Table 5.20. A comparison of sitting time within the partial desk allocation group between children located at sit-stand desks and children without sit-stand desks during baseline, 4 month and 8 months measurement phases. Data presented as median minutes (interquartile range), and the median (interquartile range) proportion of wear time spent during class time.

	Baseline		**4 months**		**8 months**	
Class time	Sit-stand desk (n=5)	No sit-stand desk (n=14)	Sit-stand desk (n=5)	No sit-stand desk (n=14)	Sit-stand desk (n=3)	No sit-stand desk (n=9)
Sitting time, mins	140.6 (100.8)	198.0 (36.2)	136.8 (82.0)	180.5 (43.0)	178.0 (68.0)	210.1 (44.0)
Sitting time, % wear time	46.1 (32.5)	68.0 (9.3)	46.7 (26.0)	68.0 (18.0)	58.4 (22.0)	68.9 (15.0)

5.3.4.2. Adiposity

No intervention effects in the FDA or PDA groups were observed in BMI or waist circumference z-scores at any time point (*P* >0.05; see Table 5.21 and Table 5.22).

5.3.4.3. Behaviour-related mental health

Multi-level model estimates for behaviour-related mental health outcomes are detailed in Table 5.23. In behaviour-related mental health models, at baseline, the FDA intervention group had a higher but non-significant total score (β (95%CI); +2.06 (-0.65, 4.78) *P* >0.05) externalising score (+1.66 (-0.38, 3.70) *P* >0.05) and internalising score (+0.40 (-0.91, 1.71) *P* >0.05). These increased to a significant difference at 4 months in the total score (+5.31 (2.55, 8.08) *P* <0.0005), externalising score (+2.60 (0.53, 4.70), *P* <0.05) and internalising score (+4.33 (1.60, 4.30), *P* <0.0005). The difference between groups increased further in all but the internalising score at 8 months and were all highly significant (total score +7.92 (5.18, 10.66); externalising score +4.13 (2.06, 6.20); internalising score +3.93 (3.00, 5.69), all *P* <0.0005).

No intervention effects in the PDA group were observed in all three outcomes at baseline (*P* >0.05) (Table 5.24). However, total, externalising and internalising scores all demonstrated intervention effects (increased) at 4 months (total score +3.6 (1.4, 5.8) *P* <0.005); externalising score +2.0 (0.5, 3.5), *P* <0.05; internalising score +1.6 (0.3, 3.0), *P* <0.05). There were no data provided by the teacher at 8 months.

5.3.4.4. Musculoskeletal discomfort

No FDA group intervention effects were observed in any musculoskeletal discomfort score variable (*P* >0.05) (see Table 5.23). Within the PDA group vs control group models (Table 5.24), combined scores for neck and back were significantly higher at baseline in the PDA group compared to the control group (+0.6 (0.1, 1.2), *P* <0.05). No other PDA group intervention effects were observed (*P* >0.05).

5.3.4.5. Cognitive function

Within cognitive function models (see Table 5.23), the FDA intervention group recorded a slower reaction time in the Stroop test at 4 months compared to the control group which was marginally significant (+133.7 milliseconds (3.7, 263.6), $P < 0.05$). No other differences were observed between groups at 4 months or 8 months follow up in the cognitive function tests ($P > 0.05$). No intervention effects were observed in the PDA group in both cognitive function outcomes ($P > 0.05$) (Table 5.24).

Table 5.21. Estimated effect sizes of the full desk allocation group (compared to the control group) in waist circumference and BMI z-score outcome variables at baseline, 4 months and 8 months from multi-level models. Control n=27, Intervention n=22.

	Time point												
	Baseline				4 Months				8 Months				
Outcome	**β**	**95% CI**		***P***	**β**	**95% CI**		***P***	**β**	**95% CI**		***P***
WC, Z-score	0.04	(-0.44,	0.52)	0.882	0.10	(-0.39,	0.58)	0.692	-0.22	(-0.70,	0.27)	0.377
BMI, Z-score	-0.10	(-0.86,	0.65)	0.786	-0.06	(-0.81,	0.70)	0.884	-0.20	(-0.96,	0.55)	0.600

WC, waist circumference; BMI, body mass index

Table 5.22. Estimated effect sizes of the partial desk allocation group (compared to the control group) in waist circumference and BMI z-score outcome variables at baseline, 4 months and 8 months from multi-level models. Control n=27, Intervention n=19.

	Time point											
	Baseline				4 Months				8 Months			
Outcome	**β**	**95% CI**		***P***	**β**	**95% CI**		***P***	**β**	**95% CI**		***P***
WC, Z-score	0.16	-0.06	0.37	0.149	0.31	0.03	0.60	0.032	0.10	-0.18	0.39	0.478
BMI, Z-score	0.31	-0.01	0.62	0.055	0.33	-0.03	0.70	0.074	0.17	-0.19	0.54	0.360

WC, waist circumference; BMI, body mass index

Table 5.23. Estimated effect sizes of the intervention in behaviour-related mental health, musculoskeletal discomfort and cognitive function at baseline, 4 months and 8 months from multi-level models. Control n=27, Intervention n=22.

	Time point								
	Baseline			**4 Months**			**8 Months**		
Outcome	**β**	**95% CI**	***P***	**β**	**95% CI**	***P***	**B**	**95% CI**	***P***
Behaviour-related mental health									
Total score	2.06	(-0.65, 4.78)	0.136	5.31	(2.55, 8.08)	**0.000**	7.92	(5.18, 10.66)	**0.000**
Externalising score	1.66	(-0.38 3.70)	0.110	2.60	(0.53 4.70)	**0.014**	4.13	(2.06 6.20)	**0.000**
Internalising score	0.40	(-0.91 1.71)	0.548	4.33	(1.60 4.30)	**0.000**	3.93	(3.00 5.69)	**0.000**
Musculoskeletal discomfort									
Whole body	-0.08	(-0.43, 0.26)	0.632	-0.27	(-0.62, 0.08)	0.132	-0.07	(-0.42, 0.29)	0.710
Upper Limb, combined score	-0.41	(-1.11, 0.30)	0.262	-0.38	(-1.10, 0.35)	0.310	-0.08	(-0.81, 0.64)	0.818
Neck and back, combined score	-0.23	(-1.14, 0.68)	0.618	-0.79	(-1.72, 0.15)	0.099	-0.09	(-1.02, 0.84)	0.851
Lower Limb, combined score	-0.13	(-1.55, 1.28)	0.852	-0.39	(-1.85, 1.07)	0.603	0.08	(-1.36, 1.53)	0.911
Cognitive function									

	Time point								
	Baseline			4 Months			8 Months		
Outcome	**β**	**95% CI**	***P***	**β**	**95% CI**	***P***	**B**	**95% CI**	***P***
Corsi Block Tapping (n=42, Control n=20, FDA n=20)	0.21	(-0.52, 0.94)	0.573	-0.33	(-1.08, 0.43)	0.398	0.11	(-0.64, 0.86)	0.769
Stroop, reaction time n= (Control n=25, FDA n=22)	25.43	(-97.35, 148.22)	0.685	133.67	(3.72, 263.62)	**0.044**	37.37	(-92.58, 167.32)	0.573

Table 5.24. Estimated effect sizes of the partial desk allocation group intervention in behaviour-related mental health, musculoskeletal discomfort and cognitive function at baseline, 4 months and 8 months from multi-level models. Control n=27, Intervention n=19.

	Time point												
	Baseline				**4 Months**				**8 Months**				
Outcome	**β**	**95% CI**		***P***	**β**	**95% CI**		***P***	**B**	**95% CI**		***P***
Behaviour-related mental health												
Total score	-0.08	-1.66	1.50	0.918	3.60	1.40	5.81	**0.001**	-	-	-	-
Externalising score	0.29	-0.93	1.50	0.645	1.98	0.48	3.47	**0.010**	-	-	-	-
Internalising score	-0.37	-1.19	0.45	0.375	1.64	0.28	3.00	**0.019**	-	-	-	-
Musculoskeletal discomfort												
Whole body	0.14	-0.07	0.34	0.202	-0.13	-0.49	0.24	0.493	0.05	-0.32	0.41	0.798
Upper Limb, combined score	0.04	-0.43	0.51	0.869	0.54	-0.31	1.38	0.214	0.02	-0.83	0.87	0.962
Neck and back, combined score	0.64	0.07	1.21	**0.029**	-0.94	-2.03	0.14	0.089	0.29	-0.80	1.38	0.601
Lower Limb, combined score	0.19	-0.59	0.97	0.631	-0.36	-1.96	1.25	0.664	-0.28	-1.89	1.34	0.738

	Time point												
	Baseline				4 Months				8 Months				
Outcome	**β**	**95% CI**		***P***	**β**	**95% CI**		***P***	**B**	**95% CI**		***P***
Cognitive function												
Corsi Block Tapping n=42 (Control n=22, PDA n=20)	0.13	-0.21	0.46	0.453	0.17	-0.42	0.76	0.573	0.35	-0.27	0.96	0.271
Stroop, reaction time n=47 (Control n=25, PDA n=22)	-2.29	-60.57	55.99	0.939	116.38	-15.21	247.96	0.083	-54.06	-200.28	92.17	0.469

5.4. Discussion

This pilot controlled-trial evaluated the impact of two 8-month sit-stand desk interventions, implemented within two year-5 primary school classrooms, using different allocation systems, in the city of Bradford, UK. This study adds evidence to a rapidly developing area of research that is currently in its infancy and consists of several fundamental gaps. Firstly, this study adds to the limited number of studies that have measured changes in sitting and standing time, which is essential for determining the impact of standing desks within the classroom. Further, this is the first standing desk study in Europe and second worldwide set within the primary school classroom to not only evaluate the longer-term effects of standing desks but also to include an intervention arm that replaces all traditional desks with sit-stand desks in a classroom. With three measurement points, objective data are also provided on the potential novelty effect of sit-stand desks which is an issue that has not been previously explored. Also, exploring sitting and standing outcomes during different domains of the day provides insight into intervention influences during exposure, any compensatory behaviour occurring away from class time (school break times and after school), and the wider impacts on posture and movement during waking hours; this has not been examined simultaneously before in a longer-term study.

This chapter also evaluated the impact of two 8-month sit-stand desk interventions on outcomes related to child health and development. This study has two important characteristics related to these outcomes. Firstly, this is the first study to measure any longer-term effects of a standing desk intervention on development-related outcomes, (behaviour-related mental health and cognitive function) that may be of interest to parents and professionals within the education system. Secondly, the two included schools in this study were based within deprived neighbourhoods and therefore many of the study sample will have been of deprived backgrounds. During childhood, socio-economic position is inversely associated with childhood adiposity (310) and low socio-economic position during childhood is associated with an increased risk of mortality during adulthood (311). Consequently, many children in this study will have been of higher health risk and are therefore an important demographic for an intervention promoting healthy behaviours.

5.4.1. A summary of the main findings

The main aim of this pilot study was to evaluate and compare the influence of two different interventions in reducing sitting time during class time over an 8-month period. Due to inadequate intervention implementation (rotation) within the PDA class, clear conclusions could not be made on the impact of the intervention on class time sitting behaviour.

Within the FDA class, large reductions were observed in the proportion of wear time spent sitting during class time in the intervention group compared to the control group at both 4 months (-25.3%) and 8 months (-19.9%). Consequently, this is the first study to suggest that sit-stand desks may sustain reductions in sitting time during class time over a longer period (almost a full school year). However, since this is a small-scale pilot study that is unlikely to have sufficient statistical power to assess differences, these and other findings from this study should be treated with caution. Intervention influences of the FDA group compared to control group were also observed in time spent sitting across a full weekday (4 months -7.7%, 8 months -5.5%), suggesting the intervention impacts during class time were large enough to have some meaningful effect during total waking hours. No differences were observed between the FDA and the control group in after school sitting time, suggesting compensation did not occur during this period. Intervention influences observed at 4 months within the FDA class in sitting and standing outcomes did reduce at 8 months, suggesting a novelty effect, although the differences between FDA and control groups were still large. Some compensation may have occurred during school break times in MVPA and during after school periods in LPA and MVPA, but these influences were not consistent in both follow up phases in the FDA group. No intervention influences were observed in adiposity outcomes in the FDA group. No impact of the intervention was observed in cognitive function outcomes in both FDA and PDA groups, suggested that both interventions were not detrimental to cognitive development. However, negative influences were observed in behaviour-related mental health scores at 4 months in both intervention groups and at 8 months in the FDA group (PDA data for this time point was unavailable), which raises some concerns about the impact of sit-stand desks on behaviour. No intervention influence was observed in musculoskeletal discomfort scores in both intervention groups, suggesting that increases in standing time in the FDA group did not lead to increases in discomfort longer-term.

5.4.2. Intervention implementation issues within the PDA class

This study piloted the comparison of a PDA and FDA system over an 8-month period in two-year 5 primary school classrooms within the same school. A PDA system, more economically viable than a FDA system, has previously demonstrated positive preliminary effects in reducing class time sitting (91), albeit within a single class pilot study. Consequently, this approach may be the more cost-effective as a classroom-based sedentary behaviour intervention. Unfortunately, due to factors largely beyond the control of the study, including teacher absence, children were not rotated adequately for each child to be sufficiently exposed to the sit-stand desks within the PDA group class. The lead researcher provided support and assistance with the rotation plan throughout the study (on a monthly basis) but this was not sufficient enough to influence effective intervention implementation. It was originally agreed between the lead researcher and teacher to allow all children to be exposed to the sit-stand desks on one full day each week. The teacher and pupils verbally stated (from general in person discussions) that rotation occurred on some days during the 8-month intervention, but these rotations were interpreted as very infrequent. As a result, it is unknown when and how often each child had exposure to the sit-stand desks. Implementation evaluation data within Chapter 6 attempts to interpret the extent to which children were rotated from interview data. Overall, it would appear that the same six children placed at the sit-stand desks at the beginning of the intervention remained at the same desks throughout the 8-month period, with some sporadic rotation throughout the intervention. With this inconsistent exposure to sit-stand desks, the data from this class, whether postural, physical activity, or other secondary outcomes, are difficult to interpret and therefore clear conclusions cannot be made. Consequently, the ability to compare findings between PDA and FDA arms are limited. As a result, the majority of this discussion section will focus on the influence of the FDA condition. Nevertheless, attempts are made to interpret primary outcome data within the PDA class (see section 5.4.3).

5.4.3. Interpreting activPAL data within the PDA class

As already stated, it would appear that the same six children remained at the sit-stand desks for most of the 8-month intervention. By separating the sitting data of these children from the remaining children in the class who were predominantly located at traditional desks (see Table 5.20), it provided some comparison to the FDA condition. One of the six children located at the sit-stand desks did not provide baseline activPAL data and therefore this sample was reduced to five children. Within these children, class time sitting reduced by 3.8 median minutes at 4 months and increased by 37.4 mins at 8 months compared to baseline. Furthermore, the proportion of wear time spent sitting during class time actually increased at 4 months (median +0.6%) and considerably again at 8 months by 12.3% compared to baseline. These data therefore suggest that exposure to sit-stand desks for the majority of an 8-month period did not influence a reduction in class time sitting. There is the possibility that there was some rotation during the follow up measurement phases potentially reducing the opportunity to stand, particularly at 8 months. The same six children did appear to be located at the desks during follow up assessment weeks however the researchers were present to witness this only sporadically during this time. In hindsight, a formal daily record should have been obtained to capture and confirm this. It may also be the case that these five children simply did not want to stand during class time despite having the option.

Peer influence may have been a factor since the remainder of the classroom, located at traditional seated desks, would have been predominantly sitting during class time. In fact, there may be scenarios in which all children in the class are seated and although a child may have the desire to stand, they may be reluctant to due to the notion of adopting a behaviour (standing while studying) that is in contrast to their entire class of peers. These are conclusions from only five children however it can be assumed that additional challenges may be faced by a PDA system compared to an FDA system. While sitting behaviour may be predominantly a more instinctive, subconscious action during a typical waking day (208) the process of shifting from sitting to standing during a lesson within the PDA class is not a subjective norm, at least not at first. Consequently, it is likely that the decision to stand, particularly when all others are sitting, will involve more conscious processes and evaluative decision making.

Within the FDA class, a teacher led standing class took place on a daily basis. Within the Social Cognitive Theory, this would be modelling of the behaviour (self-efficacy) which in turn will demonstrate to the children that standing in class is a social norm and therefore deemed acceptable. Modelling has been described as potentially having a strong influence on adopting non-sedentary behaviours such as standing during class time (180). This could be one decisive factor between FDA and PDA systems in terms of adopting standing behaviour. Future qualitative research could attempt to shed light on potential peer influences and the impact of modelling on perceptions of standing in class as a social norm. Interview data from this study (Chapter 6) suggests that there may have been some frustration and potential resentment from children predominantly placed at traditional desks towards those located at the sit-stand desks.

When considering the influence of subjective norms within the Theory of Planned Behaviour, specifically the expectation of others behaviour in relation to sitting in class, those located at sit-stand desks may be even more reluctant to adopt a standing posture since they have the option, yet most of their peers do not (and may never have had the opportunity during the 8 month period). Consequently, a more reflective evaluative process may have taken place, resulting in the choice to remain seated. If considering the COM-B model, this is despite the physical and psychological capability, the physical opportunity and both the reflective (at least initially) and automatic motivation to stand during class time. It could be that within the COM-B model, the social opportunity is counteracting other elements to determine behaviour change. Within the Socio-ecological model, within the PDA system, a behaviour change technique has only been applied at the environmental level (provision of sit-stand desks).

The environmental context has been described as a particularly influential determinant of sedentary behaviour (204). However, the social level of the Socio-ecological model may also be having a powerful influence on behaviour within the PDA class. A limitation of the Socio-ecological model is that the connection between the different levels is not explained (204). This becomes relevant in this scenario because a behaviour change technique at the environmental level has created a change in dynamic at the social level with some potentially detrimental barriers towards sitting and standing behaviour change manifesting. Since ecological models cannot explain this social-environmental interaction, it is more difficult to understand the influence of a PDA intervention. Nevertheless, in future, if adopting the PDA system, additional behaviour change techniques may be required at the individual and social level to boost the likelihood of engagement with class time standing.

It is worth pointing out that children located at sit-stand desks had low class time sitting at baseline compared to the remainder of the class (-57.4 median minutes/day, -22% median proportion of wear time) and therefore had less of a capacity to reduce sitting time at follow up periods. Why these children had particularly low-class time sitting (46% (median) of wear time) is not clear. Nevertheless, sitting data over time in children thought to be located at traditional desks followed the same trend as the children located at sit-stand desks, further suggesting that the sit-stand desks did not influence a reduction in class time sitting. This is assuming that the same children remained at the same desks throughout the study, which we cannot say with any confidence.

When considering the class as a whole, class time sitting data suggests a reduction at 4 months follow up of 4.2% ((61.2%) median proportion of wear time spent sitting). There was then a return to baseline values at 8 months (65.6%). These changes coincide with standing data trends; the median proportion of wear time spent standing during class time increased at 4 months by 6% (31%) which then reduced to a similar baseline value (22% at 8 months, 25% at baseline). Conversely, the median proportion of wear time spent stepping reduced at 4 months (-1.6%) compared to baseline but increased at 8 months (+1.8%). Therefore, the reduction in class time sitting in the PDA class at 4 months appeared to be replaced by standing, which may have reduced some time spent stepping.

Compared to the control class, the PDA class recorded a lower median proportion of wear time spent sitting during class time at all three timepoints (-8.2%, -11.4%, -6.6%) with the greatest difference at 4 months. Multi-level model data demonstrated a significantly lower proportion of wear time spent sitting during class time at baseline in the PDA class (β (CI) -5.5% (-8.5, -2.4), P <0.0005) with a reduction in this difference at 4 months (-1.9%) which was non-significant (P >0.05) and then a higher value compared to the control class at 8 months (+2.2%, P >0.05). This suggests the intervention did not influence a change in sitting behaviour at follow up.

It is worth pointing out that these models use mean group data, which will differ from median data, and account for missing data at follow ups by providing an estimated trajectory and therefore estimated observations for each participant in which model estimates will comprise of. Since there were seven participants with missing data at 8 months in the PDA group, reducing this to a very small sample (n=12), it is possible that the model estimate provided a somewhat erroneous value for the PDA group. This would explain the discrepancy between the difference in median values at 8 months between PDA and control classes in participants providing data (-6.6% in PDA compared to control) and the model estimate (+2.2%). Overall, these conflicting data could be largely due to the small sample within the PDA class at different follow periods (e.g. n=12 at 8 months) providing large variances. As already stated, it is not entirely clear the extent to which different children in this class were exposed to sit-stand desks which therefore enhances the difficulty to interpret whole class data.

5.4.4. The impact of the FDA intervention on sitting time

Within the FDA class, large reductions in the proportion of wear time spent sitting during class time were observed at 4 months (-25.3%) and at 8 months (-19.9%), in the intervention group compared to the control group, suggested a positive direction of change. This is further supported when considering that there was less than 2% difference between groups at baseline in classroom sitting time, and the control group recorded little change over 8 months. These trends are also reflected in school-day waking hour sitting minutes, with the control group reporting relatively stable values across time points (<16 min difference in follow ups compared to baseline), whereas the intervention group demonstrated large reductions at both follow ups compared to baseline (-96 min and -60min, respectively). Consequently, these findings suggest that sit-stand desks may influence reductions in total class time sitting and waking hours sitting on school days, in both the mid (4 months) and longer-term (8 months) and this study is the first to date to demonstrate this finding.

There was also evidence that the intervention influenced an increase in interruptions in sustained periods of sitting during class time. Large reductions in the proportion of wear time spent sitting in prolonged bouts (10+ mins) and greater sit-to-stand transitions per hour of wear time at 4 months were observed in the intervention group compared to the control group. These changes became greater in both outcomes at 8 months. Taken together, this suggests that the intervention group interrupted prolonged sitting bouts via a greater frequency of standing transitions during class time. Consequently, it would appear that the intervention may have had some influence on not only reducing total sitting time, but also in breaking up more sustained periods of sitting in the longer-term. This finding is important because from previous evidence it is unclear whether standing desks can promote regular breaks in prolonged sitting (294). Interrupting prolonged sitting bouts may be a more beneficial behaviour change than replacing sitting time with prolonged periods of static standing as this can carry some health risks of its own (228,295). Recent evidence suggests that a higher frequency (up to 3.1/day) of prolonged sitting bouts (30+ mins) is associated with reduced HDL cholesterol in overweight and obese children, independent of total sitting time, MVPA, saturated fat intake and body composition (95). Consequently, a reduction in time spent in prolonged sitting bouts in the present study may provide some important health benefits. This could be particularly relevant to the South Asian participants within the intervention group (46%) as there is evidence that British South Asian children have lower HDL cholesterol compared to White British children (133). However, this potential risk (of time spent in prolonged sedentary bouts) is based on a single study of just 120 children (95). Furthermore, the majority of the participants in the present study were of a normal BMI. Very few studies to date have explored the relationship between sedentary bouts and cardio-metabolic health outcomes in children (42). Those that have, have typically used accelerometry, which, as already stated in Chapter 1 section 1.4.2.1, does not distinguish between sitting and standing time, providing inaccurate sedentary data. Consequently, the relationship between prolonged sitting bouts and cardio-metabolic health in children is currently unclear, with more studies including larger sample sizes and accurate measures of sitting time needed.

The sit-stand desks, implemented on a full allocation basis, appeared to influence a positive direction of change towards reduced class time sitting merely by providing the opportunity to sit or stand and with few other supplementary intervention functions. The teacher led standing classes that took place every day within the intervention group that were approximately 20 mins in duration. When excluding this time from the total class time reductions observed, the intervention group still reduced class time sitting by 76 minutes and 40 minutes at respective follow ups. This suggests that behaviour change may have occurred more naturally, without the necessity of a behaviour change technique, where children chose to shift from sitting to standing when given the option. This finding has been evidenced in several previous standing desk studies (91,237,238), although these were small scale pilot studies and conclusions should be treated with caution due to low statistical power of these studies. Nevertheless, this may have important implications for intervention design and implementation. The self-service design of sit-stand desks means that the demand of the teacher for the intervention to be implemented sufficiently is minimal (some effort may be required to ensure children use the correct posture when standing). Previous school-based health interventions have often been insufficiently implemented by teaching staff because of crowded curriculums and day-to-day teaching demands (228). This point is demonstrated by the outcome of the PDA group within the present study where intervention implementation was insufficient. The teacher-led standing classes in the intervention class may have been a catalyst for increasing standing time by modelling standing behaviour during lessons as a social norm and providing the social opportunity to change sitting behaviour. Unfortunately the impact of this intervention function was not captured during the implementation evaluation process, however, previous standing desk interventions have not included a teacher led class and still observed reductions in class time sitting (91,237,238). This observation suggests that within the COM-B model, while it may be beneficial to target all three determinant sources of behaviour (capability, opportunity and motivation), providing the physical opportunity to stand within the classroom (via sit-stand desks) may be sufficient to elicit reductions in sitting time within the classroom setting. This suggests that by simply reversing the daily physical environments in which children commonly operate from sedentary-inducing (fixed seating) to activity-permissive (sit-stand desks), the high proportions of sedentary time that are commonly observed can be reduced. The present study and evidence base in general are preliminary and limited and therefore these are not definitive conclusions. Nevertheless, future larger scale studies may benefit from comparing the provision of a sit-stand desk alone as an intervention design to an intervention consisting of several behaviour change techniques designed to directly promote an increase in standing time during lessons in children. These comparisons would help determine whether targeting all aspects of the COM-B model (capability, opportunity and motivation) can elicit additional reductions in class time sitting beyond the provision of a standing desk alone (opportunity only).

This study is only the second to explore the effects of sit-stand desks in reducing SB within the primary school classroom in the longer-term. Ayala et al. (2016) (268) also conducted an 8-month controlled trial, with the same number of study groups (two) and the same sit-stand desk (Ergotron LearnFit) provided to every pupil in the intervention group. The same activPAL inclinometer device was also used to measure time spent in different postures in both studies, with almost identical measurement and data management protocols. In the present study, other than a daily teacher-led 20-minute standing class and support methods provided for the teacher to deliver these classes, the intervention was delivered simply as access to a sit-stand desk and the free choice between sitting and standing. Conversely, Ayala et al. (2016) (268) included several behaviour change strategies including professional development sessions with the teacher, health promotion classes with the pupils, daily standing classes and active break periods during class. Despite similarities in study designs and the additional behaviour change strategies, the Ayala et al. (2016) (268) study did not observe any changes in total class time sitting and only modest reductions in the time spent in 10+ min sitting bouts (-18 mins) relative to a control class after 8 months of exposure. The intervention group within the Ayala et al. (2016) (268) study was sedentary at baseline at a similar level (68% of wear time spent sitting) to the intervention group in the present study (70% of wear time spent sitting). This suggests that baseline sitting time was not a major factor in explaining the difference findings observed. It could simply be that the small samples or the differences between countries and school environments were the fundamental reasons for different sitting behaviour observed between studies. Future studies may benefit from the inclusion of qualitative measures to determine why children did or did not choose to stand during class time when exposed to a sit-stand desk.

Just two other standing desk studies have previously measured sitting time during class (91) or school time (238) in primary school children. Within the Clemes et al. (2015) (91) study, the proportion of classroom wear time spent sitting reduced by 9.8% (-52 min/day) in the UK trial and by 9.4% (44 min/day) in the Australian sample after 9 weeks. Aminian et al. (2015) (238) observed a reduction in sitting time of approximately 60 mins/day during school time in an intervention class, also after 9 weeks. However, when compared to a control group, a significant effect was only found in the Australian trial within the Clemes et al. (2015) (91) study. It is difficult to compare the findings of these studies with the present study since they are of shorter duration. Nevertheless, the present study demonstrated greater reductions in sitting time compared to the control group and within the intervention group at both follow up periods compared to these studies during time spent at school. A common issue identified in these studies (and by Ayala et al. (2016) (268)) was contamination, whereby the control group was located in close proximity to the intervention group and the controls had some exposure to the intervention. This is one possible reason why effects were not observed when comparisons were made to a control group. This is a strength of the present study, since the control group was in a separate school nearby and is one possible reason why large changes were observed. Small sample sizes insufficient to detect significant changes may be another key reason for limited effects compared to controls. Another reason for the large changes observed in the present study could be due to the sample being highly sedentary during class time at baseline (72% of wear time). This was also evident within the UK sample of the Clemes et al. (2015) (91) study (72%), compared to the Australian sample (62%), who consequently had more potential for change. This may be one reason why the UK sample demonstrated greater reductions in class time sitting in the Clemes et al. (2015) (91) study, despite having just one hour a day of exposure to sit-stand desks per child, compared to the Australian sample, who received a sit-stand desk each and therefore had maximum possible class time exposure (91).

The reductions in sitting time observed during class time appeared to be largely replaced with standing time. At both follow ups, identical reverse changes were observed in proportion of wear time spent sitting and standing in the FDA group compared to the control group. This finding is also reflected in minute data, where the intervention class demonstrated a large increase in standing time at both follow ups (+77 min and +46 min) which accounted for the majority of reduced sitting time (-96 min and -60 min). Increases in stepping minutes were modest (<10 min) which is reflected in potential intervention influences only being observed in stepping time at 8 months, which was small (+2.2% of wear time, $P < 0.05$). In light of this, it was somewhat surprising to find significant increases in LPA at both follow ups in the intervention compared to the control group during class time. Since little change was observed in stepping outcomes, it suggests children may have engaged in some dynamic standing, where children moved from side to side without moving their feet, or, that some stepping was too subtle to be detected by the activPAL monitor. Nevertheless, the observations within the activPAL data are somewhat consistent with previous primary school standing desk studies, where an increase in standing time is reported when sitting time reduced within intervention groups, but no change is observed in stepping outcomes (91,237,238). An exception is the UK sample within the Clemes et al. (2015) (91) study, who observed a change in stepping time and total steps but not in standing time. This was attributed to the intervention design, where children were rotated between several sit-stand desks and traditional desks on a daily basis, which will have encouraged greater movement around the class.

One important point from a practical perspective in the present study is that due to the limited classroom space from stools blocking walkways, children were instructed to remain at the same sit-stand desk for every class by the teacher.

Normally, the children would move to different desks for different subjects based on ability. This alteration will have contributed to less steps being performed by the children. If space was not an issue, and the children continued with usual classroom rotation practice, these additional steps may have resulted in more of a change in stepping outcomes. However, this can only be speculated with the evidence available. Interestingly, Hinckson et al. (2013) (237) and Amininan et al. (2015) (238) observed reductions in sit-to-stand transitions from a fixed workstation intervention design. This design promoted sustained standing which is possibly why sit-to-stand transitions reduced in the intervention group compared to traditional classroom furniture used at baseline (228). In contrast, Ayala et al. (2016) (268) and the present study observed significant increases in sit-to-stand transitions in groups using the same sit-stand desk, freely adjustable between sitting and standing positions at any time. Overall, these findings suggest that different standing desks and intervention designs can have different impacts on non-SBs and potentially result in different influences on health, although the exact health impact of regularly breaking up periods of prolonged sitting in children needs further examination in laboratory-based and free-living studies.

5.4.5. What was the impact of the FDA intervention on posture during waking hours on school days?

Changes observed during class time within the FDA class appeared to influence the overall waking day on school days. At both follow ups, significant reductions were observed in total sitting time (-7.7% and -5.5%), increased standing time (+8.8% and +5.8%), greater sit-to-stand transitions per hour of wear time (both +1.4) and less time spent in prolonged bouts of sitting (8 months only, -7.4%), in the FDA group compared to the control group. Although the levels of significance were generally lower, these observations are a close reflection of changes observed during class time. This suggests that class time changes were large enough to make an impact on posture during total waking hours. This finding could be meaningful because it is currently unknown if standing desks reduce sitting time over total waking hours, beyond the primary school classroom setting (294).

Only one previous standing desk study to date has observed a reduction in total daily sitting time compared to a control group in children (237). Using fixed workstations shared between several children, Hinckson et al. (2013) (237) observed a small reduction in sitting time during full waking hours after 4 weeks of intervention exposure in New Zealand elementary school children. Any changes during class time were not reported so it is unknown what influence the intervention may have had during exposure. Other studies have observed reductions in total daily sitting time within an intervention class (91,238) but these were not significant compared to control groups. Reductions within Intervention groups have been attributed to intervention influences during and beyond the classroom (91). In fact, in a recent systematic review, the full day reduction observed in the UK trial of the Clemes et al. (2015) (91) study (-81 mins) was found to be the largest across all school-based SB interventions (236). However, this large reduction may be partly explained by a lower wear time at follow up. A small non-significant reduction was observed in the proportion of wear time spent sitting in the intervention group (-2.3%) which was identical to the control class. Similar trends were also found in the Australian trial (large reduction in total minutes but little change in proportional sitting time in the intervention group), which highlights the need for changes relative to a control class to be observed, along with the importance of controlling for device wear time, if any assumptions of a full day influence can be made.

Clemes et al. (2015) (91) suggested that the lack of a full day influence across standing desk studies suggests multi-setting interventions may be required, particularly in highly sedentary groups. Within the present study, at baseline, the intervention sample were highly sedentary during total waking hours on a school day (68% of wear time), during class time (72%) and after school hours (70%) and still the standing desk intervention may have influenced a reduction in sitting time over a full week day compared to a control group. This therefore suggests that the classroom, when implementing a sit-stand-desk to every child, may be the only setting necessary to influence a reduction in total day sedentary time. However, it is worth mentioning that since after school sitting time did not change, it would appear that reductions in total day sitting were brought about from class time changes and therefore the intervention may not have any influence on SB away from school hours. Nevertheless, the absence of a change in after school sitting behaviour in the intervention group suggests that compensation did not occur following an increase in standing time that took place during school hours. These conclusions, drawn from small scale pilot data, are only tentative.

Recent longitudinal evidence suggests that the largest increase in daily sitting time, both spent in total and in prolonged bouts, occurs during 9-12 years of age from childhood into adolescence in UK children (96), emphasising the importance of reducing total day sedentary time observed in the present study. These findings would need to be replicated on a larger scale (i.e. using a large clustered randomised controlled trial set across multiple locations in the UK) to be able to conclude with any confidence that sit-stand desks, implemented on a full allocation basis, reduce SB over a full waking day over the longer-term in UK children.

5.4.6. Was there any evidence of compensation in the FDA group?

No differences in after school sitting time were observed between groups at both follow ups, suggesting after school compensation from reduced class time sitting did not occur. The intervention group did record less time spent in LPA and MVPA at both follow ups after school compared to the control group, but these differences were also evident at baseline and only MVPA at 8 months was significantly lower ($P < 0.05$) in the intervention group compared to the control group (-3.5% of wear time). During school break times, at baseline the intervention group recorded significantly more time spent in MVPA compared to the control group (+6.9%, $P < 0.01$), however, at 4 months follow up this trend reversed (-6.2%, $P < 0.05$) which could potentially be interpreted as compensatory behaviour. However, at 8 months follow up, while the intervention group still performed less MVPA compared to the control group, the difference between groups was small and insignificant (-1.9%, $P > 0.05$). Therefore, if the finding at 4 months does reflect compensation, it was not evident at 8 months.

Over a full week day, the FDA group demonstrated significantly less MVPA minutes at both follow ups (-17.6 min and -14.8 min; $P < 0.05$) and in the proportion of wear time spent in MVPA at 4 months compared to the control class. However, the FDA group did record less MVPA at baseline compared to the control group.

Furthermore, within FDA group data, MVPA minutes increased at 4 months (+9.7 mins) and then again at 8 months (+14.4 mins) compared to baseline. Total MVPA minutes were also greater than the recommended 60 minutes per day for children (28) at every time point in the FDA group (as well as in the control group). So while some MVPA compensation may have occurred during school break times at 4 months, and after school at 8 months, this did not seem to be of detriment to a full day of MVPA engagement in the FDA group. No previous standing desk study with children has reported MVPA data and therefore any previous evidence of MVPA compensation is unknown. The increase in MVPA minutes that children engaged in at 8 months compared to 4 months, in both groups, is probably due to the contrasting seasons during these measurement periods. The final follow-up measurement occurred during the summer (July) whereas the first follow up occurred during the winter (February). The summer season has been associated with more time spent in MVPA in English children before compared to the winter season (291) and the longer daylight hours during the summer has been associated with greater total PA compared to other seasons (284).

In adults, reduced sitting time and increase standing and LPA during office hours from a standing desk intervention has resulted in an increase in time spent sitting during non-work hours and less LPA, but no effects on MVPA were observed (265). Ayala et al. (2016) (268) found no evidence of sitting, standing or LPA compensation when school breaks were included in their analysis, although class time changes were modest and therefore compensation may be less likely. The authors did suggest that after school compensation of time spent in prolonged sitting bouts may have occurred but behaviour during this time was not reported so this is somewhat speculative (268). No other standing desk study in children has reported PA behaviour during school break times to date. Only one previous study has reported after school behaviours (238) which did not observe any sitting, standing or stepping time compensation after 5 and 9 weeks of intervention exposure. Overall there would appear to be some evidence of compensation in standing desk studies, but it is scarce and generally little attention has been given to this outcome. More studies need to explore time spent in different postures and physical activities during different periods of the day and the day overall when examining compensatory behaviour (294).

5.4.7. Was a novelty factor observed in the FDA group?

There was some evidence of a novelty effect after 8 months of intervention exposure in the FDA class in this study. The positive direction of change observed at 4 months in sitting and standing time in the FDA group reduced at 8 months where the difference between FDA and control groups narrowed. However, the difference between groups for both outcomes was still large at 8 months (proportion of wear time spent sitting -19.9%, standing +17.8%) and highly significant (P <0.0005). These changes also appeared to have an impact on sitting and standing time during a full waking day. Consequently, any novelty effects that transpired did not prevent the intervention within FDA class from potentially having a positive influence. This is further supported by the finding that a reduction in time spent in prolonged sitting bouts and an increase in sit-to-stand transitions per hour of wear time observed at 4 months, further improved at 8 months during class time. Interestingly, reluctance of the children to stand at the desks during lesson time was evident in the second class observation conducted around the 4 month period (see Chapter 6). This suggests that some novelty effect may have developed by the first follow up and influences of the intervention in sitting and standing time may have been even greater during the earlier months. Nevertheless, it is potentially encouraging that with such high daily intervention exposure time, whereby novelty effects may develop faster, the sit-stand desks appeared to influence positive change after a long period. Further research is required to determine the long-term (e.g. 2 – 3 years) impact of sit-stand desks on posture.

This is the first standing desk study to consider novelty effects in children to date (294). Aminian et al. (2015) (238) used two follow up measures in their study, however the final follow up of objective measures was conducted over the short-term (9 weeks). While the intervention did not appear to influence a reduction in sitting time relative to the control group, class time sitting continued to decrease at week 9, beyond week 5 changes observed in the intervention group. Qualitative outcomes with children and the teacher after 5 months of exposure did not reveal any evidence of a novelty effect developing, despite also including high standing desk exposure time per child. This intervention included shared standing workstations as well as Swiss balls, bean bags and mats for sitting/resting. This set up may have provided a more fun classroom environment compared to the more individualised and simplistic design in the FDA class within the present study, and subsequently the interest of the children may have endured further. Future studies should better explore novelty effects of standing desk interventions by including short, mid and long-term follow up measures of sitting and standing time, with frequent classroom observations throughout, and in-depth focus groups and interviews with pupils and staff, with questions directly addressing user interest in the intervention. Such studies will be essential to inform our knowledge about sit-stand desk use and could impact future policy changes in terms of classroom furniture provision.

5.4.8. What were the influences on adiposity?

No change was observed on the adiposity outcomes in this study in both FDA and PDA groups. These findings are consistent with Ayala et al. (2016) (268) who also observed no change in the same outcomes after 8 months, although this is more expected from the modest reductions in sitting time they observed (compared to the 60 minute reduction in waking hours spent sitting we observed at 8 months in the FDA group). These findings are also consistent with previous SB interventions based within an educational setting and of single-component design (targeted SB and no other lifestyle-related behaviours) (135).

It is worth pointing out that both BMI z-scores and waist circumference z-scores were lower in the FDA group compared to the control group at 8 months (-0.2 for both), and the difference between groups was greatest at this time point, suggesting these outcomes may have had some influence from the reductions in class time sitting. The control group demonstrated their highest values in both outcomes at 8 months, whereas the FDA group had the same BMI z-score and a lower waist circumference z-score at 8 months compared to baseline values. With only a small change in these outcomes required for a meaningful effect, the small sample may have lacked statistical power to detect a difference. Furthermore, it is possible that more time was needed to observe larger effects. A recent study with

3rd and 4th grade children in Texas, USA (n=193), reported a reduction in BMI percentile (-5.24%) after two years of exposure to stand-biased desks (n=62) compared to children who had no exposure (299). Children using the standing desks for one of the two years (either the first or the second year) did demonstrate reductions in percentiles compared to the control group but these were less than the full exposure group and non-significant. Consequently, it is possible that the present study was too short in duration to observe large enough changes in body composition outcomes. Unfortunately, time spent in different postures and physical activities were not reported in the Wendel et al. (299) study, so conclusions about the required changes in these outcomes to influence BMI outcomes meaningfully are not possible.

Stand-biased desks have consistently demonstrated increased energy expenditure over short periods of time (2 hours) within the school classroom (256,258,260), with some evidence of an increase in total steps being a possible reason for this finding (258,260). Since only steps were reported, it is unknown what impact the stand-biased desks had on sitting, standing and other PA outcomes. Nevertheless, one reason why larger effects in adiposity outcomes were not observed in the present study may be because total day sitting time was largely replaced with standing with minimal change in stepping or other intensities of PA. The energy costs of time spent standing in children is currently unknown, but laboratory (56) and office-based studies (57) in adults have demonstrated modest but meaningful increases in energy expenditure with prolonged (56,57) or intermittent standing (56) over several hours compared to sitting. While standing time increased substantially, there are suggestions from classroom observations and focus groups that children often used the desks to lean on when standing, which would have reduced the physical exertion on postural muscles and any subsequent energy demands or physiological adaptations. This may be another possible reason for a lack of change on adiposity. To better understand the role that standing desks can play in this area, controlled laboratory studies are needed to compare energy expenditure (measured with validated indirect calorimetry) during a prolonged (i.e. 3-hours) sitting condition with intermittent and prolonged standing conditions in children. While not entirely representative of child classroom behaviour, these controlled conditions will more accurately shed light on the specific metabolic elevations elucidated from periods of standing in combination with sitting compared to sitting exclusively, which children may experience with traditional classroom furniture.

Since most of the reduced sitting time over waking hours observed in the FDA class appeared to take place during class time, screen time SB may have remained unaltered, which is important in terms of adiposity. Screen time, particularly TV viewing, is adversely linked with adiposity and cardio-metabolic outcomes in children (42). Thus, while the FDA class successful reduced class time sitting, strategies to reduce TV viewing out of school hours may still be needed for changes in adiposity. It has also been suggested that for meaningful changes to be observed, strategies addressing dietary intake and nutrition need to be implemented in addition to any SB intervention (15,135). Even if the intervention within the FDA group influenced greater energy demands from reduced sitting and increased standing time during waking hours, it is very possible that energy intake increased accordingly to balance out this change, preventing a net reduction.

Furthermore, pubertal maturation will influence large changes in lean and fat mass which will confound and further complicate outcomes within longitudinal and experimental studies (15). It was highlighted in Chapter 4 that measuring adiposity at a single time point does not account for growth (height and weight) trajectories over time. Consequently, the relationship with sedentary and PA outcomes are likely to be confounded to a greater extent than in longitudinal data. The longitudinal design in this study will have accounted to some extent for the varying rates of maturation and therefore natural alterations in adiposity indicators over time. Despite this, it is still difficult to extrapolate any influence of a change in sitting and standing behaviour on BMI or waist circumference during follow up measurement phases amongst the abundance of widely varying changes in body shape, size, lean mass and fat mass within the FDA class, particularly in a small sample. Trends within the control and PDA classes can serve as meaningful comparisons to those within the FDA class to potentially help clarify this. Since trends within PDA and control groups did not demonstrate a consistent direction of change in BMI or waist circumference z-scores over time, in contrast to FDA data, this then potentially suggests that there was some positive influence of sit-stand desks on these outcomes within the FDA condition. However, with small samples in each condition, and the fact that the development of secondary sexual characteristics was not measured in this study, the trends in adiposity data observed within the FDA group at follow ups (compared to baseline and the control group) could simply be due to factors associated with pubertal maturation.

It may be worthwhile to incorporate more intense PA breaks in sitting time during class, in addition to increases in sit-to-stand transitions and standing time available from sit-stand desks, to enhance effects on body composition (268) and cardio-metabolic health. Belcher et al. (312) observed meaningful reductions in insulin, C-peptides, glucose and free fatty acid concentrations in healthy children (7-11 years old) when prolonged sitting (3 hrs) was interrupted with 3 mins of moderate intensity walking every 30 minutes, compared to continuous sitting, without an increase in dietary intake following the 3 hours. While this frequency and mode of interruption may be unrealistic during class time, it highlights the acute health benefits that an active break of higher PA intensity can produce.

Although the evidence base is very small, the relationship between total SB and adiposity in children is inconsistent and unclear from cross-sectional, longitudinal and experimental evidence (15). Consequently, it may be unrealistic to expect changes in body composition from a school-based standing desk intervention alone. Despite this, evidence from a recent high quality meta-analysis study reported that SB interventions are more effective in overweight and obese children in improving body composition, potentially to a clinically meaningful extent at population level (135). Consequently, standing desk strategies could still play some part in reversing or at least delaying the onset of obesity as children progress into adolescence. Although less feasible, it seems worthwhile for future standing desk studies to span two school years (i.e. year 5 and 6 of primary school) to determine whether previous evidence (299) can be replicated and whether longer-term follow up is a key factor in improving adiposity. Furthermore, if DEXA scanning is possible in at least a small sample, it would provide accurate data on proportions of fat and fat free mass, which have important health-related metabolic influences (313). A shift from sitting time to standing time, although a small stimulus, may influence some increase in muscle mass and strength, and subsequent reductions in adipose tissue. Consequently, this measure may provide sensitive enough data to detect small yet important adaptations in children over the long-term from a standing desk intervention, particularly in obese children.

5.4.9. Impacts on behaviour-related mental health

This is the first study to explore classroom behaviour over the longer-term within a primary school standing desk study. There was evidence that the FDA intervention had a negative effect on behaviour-related mental health. Although total Strengths and Difficulties scores were higher at baseline in the FDA group compared to the control group (+2.1), the difference increased with time (+5.3 and +7.9). The control group had relatively consistent scores across the three measurement points, whereas the FDA group demonstrated continuous increases from baseline onwards (9.6, 11.0, 14.0). A score of between 12 and 15 is the threshold for a 'slightly raised risk' of behavioural disorders. Consequently, by 8 months the FDA group had progressed from a 'close to average' risk to 'a slightly raised risk' of behavioural disorders, which is concerning.

Within PDA class data, a similar development occurred in that after 4 months of sit-stand desk exposure, total score (+3.6), externalising (+2.0) and internalising scores (+1.6) all increased significantly compared to the control class. Unfortunately, due to the PDA teacher losing the completed questionnaires for that class at 8 months, a comparison of behaviour compared to baseline cannot be made for the final time point. Nevertheless, the 4-month data further suggests that the presence of sit-stand desks within the school classroom may attenuate behaviour-related mental health, even when occupying a small section of the classroom.

During the semi-structured interview at 4 months with the FDA class, the teacher of the FDA group stated that classroom behaviour had improved since the sit-stand desks were installed, which clearly contradicts the behaviour-related mental health scores that the teacher provided. He did also state that there was a lack of space to move around the classroom due to the stools blocking the walkways, causing some children to 'bump' into each other. This was also highlighted by several children during the focus groups at 4 months, stating the desks were distracting due to more movement and 'bumps' and 'nudges' while working. This suggests that a lack of space in the classroom may have caused some conflict between pupils and gives some explanation for attenuated behaviour. If this is the fundamental reason, and not due to changes in adopted postures during class time, it is less of a barrier to standing desk acceptability. If manufacturers would be prepared to take this issue on board and design a more space saving sit-stand desk (i.e. space for the stool to fit under the desk when in the standing position), this issue is less likely to be repeated. This is generally a limitation of a full allocation intervention design, because if insufficient space is an issue, it will affect the entire classroom. This problem forced the teacher in the FDA classroom to change his teaching methods, whereby children were instructed to remain at the same desk for every class, instead of rotating throughout the day as was usual practice. The lack of space along walkways was also a health and safety risk for the teacher to contend with. Conversely, having a partial allocation system, where only a small section of the classroom is occupied by a sit-stand desk, limits the lack of space to one section of the room.

However, within qualitative data from the PDA class (Chapter 6), children did indicate that some children got “into trouble” due to the extra distraction of the new desks. The teacher suggested that the inclusion of the desks made it more difficult to manage more behaviourally challenging children. He went on to state that when rotation did occur, this caused “chaos” and was not feasible. He described difficulties with children moving their personal belongings each time and that children were possessive of their desk and did not favour being systematically moved around the classroom. This all suggests that while less classroom space is occupied by sit-stand desks in a PDA system, the nature of child rotation on a regular basis may bring behavioural issues of its own. The contrast between some children located at sit-stand desks and others at traditional desks, with differing seating heights or postures if standing occurs at a sit-stand desk, could have resulted in some children becoming distracted merely by the novelty of this new dynamic. However, the teacher stated that classroom behaviour in general had not changed (after 4 months). Nevertheless, whether a full or partial allocation system, questionnaire and interview data suggests that these desks can potentially be disruptive and create new challenges in classroom management for teaching staff. Despite the evidence discussed here however, this study lacks the required level of qualitative data to more clearly determine reasons for attenuated behaviour in both the FDA and PDA classrooms.

There are previous examples, albeit scarce, of space issues in the classroom and conflict between children within standing desk classrooms. Within the 'dynamic classroom' of the Aminian et al. (2015) (238) study, one child reported overcrowded shared workstations and conflict with demand for Swiss balls (for seated rests) as there was an insufficient number. Clemes et al. (2015) (91) also observed issues with insufficient classroom space from a PDA sit-stand intervention in a UK sample, but detrimental effects on behaviour were not mentioned (228). Overall, few studies have explored the influence of standing desks on classroom behaviour (238,257,261,263), of which, there is little evidence of a negative impact. Koepp et al. (2012) (261) did not observe any change in classroom behaviour after 5 months from teacher observations in a small sample of 11-year olds (n=8). Aminian et al. (2015) (238) found no change in ADHD symptom scores or in normal behaviour in 9-11-year-old New Zealand children after 4 and 8 weeks of exposure to shared standing workstations (4-5 children per station), Swiss balls, bean bags and mats. Also, after 5 months, focus group data suggested that children were generally positive towards the intervention and happy with classroom space. The teachers were of similar opinion in interviews, suggesting the children were happier and better behaved. Blake et al. (2012) (257) reported an improvement in child (6-7 years old) focus and concentration from stand-biased desks from teacher feedback after 5 months in a US elementary school. Dornhecker et al. (2015) (263) observed a small non-significant increase in academic engagement after 5 months of exposure to stand-biased desks in a large sample of 7-10-year olds (n=282). These studies all provided a standing desk to every child in the class yet negative effects on behaviour were largely unobserved. This suggests that the current findings from a full allocation intervention are an exception to the wider evidence, although this study provides the first longer-term evidence. Interestingly, within the Amininan et al. (2015) (238) study, researchers integrated teaching staff into the intervention design process. Since teachers will know what is most likely to influence child behaviour positively, this decision may have been a major contributor to positive classroom behaviour. Future studies should try to follow this practice if available budgets and resources are permitted. Generally, more qualitative evidence is needed into the impact of different standing desk intervention designs on class behaviour.

5.4.10. Influence of the FDA intervention on musculoskeletal discomfort

Despite a large increase in class time spent standing at both follow ups in the FDA group, no changes in musculoskeletal discomfort scores were observed. This includes lower limb, upper limb, neck and back and whole-body scores. This finding is consistent with previous standing desk studies of 5 months (261) and 8 months (268) durations. Both studies provided standing desks to every child so intervention exposure per day was high, although changes of time spent in different postures was small in the 8-month study and the 5-month study did not report time spent in different postures. This study also contained a small sample (n=8) and did not include a control group. Benden et al. (2013) (259) observed improved discomfort scores from standing at a stand-biased desk compared to sitting at traditional class furniture in 7-9 year old Texan (USA) children. However, measurements were conducted at a single time point and so temporal effects were not explored. Nevertheless, the present study findings add to previous evidence by suggesting that standing desk interventions, including those with high class time exposure, do not influence increased physical discomfort in the mid and longer-term, even after large increases in daily standing time are observed. This finding is somewhat surprising in the present study when considering that poor postures were observed in many children when in a standing position from both class observations (day 1 and week 16 of exposure). Some children also mentioned that many pupils in the class did not know the correct posture when standing at the desks, and one child stated during focus groups in Chapter 6 at 4 months that children often lean to one side. There is evidence that a poor standing posture can lead to lower back pain (314). Our evidence suggests that a poor standing posture does not influence musculoskeletal discomfort in young ages over time, possibly because the desk was used as a standing support, lessening the load on muscles and joints. However, this study only has limited observational and qualitative evidence of the extent to which incorrect postures occurred. The FDA group accumulated very few minutes in prolonged standing bouts (<8 min at both follow ups) during class time, suggesting sit-stand desks do not influence shifts towards prolonged standing. This is important because prolonged static standing can cause lower back pain in children (315). Like in cognitive function outcomes, no evidence of a negative direction of change from a standing desk intervention in discomfort related outcomes is a positive finding. An increase in discomfort in the legs and back has been reported by adolescents (12-16 years old) when standing at sit-stand desks after 7 weeks (316). Consequently, age may be an important factor in discomfort and pain experiences when shifting from sitting to standing behaviour. Further research with sit-stand desks should provide more information to children and their teachers on how to achieve appropriate postures when standing at these desks in class to prevent any long-term detrimental musculoskeletal effects, should sit-stand desks become a permanent feature within school classrooms.

5.4.11. Cognitive function

This is the first study to measure cognitive function in a standing desks intervention within the school classroom. Although reaction time within the Stroop test was marginally slower in the FDA group compared to the control group at 4 months, generally no significant changes were observed in cognitive function in both FDA and PDA groups compared to the control group. This suggests that standing desks were not detrimental to cognitive development over the longer-term, which is consistent with a previous standing desk study (261). Koepp et al. (2012) (261) did not observe any change in concentration after 5 months within an intervention group allocated one standing desk per child, although this was in a sample of just eight children. In a recent thorough systematic review, either no association or inconsistent evidence was found in studies exploring patterns of objectively-measured SB and the relationship with psychosocial, gross motor skills or cognitive outcomes in children (43). Consequently, compensating sitting time with standing time may be unlikely to have an influence on learning and development outcomes. However, there are currently few studies available, most of which being of low quality with high risk of bias (43) with sedentary time being measured by accelerometers which cannot accurately distinguish between sitting and standing postures (23). Consequently, conclusions cannot be made about the relationship between SB and learning and development in children as yet. Cliff et al. (2016) (43) concluded that more intervention studies influencing subtle shifts from sitting to standing and light physical activities to investigate the impact on youth development are needed. If no intervention effects are observed, this can be interpreted as a positive outcome for standing desks within an educational context, in that, this type of intervention can be considered not to be detrimental to learning and development

5.4.12. Limitations and strengths of the study

This study had several limitations. With just two intervention groups and one control group, this study had a small sample of groups and participants which limits the inference of the evidence. Another major limitation is being unable to compare the PDA class to the FDA class due to insufficient rotation of the children within the PDA class. This emphasises the risk of a partial allocation system that requires greater reliance on teaching staff in intervention implementation. A number of potential barriers to the teacher rotating the children were identified during the intervention design process, with potential solutions put in place accordingly. These solutions were based within a Professional Development manual and monthly in person support from the researcher. Clearly these intervention functions were insufficient to overcome the barriers that the teacher experienced during the study. The study was limited by the principle researcher residing in a different UK region to the intervention location and therefore regular in-person support was not possible. Future standing desk studies utilising a rotational system would benefit from greater researcher presence within schools or to consider other solutions to maintain teacher motivation if this type of FDA is to be sustainable. Even with these additional solutions, perhaps a rotational system can only be used in classrooms with teachers who are enthusiastic about the intervention, which is likely to vary between teaching staff within and between schools. Larger scale trials implementing a rotational system across several schools and classrooms and implementing fidelity measures would shed light on this potential issue.

Although originally planned to span a full school year (September – July), for several reasons the study was reduced to 8 months. Consequently, the influence of the interventions over an entire school year are unknown. Nevertheless, this is only the second longer-term study worldwide and first in Europe of its kind which therefore provides important evidence within the standing desk literature. While study groups appeared to be well matched across many outcome variables at baseline, particularly in the FDA and control groups, the control group had a much higher proportion of South Asian children and less White British children, which does make group outcomes less comparable, albeit in a small way. To address this difference, sensitivity analyses were performed, whereby South Asian ethnicity was used as a covariate within multi-level models exploring sitting, standing and stepping outcomes (Appendix G). There is evidence that British South Asian children are more sedentary than White British children (277,317) and so responses to a sitting FDA may differ. Although slightly reduced, the same directions of change in the FDA group were observed in sitting, standing and stepping variables during different time periods (class time, after school and full week day) from the analysis.

activPAL monitor compliance was poor at 8 months follow up, particularly in the FDA group (56%) and PDA groups (48%). Consequently, the data provided may not entirely reflect the influence of the intervention within these groups. A common issue was with the hypoallergenic medical adhesive dressing used to attach the device to the leg; children repeatedly complained that the dressing had peeled off, with the device falling off in the process. This was most common when the child's leg temperature increased during play at break times and during physical education class (involving MVPA) and may be a limitation of the material. A number of children decided not to continue wearing the monitor during the 7-day period due to this issue, and this will have likely occurred in others, reducing wear time compliance. Furthermore, some children had adverse skin reactions from the medical dressing, a few of which were quite severe, resulting in the monitor being removed for that measurement period. The UK sample within the Clemes et al. (2015) (91) study used the same device and attachment methods, and reported poor data compliance (56%) at 10 weeks. Conversely, the Australian sample reported 92% data compliance, also using activPAL monitors but attaching the device to the leg using an elastic garter. This may be a better approach in future studies using activPAL monitors with children.

In the present study, the FDA and PDA groups had lower data compliance in almost every outcome measure and at almost all timepoints compared to the control group. The PDA group had particularly poor data compliance across outcomes in a sample with initial parental consent that was already smaller than the other two groups. Within this group, the main outcome data was down to just 12 children and behaviour related mental health data was entirely missing at 8 months. This class was described as behaviourally challenging by the teacher (see Chapter 6) which may partly explain the poor data compliance rates.

In studies using devices with children, loss of data over time is common and difficult to avoid. This is particularly detrimental in pilot studies with small samples. A lenient wear time inclusion criteria for both devices was applied in this study (>8h/day on ≥ 2 days) so it is unlikely that this data reduction decision had a substantial impact on poor data compliance. When observing the control groups main outcome data (activPAL) compliance at all three time points, they could be considered acceptable (96%, 75% and 79%). This sample already had the highest number of children with parental consent. It would seem that issues with the hypoallergenic medical adhesive dressing, more common within the two intervention groups, was a key factor in poor data compliance in this study. Setting a lenient wear time protocol, while consistent with previous studies, will result in data that is less reflective (and potentially less accurate) of the participants true sitting and PA behaviour. This limitation is compounded within the intervention groups through poor wear time compliance rates. This emphasises that the evidence presented within this study, including in main outcome data, needs to be treated with caution and that only tentative conclusions can be made.

The use of multi-level modelling will have maximised the statistical power since all data from all participants providing data at baseline were included in the analysis. Furthermore, the inclusion of three measurement phases provided more insight into the changes in sitting and standing behaviours over the 8-month period, which is important from a novelty effect perspective.

Due to the differences in wear time in activPAL data during class time and full waking hours between groups, proportional sitting time data was used in the main analysis, which has some limitations. For example, two different participants could both record 65% of wear time sitting during a full day, however, one participant could have provided 600 mins (10h) of wear time (e.g. 7am-5pm) which would be 390 mins of time spent sitting, whereas the other participant could provide 900 mins (15h) of wear time (e.g. 6am-9pm) resulting in 585 mins of sitting time. This means that the second participant had recorded 195 mins more time sedentary on average per day but would be interpreted as equally sedentary based on the 65% proportional value. It is possible that the first participant had spent a similar total amount of time sitting during a full waking day, but with 5h of wear time missing compared the second participant, this is unknown. This is also a limitation when observing changes in the proportion of sitting time during follow up periods. While a participant within an FDA class may have reduced in the proportion of time spent sitting during a full waking day at 4 months and 8 months compared to baseline, they may have engaged in the same total minutes of sitting (e.g. 600 mins at all three time points), yet provided more wear time at follow ups (e.g. 800 mins at baseline compared to 900 mins at 4 months and 850 mins at 8 months). This would have resulted in an 8% reduction in the proportion of wear time spent sitting at 4 months and a 4% reduction at 8 months compared to baseline, yet the participant had spent the same total amount of time sedentary. These limitations should be considered when interpreting the findings in this study, particularly in full day data as variations in wear time will be the highest.

With a 24 h wear time protocol, it was expected that the activPAL would have provided more valid data compared to the ActiGraph protocol (waking hours and removal during water-based activities) in this study. In this study and Chapter 4, the activPAL devices did provide longer waking hour data on average (Chapter 4: 911mins, Chapter 5: 800-900mins vs 700-800 mins approx. of ActiGraph wear time). Consequently, the ActiGraph protocol will have resulted in less representative data compared to a 24 h valid day criteria. Beneficially though, it has been suggested that less wear time is required for children compared to other age groups (i.e. adolescents) for the data to be representative of usual activity (64). A minimum of four days is recommended for accelerometer data in all age groups

(62,64) which is therefore a limitation of the accelerometer data in this Chapter. Furthermore, the samples of ActiGraph data were lower than activPAL data at every time point in all three study groups in this Chapter. Although more of a secondary outcome, this data may not represent the study groups PA behaviour and responses to the different interventions as well as the activPAL data.

It could be argued that the use of a 15-second epoch in both activPAL and ActiGraph devices was too long in duration due to the intermittent short bursts of physical activity in children (62). Shorter epochs may have resulted in less time spent sitting and more time spent standing and stepping in activPAL data since standing and stepping activity may occur at times in very brief periods (i.e. <5-s) in between periods of sitting in children. Less time would also be identified within more prolonged bouts of sitting since there are more opportunities (more epochs) over time to register a change in posture and therefore break the bout. However, since this parameter was applied to all three study groups at all three timepoints, the ability to explore any change in behaviour over time was not limited by this factor.

As already discussed in Chapter 3 and like in Chapter 4, there was a blanket removal of estimated sleep within activPAL data (11pm-6am) in this study, which has limitations (61). This should result in 1020 mins of waking data per day should no other strategies be implemented; however, a child could go to sleep at 9pm and wake up at 7am, meaning 3 h of data has been miss-classified as waking hours. To identify periods of sleep during the designated waking hours (6am-11pm), the 3-axis acceleration data in this study will have detected periods of no movement. If these periods exceed 20 mins then this period will have been excluded as non-wear. This is reflected in the wear times for this study being below 1020 mins. For example, there was a mean of 800-900 mins for week day data across groups. As discussed in the previous chapter, this is evidence that periods of sleep during the 6am-11pm waking hours period were successfully removed when applying the Excel macros. This is further supported by wear time data during specific times of a week day in the present study. For example, the baseline activPAL data show an almost 100% total class wear time in the control class (309 mins of a possible 310 min class time) and 100% mean wear time compliance in both intervention groups (305 mins class time). Hence, negligible non-wear time was recorded during school time which of course does not include sleep periods. Conversely, approximately 50-70 mins of wear time was removed in all three groups during the after-school wear period; Control class – 395 mins recorded of a possible 465 mins (15:15-23:00), Intervention classes – 424 and 422 mins recorded of a possible 470 mins (15:10-23:00). Hence, data have been removed from the allocated waking hours and some if not all of this, within each participant, should be sleep. As discussed in Chapter 3, the combined data reduction methods for identifying and removing sleep in activPAL data has limitations however there is a distinct lack of validated methods for this purpose currently available in children. Monitor logs were provided to better identify sleep and awake onset but these diaries were poorly completed and thus inadequate.

Since each multi-level model in the main analysis was univariate, this resulted in multiple group comparisons at each time point across outcome measures which therefore increased the risk of a type I error. Since significant changes (some of which at $P < 0.0005$ level) were found in sitting and standing variables at both follow ups, but not at baseline, during class time and a full day, but not after school, we do not believe type I error occurred in primary or secondary outcomes.

As discussed in section 5.4.8, pubertal maturation was not measured in this study. This will mostly confound outcomes related to adiposity, however, other secondary outcomes may have been impacted. The dramatic changes in body shape, size and body composition in those children experience pubertal maturation and especially during a growth spurt, may have some changes in musculoskeletal discomfort irrespective of sitting and standing behaviour. However, no changes were observed in this outcome. Dynamic hormonal and cognitive developments during puberty may also have some influence on behaviour-related mental health and cognitive function data within this study. Future research should attempt to capture this confounder and statistically adjust accordingly.

There were some important strengths to this study. Bradford is a northern UK city that is ethnically diverse, deprived and with high child morbidity (300). While individual data on socio-economic indicators were not measured, the two schools in this study are located within neighbourhoods highly ranked for deprivation (300).

Consequently, many of the sample are likely to be of deprived backgrounds, which is a risk factor for chronic health conditions (313), and therefore a meaningful setting to implement a health-related intervention. Furthermore, the study setting also resulted in a high proportion of British South Asian children in the sample. With an elevated cardio-metabolic health risk emerging in childhood in this ethnic group compared to White British children (133), a potentially health-enhancing FDA is of great relevance and importance in this demographic. With many health-related behaviours first developing in childhood, it is important to intervene early before unfavourable habits form, and/or have more time to cause harm and are more difficult to change in later years.

Including a control group that was in a different school (but nearby) avoided the risk of contamination. As already mentioned, this issue has been repeatedly reported in previous standing desk studies which may have impeded intervention effects (237,268). This is the second longer-term study (268) to explore the influence of an intervention during different periods of the day and overall throughout waking hours. With school breaks and after school time explored in isolation, more sensitive information was provided on potential compensation, which was not included in the Ayala et al. (2016) (268) study. While several different intervention designs and standing desk models have been implemented to date (294), there appears to be an increasing interest in sit-stand desks (Ergotron LearnFit) within primary schools (268,318) and secondary schools (316). This trend allows for more direct comparisons between study findings, of which the present study contributes to.

5.4.13. Conclusions

This pilot study, although small-scale, provides evidence to a rapidly developing area of research that is still in its early stages. This is the first study to suggest that sit-stand desks can influence a reduction in class time sitting over the longer-term in primary school children when using a FDA system. The changes observed during class time in the FDA group were sufficient to reduce sitting time in total and to reduce the time spent in prolonged sitting bouts over a full week day. Some compensation was evident in MVPA during school breaks at 4 months, but this did not seem to influence total MVPA over a full week day. Some novelty effect was observed at 4 months compared to 8 months in the FDA group compared to the control group, but the intervention appeared to still reduce sitting time at 8 months.

To build on the findings from this study, a large clustered randomised control-trial set across multiple locations in the UK should be implemented, to determine whether sit-stand desks, on a full allocation basis, can reduce class time sitting and total week day sitting over the long-term across different primary school settings. There is also a need to further investigate the PDA system since this could be far more financially feasible. In light of the findings in this study it may be beneficial to utilise focus group research to explore how teachers could be best supported in implementing a PDA system. It would be ideal to include a sample of teachers of varied attitudes towards the need for a classroom based sedentary behaviour intervention. Such findings could then potentially be used within a further study piloting these specific intervention functions.

This chapter also reported on the influence of two 8-month sit-stand desk interventions within the school classroom on important outcomes related to health and development in children. The FDA group demonstrated no influence on adiposity outcomes, but it is possible that the study was too short in duration and lacked sufficient statistical power to observe changes. The sit-stand desks appeared to have a negative influence on classroom behaviour over time in both intervention groups, possibly due in part to a lack of space in the classroom. No change was observed in musculoskeletal discomfort scores in either intervention group, suggesting large shifts from sitting to standing time in the FDA group had no negative implications in this outcome. No change was observed in cognitive function outcomes in both intervention groups which suggests that interventions were not detrimental to the children's cognitive development. It would seem worthwhile to extend the duration of a study period beyond 8 months, to assess whether a sit-stand desk intervention with a FDA system influences positive changes in adiposity when administered beyond a single academic year. Lastly, the long-term influence of both PDA and FDA interventions on academic performance should be explored.

CHAPTER 6 – Implementation evaluation of the Stand Out in Class intervention

6.i. Preface

This chapter presents findings from the implementation evaluation of the Stand Out in Class intervention. For general intervention study methodology see Chapter 5 section 5.2 for details. Findings from direct classroom observations within the full desk allocation group (FDA) are also presented in Chapter 6. Some of the data presented within the results of this Chapter have been referred to in Chapter 5 due to some of the content being relevant to the outcomes discussed as part of Chapter 5. These discussions relate to insufficient intervention implementation within the partial desk allocation group (PDA) (section 5.4.2), peer influences on children choosing to stand in class in both intervention groups (5.4.3), resistance within the FDA group during standing classes and novelty effects (5.4.7), classroom behaviour when children are rotated within the PDA class and behaviour-related mental health (5.4.9), incorrect posture when using sit-stand desks in relation to musculoskeletal health (5.4.10) and how the PDA class, which included behaviourally challenging children, may have influenced poor monitor wear time compliance. Please see these sections for further details on these discussion points.

6.1. Introduction

Implementation assessment is recognised as an essential part of intervention evaluation because health interventions, when implemented effectively, are associated with better outcomes (319). The internal and external validity of an intervention depends on the measurement of implementation (319). No matter how well designed an intervention may be, or how positive the effects may appear, interpretation of outcomes can only be accurate when knowing what aspects of the intervention were delivered and how well they were conducted (319). Current evidence of implementation within standing desk intervention research is lacking despite the logistical challenges associated with restructuring a classroom environment. Such evidence is particularly important for studies that rely substantially on teaching staff to implement components of the intervention, such as a PDA system. The purpose of this chapter was to evaluate the implementation of the Stand out In class intervention within FDA and PDA classes.

6.2. Methods

6.2.1. Implementation evaluation

A brief semi-structured interview was conducted with the teacher of the FDA group and focus groups with six randomly selected pupils (by the teacher) in two groups of three. These took place on the same day during school hours, nine weeks after intervention installation. The interview and focus groups were conducted during this time to ensure sufficient time for the teaching staff and pupils to become familiar with the new desks and find some kind of routine. The interview questions were developed based on a list of factors that can influence the implementation process outlined by Durlak and Dupre (2008) (319). Factors that were interpreted as relevant to a classroom based behavioural intervention were selected. These factors were then used as a guide to produce questions for semi-structured interviews and focus groups to evaluate the implementation of the sit-stand desk intervention. This list of factors and all questions prepared for the present study are detailed in Appendix F. Child and teacher responses to interview questions were hand written by the lead researcher. The same qualitative data collection conducted with the FDA group was also planned for the PDA group. However, focus groups and interviews could not be conducted at the same time as the FDA group due to the lead teacher of the PDA class taking a prolonged leave of absence due to sickness. Consequently, implementation evaluation data for this class had to be conducted at a different time, and by a different researcher. An associate researcher linked to the project (Daniel Bingham, DB) conducted a one-to-one semi-structured interview with the PDA classroom teacher and focus group, during class time, with five pupils (3 males and 2 females) in the PDA class.

Focus groups and interviews with the PDA class were audio-recorded and transcribed verbatim. The questions and associated raw transcribed data that were most closely related to the Durlack and Dupre (2008) material, as presented in Tables 6.1 and 6.2, were subsequently extracted. To be consistent with the focus group and interview data reduction methods conducted within the FDA class, summaries of responses to each question from pupils and the teacher were produced.

6.2.2. Classroom observations

An additional step of implementation evaluation included two thirty minute classroom observations conducted within the FDA class by research team members, who recorded field notes based on these observations (320), on day 1 and during a single day during week 16 of the intervention. The first observation took place during a morning class, carried out by a trained occupational therapist, on the first day that the children and staff were exposed to the sit-stand desks. This was a general observation to collect information (field notes) on the how the teaching staff and pupils were using and reacting to the intervention. The second observation, conducted by a different research team member, occured during a teacher-led standing class. These standing classes were agreed between the teacher and research team to take place every day during mathematics. During this observation, the researcher made field notes on the childrens responses (e.g. positive or negative responses) to the enforced standing class, the childrens attitude towards standing during this class, and sitting and standing behaviour immediately after the enforced standing class. The teacher informed the research team that at the start of every mathematics lesson the following process occured:

The teacher asks all children to stand (using sit-stand desks) for the first 20 minutes of the first lesson of the day (mathematics). The children have a small number of mathematic activities on the white board to complete while standing. If the children sit down, the teacher asks them to stand back up. Once the 20 minutes is over the teacher then allows the children to freely choose between sitting and standing.

6.2.3. Data management and analysis

Some of the originally planned questions for implementation evaluation were not asked during the semi-structured interview and focus groups with the FDA teacher and the six children, respectively. This was due to the limited time available with the teacher and children and to avoid repetition of reponses from the answers that had been provided from earlier questions. Rather than using any specific analytical technique within the data, a simple summary of the data was applied due to the low volume of raw data and limited number of questions covered in the interviews. Due to the short duration (30 mins) of classroom observations and low volume of field notes produced, a simple summary of these field notes are provided in the results.

Table 6.1. Questions from focus groups and semi-structured interviews with pupils in the full allocation and partial allocation groups relating to implementation evaluation.

Full desk allocation questions for pupils	**Partial desk allocation questions for pupils**
Do you think the sit-stand desks are needed within your classroom and why?	What were your thoughts about the adjustable desks just before they were put into your class room?
How well do you think you are able to learn with the new standing desks?	Do you think the desks have changed how you learn and concentrate?
How has the desk affected the class atmosphere?	How have you found using the desks only some of the time?
Do you know how to use your standing desks correctly and what the correct posture is when standing?	

Table 6.2. Questions from focus groups and semi-structured interviews with teachers in the full allocation and partial allocation groups relating to implementation evaluation.

Full desk allocation questions for the teacher	**Partial desk allocation questions for the teacher**
Do you think the sit-stand desks are needed within your classroom and why?	What were your thoughts about the amount of time your pupils spent sitting during school time before the intervention began?
How well do you think you are able to teach with the new standing desks?	Is there any difference in the way you have taught since the introduction of the adjustable desks in comparison to previous years when you had standard sitting desks?
How has the desk affected the class atmosphere?	Do you think the adjustable desks have made a difference to how children learn and concentrate?
Other than teacher led standing classes, have other sit-stand desk strategies (e.g. standing champions (pupils)) been discussed with other staff and pupils along with correct postures when using the desks?	How clear was your role in this intervention? e.g. rotating of children

6.3.1. Implementation evaluation

The questions that were included within the semi-structured interviews and focus groups and a summary of the answers are detailed below.

6.3.1.1. FDA group

'Do you think the sit-stand desks are needed within your classroom and why?'

The teacher stated that instead of an intervention to reduce sitting time, he would have prefered a physical education based intervention to replace some English and Maths classes (the teacher was a PE teacher in a previous occupation). The pupils stated that the desks are needed because “they make you stand more which is good for your health and learning”. They also stated that it “feels more comfortable when you stand”.

'How well do you think you are able to teach/learn with the new standing desks?'

The teacher stated that he had to adapt his teaching methods to cater for the new desks. For English, Maths and Science he would normally have a different seating plan for each class. However, due to the stools taking up so much aisle space, this was no longer possible. He therefore had children sat in the same place all day and tailored his teaching and materials to each group of children. He also could not walk around the class like before, due to the stools blocking the walkways; children must come to him at the front of the class. The stools are often pushed to the back and sides of the class but there is still not enough space for them to be stored and other parts of the classroom were affected. Also, when children stand, other pupils may bump into them when moving around due to stools in walkways.

The pupils had positive and negative comments. Positive comments included “it is good to have the option to sit or stand” because “sitting can become uncomfortable”. More than one child stated that standing can be more comfortable (than sitting) and can help with concentration. One negative point was that the new desks can be distracting. The reasons for this included “because the new desks move around” and that “pupil’s move around the class more and can bump into you” and “nudge you while you work”. Due to the teacher having the pupils remain at the same desk and classroom location throughout the day (and not changing locations from lesson to lesson as they had done prior to the new desks being installed), several students stated that “it is better to stay in one place with your work instead of moving around like before” whereas another student stated “standing desks encourage standing and more moving around so less work gets done.”

‘How has the desk affected the class atmosphere?’

The teacher stated that overall behaviour has improved but this is due to the children remaining in one place from lesson to lesson and not because of an increase in standing. One pupil agreed that class behaviour had improved because the children stay in the same place during the day. However, one child stated that the class is “noiser because they can talk about the desks.”

‘Other than teacher led standing classes, have other sit-stand desk strategies (e.g. standing champions (pupils)) been discussed with other staff and pupils along with correct postures when using the desks?’ (teacher only)

The teacher stated that this has not happened at this stage. He stated he may try standing champions (at each cluster of standing desks, one pupil is tasked with encouraging more standing time in the other pupils) and posture champions (one pupil ensures that the other pupils within each cluster of desks use a correct posture when standing).

‘Do you know how to use your standing desks correctly and what the correct posture is when standing?’ (pupils only)

All six pupils stated that they know the correct height that the desks should be. One student stated that “we don't know the correct posture”. Several of the pupils mentioned that class mates often lean to one side when standing at the desks, particularly when writing.

6.3.1.2. PDA class

What were your thoughts about the adjustable desks just before they were put into your class room? (pupils only)

Pupils reported that before the desks were implemented, they were excited about the prospect of standing more during lesson time. Pupils had been taught that too much sitting time was "bad for [their] health" and could lead to bad posture and back pain.

What were your thoughts about the amount of time your pupils spent sitting during school time before the intervention began? (teacher only)

The teacher felt that pupil sitting time was "broken up" by many activities throughout the school day (e.g. break time, lunch time, PE, walking up to the board, and around the classroom). The teacher reported that sitting time was not a concern: "In normal activities, depending on the activity, I didn't see any issue with them sitting at the [original] table… there's still movement there that's structured into the day".

The data suggest that the teacher's attitudes towards the sit-stand desks had not changed after 4 months of exposure, stating that the desks may not be necessary because sitting time is broken up with activity throughout the day. Overall, due to pressures of the curriculum, the distracting nature of the desks, lack of space, and time factors, the teacher had a preference to resume with the traditional desks. However, the teacher reflected that the implementation difficulties may be due to the specific class included in the trial, as the pupils have particularly challenging behaviour.

Do you think the desks have changed how you learn and concentrate? (pupils only)

Pupils felt that some children "get into trouble" due to the extra distraction of the new sit-stand desks. Some pupils suggested that the sit-stand desks were beneficial for concentration. However, a minority felt that they were more distracted when using the sit-stand desks as they spent time deciding whether to sit or stand.

Is there any difference in the way you have taught since the introduction of the adjustable desks in comparison to previous years when you had standard sitting desks? (teachers only)

The teacher reported thinking carefully about where to seat visually impaired students (n=2) as a result of the sit-stand desks as there were safety concerns regarding their movement around the classroom. The teacher felt that the sit-stand desks made the management of behaviourally challenging students more difficult. He was mindful of where to place pupils based on their height and, therefore, their ability to see the board. There were specific issues relating to rotation of pupils onto the six desks. Both the teacher and pupils reported the difficulty of having to move their belongings each time they were rotated. The teacher felt pupils were quite “possessive” of their desk space and were not happy to systematically move around the classroom, and rotating the pupils caused “chaos” and therefore was not feasible.

How have you found using the desks only some of the time? (pupils only)

In the PDA class, pupils stated a preference to sit down during most of class time but liked to stand during specific lessons (e.g. “art and literacy”). Children preferred to sit down in the afternoon as they were more tired and while they were happy to stand, they sometimes sat down without thinking.

Do you think the adjustable desks have made a difference to how children learn and concentrate? (teacher only)

The teacher suggested that the sit-stand desks had not made a difference to classroom behaviour. The teacher suggested that classroom learning and concentration had improved, however this was a result of factors unrelated to the sit-stand desks: “they have come on, but I’d be very loathed to say that [the sit-stand desks] is the reason they’ve come on”.

Did you know that your teacher was going to rotate your class around so everyone could use the sit-stand desks? (pupils only)

This question was not directly answered by the children. However, some of the children stated that they had not been rotated onto the sit-stand desks. When asked why this was the case, some of the children said that the teacher was very busy, he is trying to help the children and is trying his best. When asked why children are meant to be rotated, one child said they didn't know why and two others stated it was for everyone to know what it “felt like” and to see if “you like it” and for your “opinions”.

how clear was your role in this intervention? e.g. rotating of children. Have any of the teacher assistants rotated the pupils? (teacher only)

The teacher left standing time up to the choice of the pupils and did not enforce any stringent ‘rules’. The teacher’s encouragement to stand primarily involved promoting good posture to pupils while they were standing. The teacher suggested it would be helpful to communicate with other teachers using the sit-stand desks to compare methods of promoting standing behaviour.

6.3.2. Classroom observations

FDA class

Observation one: Day 1 of intervention

The researcher stated that during the 30 minutes within the FDA class, 3-6 children were standing and 3-4 children were "perching." When in the standing position, "quite a few" children were leaning on the desks instead of standing upright with a correct posture. Some children were also leaning excessively on one leg, causing increased spine curvature. When sitting down, the children tend to sit on the edge of the stool, so all angles at hip, knee and ankle were greater than the 90 degrees which is the recommended posture (90-90-90). Several of the children could not reach the floor with their feet. The researcher stated that overall the teaching staff and pupils, after having brief conversations with them, liked the sit-stand desks but the teacher stated that the fit of the desks within the classroom was "a little tight."

Observation two: Week 16 (4 months) of intervention

During the second observation within the FDA class, the researcher described the following:

"The children walk in from the morning assembly and the teacher immediately tells all children to raise their standing desks and begin working on the maths activities on the white board. There are a number of moans and groans from the children. It is clear this is a common practice. For the duration of 'standing time' a lot of children are leaning on the desks and are not actually standing up. A lot of the children kept sitting down on their stools. I counted the teacher telling individuals (not the same children) 10 times to stand back up during the 20-minute period. Once the 20 minutes is complete and the teacher declares everyone can either sit or stand, 22 out of 27 children immediately chose to sit back down. After another five minutes two more children sit down, leading to three children standing. After a further five minutes two more children sit back down, leading to one child choosing to stand up to work. No other children chose to stand up during the remainder of the 30-minute observation."

6.4. Conclusions

A strength of the FDA system is that, whatever the level of involvement from teaching staff to encourage standing at the sit-stand desks, the user always has the choice to sit or stand whenever using the furniture. Consequently, whether the teacher conducted a daily standing class or not, the children in this intervention condition could still fully benefit from the intervention. As outlined in Chapter 5, the teacher-led daily standing lessons could serve to demonstrate standing during class time as a social norm, potentially boosting the likelihood of children adopting this posture. While the first classroom observation is evidence that the FDA teacher adhered to the daily standing class on that particular day, there is no other data to demonstrate the extent to which this plan was followed throughout the 8-month intervention. Confirmation was instead gained from monthly communications between the lead researcher and the FDA teacher; the teacher stated consistently throughout the study that standing classes were conducted every day during the first 20 minutes of a maths lesson. Consequently, a large element of trust was invested in the teacher. In hindsight, it would have been beneficial to have provided the teacher with a daily standing class log for the teacher to record standing classes and provide evidence of intervention implementation. However, with school-based interventions, it is a fine balance between collecting as much relevant evidence as possible while not over burdening the teachers with administrative tasks. Even if a daily log was provided, the same level of trust would have been required as a verbal agreement, however, a daily log may serve as a reminder of their role in the intervention in addition to capturing specific implementation data.

Within the PDA system, more emphasis and trust were required of the teaching staff than of the FDA teaching staff. During monthly communications with children and teachers throughout the study it became apparent that the teacher had not been rotating the children consistently. In fact, it appeared that little action was taken to allow all children to have regular exposure to the sit-stand desks. This is supported by the focus group data conducted at 4 months as some children stated that they had not been rotated onto the sit-stand desks. When asked why this was the case, the children suggested that the teacher is “very busy” and is “trying his best”. The teacher suggested that his class were behaviourally challenging, which may have been a factor in poor intervention engagement. The teacher stated that prior to desk installation he did not believe sitting in class was a problem because the children's day is already broken up with many "activities". After 4 months of sit-stand desk exposure (when the interview was conducted) the teacher had not changed his opinion (the sit-stand desks were not needed). It is very likely that the teachers lack of enthusiasm for the intervention contributed to a lack of intervention implementation. The teacher also mentioned curriculum pressures, the distracting nature of the desks, a lack of space and time factors as other reasons for insufficient classroom rotation. With everything considered, this classroom setting contained a host of barriers to intervention implementation which highlights how challenging the implementation of a PDA system can be, particularly over the longer term. It may be that in some circumstances the PDA model is unfeasible if you consider the dependency on teachers for sufficient implementation. It may be necessary for research groups and school management to therefore be selective with where such a system is applied. Firstly however, more mixed method evidence is needed within different school settings that vary in socio-economic position, child behaviour and attitudes of teachers towards classroom-based sedentary behaviour. Qualitative measures within such studies should seek to understand in greater depth the barriers to effective child rotation and potential solutions. A PDA system is a more economically feasible model than the FDA system when implemented on a large scale (i.e. multiple schools), and therefore efforts should be made to explore potential strategies for effective classroom implementation.

6.4.1. Study limitations and future directions

There were some limitations to this study. The focus groups and interviews with teachers and pupils were conducted with FDA and PDA classes at different phases of the study due to prolonged teacher absence within the PDA class; 3 months after desk installation (February) within the FDA class and 4 months after installation (March) within the PDA class. Consequently, perceptions of respective interventions may have altered somewhat between these different periods of the school year and changes in season (Winter (February) vs Spring (March)). Furthermore, the focus groups and interviews were conducted by different researchers at these different data collection phases. Consequently, different questions and approaches have been used which reduces standardisation of the process. If the same researcher conducted all qualitative research, it is possible that some alternative findings may have emerged. The focus group and interviews would have also been better guided if based on an established conceptual framework (321), such as that of Hasson (322). Use of this framework, for example, will have better enabled the exploration of intervention fidelity (e.g. standing classes and child rotation), examining adherence to the intervention and potential moderators of adherence to the intervention. All focus groups and interviews should have been audio-recorded digitally, transcribed and analysed using thematic analysis (323) so that more comprehensive and robust data processing and analytical procedures were applied to the raw data. This is particularly important for intervention studies at the pilot and feasibility stage; in-depth qualitative data should be collected to provide detailed understanding of intervention functioning on a small scale (232).

As already highlighted, a log system for child rotation within the PDA class and for the daily standing classes within the FDA group would have been beneficial for recording teacher intervention engagement. This system would have also been beneficial for periods when lead teachers were absent and supporting staff covered their duties. From discussions with supporting staff while the main PDA teacher was absent, child rotation did not occur. This was understandable in a class of children that were behaviourally challenging, and with the supporting staff being less familiar with the intervention. There will have also been occasions within the FDA class over an 8-month period where the lead teacher will have been absent. Again, without a daily log of standing class implementation, it is unknown whether support staff also implemented standing classes. From conversations with the main FDA teacher, his absence was few and far between during the study. Furthermore, whether standing classes were implemented consistently or not, children still have full exposure to the sit-stand desks and therefore were not prevented from opportunities to stand, unlike children remaining at traditional desks within the PDA class. That only two classroom observations were conducted, both of which were conducted within the FDA class, is another limitation of the implementation evaluation process within this study. The absence of observations within the PDA class means there is no direct evidence of children being rotated, of how this process occurred, and the opportunity to detect signs of “chaos” as described by the PDA teacher from interview data. While these measures can be demanding of a researcher’s time, frequent observations (e.g. once per month) would provide better evidence of the changes in intervention implementation within both systems over time. Each observation could have also been extended to half a day. By extending the observation period, postural behaviour across different times of the day and different subjects can be explored. Furthermore, records of the frequency and duration of children adopting standing postures by sex and ethnicity would help establish interactions with the intervention by different subgroups (324).

Much can occur over an 8-month period within a school and classroom, including child and teacher attitudes towards interventions, alongside external factors (i.e. school inspections) potentially altering teacher priorities and attitudes towards intervention implementation. Regular observation within a PDA system will not only provide direct evidence of intervention fidelity, but also how the design (i.e. the rotation plan) could potentially be adapted to improve chances of effective implementation. Each school and classroom are likely to be different and therefore some may find an initial agreed rotation plan feasible and demonstrate high implementation fidelity (e.g. >90% of successful daily rotations). However, in other cases, such as the PDA class discussed within this Chapter, implementation fidelity could initially be poor, despite agreeing a rotation plan with the teacher. Consequently, an adaptation may be necessary (i.e. a change to the rotation schedule, responsibility delegated to responsible pupils) to boost chances of desirable rotation rates.

The possible improvements to this study discussed above address specific limitations and challenges that emerged during the implementation of the intervention. On reflection, this study could have been improved in a more general sense if more fundamental concepts of process evaluation were applied to this intervention trial. This study was piloting the comparison of two different sit-stand desk intervention systems and therefore it is important to collect data that could inform a larger trial design (165). While this chapter has focused on the implementation of the interventions, opportunities have been missed to collect important process evaluation data relating to feasibility and acceptability of the study. More in depth process evaluation would help to establish whether the interventions in this study where inherently faulty or insufficiently delivered (324).

Qualitative and quantitative data related to recruitment and measurement procedures would be important for guiding a follow-on trial, in addition to process evaluation data specific to the interventions. Firstly, the control school was not incorporated into the process evaluation of the study, however, control groups are essential to randomised controlled trials. Therefore, outcomes related to the acceptability of recruitment and data collection are important as they apply equally to the control school and should have therefore been collected. Parents and guardians should have also been incorporated into process evaluation procedures. They determined whether their child took part in the study and are likely to have meaningful influence on their child's attitudes and interactions with the study, measurement tools and intervention components. Alternatively, or additionally, questionnaires exploring parents and pupils' experiences and attitudes towards the interventions could be administered via email or hard copies, boosting sample sizes and available data. While recruitment rates of pupils within control and intervention classes were positive (74% overall), it would have been beneficial to explore reasons why parents did not provide consent for their child to take part at both control and intervention school sites. Furthermore, more individual and household level data, such a socio-economic position, household income, and academic achievement of the child, would have helped establish any potential patterns within subgroups in study participation as well as intervention engagement, measurement tool fidelity and influences on targeted behaviour change outcomes. Furthermore, while this is beyond the scope of this small scale pilot study, in a larger scale study (i.e. more schools, more intervention classes) this additional data, along with data on intervention implementation, could be used within statistical analysis to combine process and outcome evaluation, helping to establish the circumstances in which sit-stand desks can be most effective (324).

Senior school staff should have also been included in focus group and interview proceedings. While the study was concentrated into year 5 classrooms, the study was a disruption to traditional school proceedings, and therefore, from a feasibility perspective, opinions and experiences of senior staff would have been highly beneficial as they are the key decision makers for school participation in future trials. There were a range of measurement tools implemented throughout the study, including activPAL and ActiGraph monitors which were required to be worn for 7 days, supplemented with diaries. If these measures were to be repeated within a larger trial, qualitative data should have been collected during focus groups and interviews with pupils, parents and teachers to assess the acceptability of these procedures. Data compliance was poor with both monitors throughout the study and the possible reasons should have been explored more thoroughly. Posters demonstrating the correct posture to adopt when standing (and sitting) were provided in both intervention classes, however, anecdotally it was evident that children often adopted irregular desk heights and postures when standing at the desks. This may lead to musculoskeletal injury and potentially counteract the possible benefits of replacing sitting time with standing. There were no measures in place to capture whether children were using the desks correctly. Potential risk of musculoskeletal injury could have been assessed by the research team by using a Posture Observation Sheet which profiles the overall posture of a child in the sagittal plane (259). This tool has been used within a previous standing desk study in children (259).

Future studies should address the limitations outlined in this Chapter to provide better insight into how intervention implementation can be enhanced in standing desk studies. To demonstrate how a process evaluation could be better applied to a future trial, it would be opportune to describe the design of such a trial using an example. A follow up pilot cluster randomised controlled trial is used as an example herein, whereby one participating class per school is involved in the trial. As the intervention is delivered within the classroom setting, and not at an individual level, a cluster design would be most appropriate. The study period could span an entire academic year. There could be two control groups and two intervention groups, both of a full desk allocation system (this is due to the relative success of intervention implementation from this design within the study evaluated within this chapter, however, a partial desk allocation system in other future trials should not be overlooked). The process evaluation within this study could explore the feasibility and acceptability of the trial in relation to school and participant recruitment, acceptability of randomisation, acceptability of the measurement instruments and the intervention, any negative consequences of the intervention and intervention fidelity. Focus groups with children and with parents/guardians and interviews with participating teachers at both intervention and control schools would be conducted approximately 1 month after baseline measures and randomisation has occurred, to explore the acceptability of trial procedures, including randomisation, and acceptability of the measurement instruments, using semi-structured topic guides. These proceedings would be audio recorded digitally and transcribed verbatim. These procedures would be repeated with the same participants at the end of the intervention period to further explore the acceptability of the study procedures and intervention (intervention class participants only). Comprehensive individual, household and school (i.e. OFSTED rating, financial challenges, proportion of pupils eligible for free school meals) level data would be collected to determine any contextual factors associated with variations in outcomes that may be external to the intervention design (325). Any potential negative effects of the intervention, such as musculoskeletal discomfort or classroom disruption from the study, would also be explored during these follow up procedures.

To help inform recruitment for a future trial, parents/guardians who did not provide consent for their child to take part would be approached informally at school drop-off times in an attempt to establish why they made this decision. Interviews would also be conducted with senior school staff at each intervention site towards the end of the intervention period to further establish acceptability of the study and intervention. Classroom observations would take place once a month for half a day each time within both intervention classrooms by two researchers throughout the study. During these observations, posture would be recorded using a Posture Observation sheet (259) for every child over a 10 minute period, to establish future risk of musculoskeletal injury whilst using the sit-stand desk. Also, during these observations, both researchers would observe and tally the number of boys and girls sitting and standing every minute, providing minute-by-minute data of how the sit-stand desks were being used during class time.

With school-based interventions, it is a fine balance between collecting as much relevant evidence as possible while not over burdening school staff, pupils and parents. In perfect circumstances, all procedures outlined in the above example would take place, however, it is likely that some characteristics of the process evaluation plan will need to be amended or sacrificed once the challenges of daily school operations compete with the study. Care should also be given not to over burden participants with process evaluation procedures that then compromise outcome data or study participation (232). To avoid learning that some process evaluation data cannot be collected during the trial (i.e. focus groups and interviews with senior school staff) or receiving data of insufficient compliance (i.e. standing classes insufficiently implemented), it would be prudent to have open discussions during the planning stages of the study with all groups involved within the process evaluation plan (researchers, school staff, pupils and parents) about what is required, how and when these measures may take place and conclude on what is feasible. If aspects of the process evaluation still fall short, this can still provide meaningful conclusions for feasibility and acceptability outcomes and help inform future intervention studies.

CHAPTER 7 - Conclusions

7.1. Key findings and implications

Each study within this thesis is a standalone study however there is a connection between each study that combined provides new evidence into sedentary behaviour (SB) research in children. This chapter will outline the aims and objectives of the work conducted in this thesis, synthesise findings from chapters 2 to 6 and evaluate the implications for SB research, public health and education policy by considering the evidence, trends and contemporary challenges outlined in chapter 1.

7.1.1. Thesis aims and objectives

As highlighted in Chapter 1, standing desks within the school classroom have emerged as one of the most promising strategies for reducing total sedentary time in school-aged children. Therefore, the aim of this thesis was to further explore the influence of this method of classroom modification on reducing sedentary time within this population. The four objectives of this thesis are summarised in Table 7.1. The table also includes an overview of how these objectives were met and the key findings of the research conducted to address each objective. Discussions of the implications of key findings within this thesis follow Table 7.1.

Table 7.1. Thesis overview and key findings

Objective	Location	The purpose	How the objective was met	Key findings
1) Systematically review the evidence of the effectiveness of standing desks within the school classroom	Chapter 2	To map all current evidence of standing desk studies implemented within schools. This will help identify what is currently known about these interventions and the gaps in the evidence that need addressing in future standing desk studies.	A systematic review was conducted using relevant database searches to identify and comprehensively summarise all studies that have explored the impact of standing desks within the school classroom. Studies with samples of any school age and with any outcome measure were included in the review.	Standing desk interventions implemented within the school classroom is a rapidly emerging area of research. There were promising early findings from small scale pilot studies in important outcomes related to health, feasibility and development. However, long-term studies and more studies measuring sitting behaviour are needed.
2) To outline the data reduction methods and decisions when using activPAL and ActiGraph devices in this thesis	Chapter 3	To fully disclose and critically evaluate all data reduction processes for objectively-measured sedentary behaviour and physical activity data presented in Chapters 4 and 5.	All data reduction methods for activPAL and ActiGraph data presented in Chapters 4 and 5 were fully detailed. A critical review of the key decisions are also presented, evaluating the impact that these decisions will have had on the results presented in Chapters 4 and 5.	Many decisions made for activPAL and ActiGraph data reduction procedures were standard practice and recommended within SB and PA research. However, with small samples in Chapters 4 and 5, there was a conflict between retaining as large a sample as possible while also gaining the most valid and representative data of behaviour.

Objective	Location	The purpose	How the objective was met	Key findings
				Data compliance was modest in Chapter 4 and poor within intervention groups in Chapter 5 at follow ups.
3) Explore children's levels and patterns of sedentary time and PA accumulation at and away from school	Chapter 4	To better understand the SB and PA profiles of UK children using a valid objective measurement. The evidence will identify the extent to which a SB intervention is needed in UK children overall and in specific domains and settings.	Levels and patterns of sitting, standing and stepping behaviour in 9-10-year-old children from the city of Bradford, UK, were explored in a cross-sectional study. Baseline activPAL data from the intervention study outlined in Chapter 4 and a previous pilot study (91) were examined.	Children were highly sedentary during different periods of the week and particularly during after school and weekend day periods. High proportions of waking hours were also spent in prolonged sitting bouts not observed in European children previously. These findings emphasised the need for SB interventions within this demographic.
4) Evaluate the medium-term and longer-term impact of two different standing desk intervention systems as strategies to reduce classroom sitting time and increase PA in	Chapter 5	To determine how effective a standing desk intervention is in reducing SB in UK children using a valid objective measurement. Aspects of the intervention design and evaluation process is informed	A pilot sit-stand desk controlled-trial named *Stand Out in Class,* implemented with 9-10-year-old children in primary school classrooms in the city of Bradford, UK, was evaluated in this chapter. Outcomes include	The intervention appeared to positively influence several sitting and PA outcomes during class time and during total waking hours at both 4 month and 8-month follow-ups. Some negative changes were observed in behaviour and

Objective	Location	The purpose	How the objective was met	Key findings
children. The impacts of the two interventions on secondary outcomes including adiposity, cognitive function, musculoskeletal discomfort and behaviour-related mental health are also explored.		by findings from chapters 2 and 3.	changes in sitting time (activPAL data) and PA (activPAL and ActiGraph data), adiposity, cognitive function, musculoskeletal discomfort and behaviour-related mental health during class time after 4 and 8 months of desk exposure. Data comparing the full desk and partial desk allocation classes to a control class are presented.	feasibility-related outcomes, however. Chapters 5 and 6 suggest sit-stand desks in the classroom can positively influence a reduction in sitting time over the longer-term but careful consideration is needed for implementation strategies and day-to-day teaching practicalities. The findings should be interpreted with caution and not generalised due to this intervention study being a small-scale pilot.
5) Implementation evaluation of the pilot Stand Out in Class Intervention.	Chapter 6	To explore the extent to which the full desk allocation and partial desk allocation system were implemented by teaching staff. What were the impacts of this and the intervention in general on the classroom environment and child behaviour	Focus groups and interviews with pupils and teachers from the full desk and partial desk allocation systems were conducted. Summaries of this qualitative data is presented and evaluated. Findings from the two intervention systems are compared and suggestions for future research are provided	

7.1.2. What is the best way to implement a standing desk intervention within the primary school classroom?

Chapter 2 highlighted that to date there have been a number of different standing desk models and intervention designs implemented within the primary school classroom. Since the evidence base is particularly small and consisting of mostly small-scale pilot studies, conclusions could not be made on the most effective design. More recent research, including the study in Chapter 4, has begun to move towards the Ergotron LearnFit sit-stand desk (268,302) possibly because they are more adaptable to each individuals physical needs and are relatively small, allowing for more classroom space. However, as detailed in Chapter 6, because the stools could not fit under the desks, classroom space was a logistical issue and may have influenced attenuated behaviour-related mental health scores. It is important that manufacturers are informed of these design limitations and more suitable models continue to be produced for the school classroom in future.

In Chapter 5, the intervention study implemented two desk allocation systems (partial desk allocation (PDA) and full desk allocation (FDA)) with contrasting success. PDA has demonstrated positive changes in a very similar study location and sample previously (91) but was exposed in Chapter 5 as a high risk system susceptible to a lack of teacher motivation (and teacher absence) to implement the intervention. This system may only be possible in already enthusiastic teaching staff although greater support and presence from researchers may be able to improve rotation adherence in some teachers. Furthermore, it would be beneficial to include a recording system of daily or weekly rotational activity within a PDA system to provide clarity on sit-stand desk exposure among the class. This may burden the teaching staff however this task could be delegated to a responsible pupil. In fact, responsibility for the maintenance of rotation compliance could be allocated, at least in part, to pupils. Existing reward systems could be incorporated to further motivate the pupils to ensure the rotation plan is carried out successfully. These approaches should be suggested when consulting with teaching staff for the purpose of planning and implementing a standing desk intervention in future research.

A few recent studies that were outlined in the systematic review in Chapter 2 as well as the intervention study in Chapter 5 have been successful when providing little more than access to a sit-stand desk. It is not yet known whether including multiple behaviour change techniques that promote an increase in standing time in addition to sit-stand desk exposure can bring about further reductions in sitting time than demonstrated in Chapter 4. Additional behaviour change techniques in future studies should target all aspects of the COM-B model (beyond physical and social opportunity in children and reflective motivation in teachers targeted in chapter 4) while also attempting to minimise the requirements of teaching staff to deliver the intervention. Habit Formation theory that should be considered when designing future standing desk research. As explained within Chapter 1 section 1.12.2.3, habit formation is one of the more relevant behaviour change theories to SB. Within the FDA class in Chapter 5, it is not obvious if, how or when a habit of standing during class time occurred. The teacher led standing classes were imposed on the children and therefore this is not habit formation. Habits are based on situational cues automatically promoting a behaviour due to learned cue-behaviour associations (210). It could be argued that being exposed to a sit-stand desk is the necessary cue, creating an association with standing during class time which with repetition will reinforce the association and enable standing through a more impulsive, instinctive pathway. However, within the FDA system, children are exposed to the desks during a full school day, 5 days a week and it is unrealistic (and undesirable) to expect that children stand every time they are exposed to the desks. Sitting during class time did appear to decrease and be replaced with standing overall. If this is based on a new habit formation (standing during class time), what is the cue to enable this new behaviour and what were the timings and frequencies of this new habit? It could be that a sit-stand desk functions as a cue to stand at different moments of a school day (i.e. when first walking into the classroom in the morning, immediately after a break, during a particular lesson) rather than being a constant cue during all periods of desk exposure. On the other hand, it could that a sit-stand desk does serve as a constant cue to stand but the user chooses to act upon this cue only some of the time. It may be that all of the above are accurate but vary from child to child. If this were to be examined in future research, this would assist in providing potential targets for enhancing the impact of non-sedentary cues on forming positive non-sedentary habits.

Another point worth considering is that if intervention effects reduced at 8 months compared to 4 months within Chapter 5, was this the result of children returning to old traditional classroom sitting habits and the new habit formation established at around 4 months dissipating? As explained in chapter 1 section 1.12.2.3, a health habit should persist when conscious motivation wanes (211), therefore optimising the chance of long-term change (212). However, little attention has been given to the potential enduring effect of habit formation in health psychology research (211). It would be highly beneficial to conduct focus groups with children in future standing desk studies conducted over the longer-term to try to understand 1) the degree to which behaviour change at first (replacing sitting with standing) is via conscious or unconscious processes; 2) whether during the intervention a non-sedentary (i.e. class time standing) habit has been formed; 3) what the behavioural cues are to elicit standing and what the timings and frequencies are; and 4) how does a non-sedentary habit endure over time. This qualitative data could help inform the development of future standing desk intervention studies by highlighting potentially relevant behaviour change techniques that could enhance the non-sedentary habit formation process. Furthermore, if there is an initial conscious evaluative decision-making process to stand during class time, because of the dramatic environmental change and novelty aspect of the new sit-stand desks, what attitudes and beliefs form during this early stage? To what extend do their own attitudes towards the sit-stand desks influence their sitting and standing choices compared to the behaviours and attitudes of peers and teaching staff? Furthermore, how does the transition from conscious decision making to more instinctive subconscious sitting and standing behaviour develop in relation to habit formation? There may be much to gain from further qualitative research in relation to these questions that could inform and potentially enhance behaviour change strategies within the classroom. SB is thought to be complex and multi-faceted, where individual level theories alone may be too simplistic and lack sustainability. Theories or models such as Habit Formation and the COM-B model should be incorporated into future standing desk research more frequently.

While teachers can have huge influence over child behaviour, a fine balance is required between making use of this influence and over burdening. A wise strategy for effective intervention engagement may be to allow teachers to select and implement their own behaviour change techniques (326). A recent mixed-methods protocol paper detailing the CLASSPAL (Physical Activity Learning) programme, reported that teachers, following training, would be provided with an online resource that provided a series of 'movement integration' strategies for teachers to select and receive guidance on. These active breaks and teaching strategies were encouraged to be used daily however the frequency, time of day or manner of implementation was at teacher discretion. By enabling this manner of control and autonomy, teachers may engage with SB reduction strategies within the classroom with greater enthusiasm and long-term adherence. This certainly may be a prudent approach when designing interventions with components intended to supplement standing desk interventions in future.

7.1.3. Should targeting the school classroom for reducing sitting time with standing desks be prioritised over other settings and domains?

In Chapter 4, activPAL data demonstrated that children were the most physically active (e.g. time spent standing and stepping) and least sedentary in total and in more prolonged sitting bouts (30+ mins) during school time. In contrast, sitting time in total and in prolonged bouts was highest and physical activity (PA) lowest during after school periods and on weekend days during a 7-day week. These findings suggest that SB interventions in these children should prioritise after school and weekend periods rather than the classroom setting. This sample of children (n=79) consisted partly of baseline data from children within the intervention study (Chapters 5 & 6) and partly of children from the same school site as the intervention group but in children from a previous year 5 cohort. However, baseline data within Chapter 5 demonstrated that children spent more time sitting during class time in control (74%) and FDA groups (72%) compared to after school (control 69%, FDA 70%). The PDA group demonstrated little difference between domains (Class time 65%, After school 67%). Time spent standing was very similar between class time and after school in control (17% vs 18%) and FDA groups (19% vs 19%) and the PDA group demonstrated more standing time during class time compared to after school (25% vs 19%). Importantly though, more time was spent stepping after school in all three groups (control +3%, FDA +4%, PDA +5%). Since stepping can encompass light, moderate and vigorous intensity PA, children spent less time in health-enhancing PA (11,160) during class time compared to after school. This evidence supports targeting the classroom setting to reduce sitting time and is consistent with other recent evidence demonstrating that children are highly sedentary, and potentially the most sedentary during a 7 day week, during class time (84). It should be emphasised that the PDA group were less sedentary during class time compared to after school, in contrast to the other study groups. This highlights the inconsistency within the data in a sample of three groups. Therefore, definitive conclusions should not be made about children's sitting and PA behaviour at and away from school based on the evidence within this thesis alone. Furthermore, It could still be argued that time away from school should be prioritised since leisure time is a more likely period when traditional screen-based behaviours (particularly TV viewing) occur which are more consistently associated with attenuated health and development-related outcomes than total sedentary time in children (42). The sample of children in Chapter 5 (and Chapter 4) were recruited from schools based in neighbourhoods of low socio-economic position (SEP) and therefore many of the sample will have been of this status. UK Children of low SEP have demonstrated higher screen time SB than children of higher SEP (285) suggesting that many children in the intervention study will have engaged in high volumes of screen time away from school hours, although screen time was not directly measured in this study. Targeting screen time during after school periods would involve the community or home setting which may be more challenging to engage large populations of children compared to the school setting.

As highlighted in Chapter 1 section 1.13.1, there are many advantages to targeting the school classroom including access to populations of potentially diverse demographics (including high health risk groups) in one controlled and highly structured environment. It may be that a classroom-based intervention such as a standing desk is likely to reduce sedentary time in more children. Conversely, while an intervention implemented away from school that specifically focuses on screen time such as TV viewing may be likely to impact fewer children, it could influence a behaviour change that provides greater health and development-related benefits. Consequently, it may be prudent to target both domains of a school day (and types of SB) for greater gains in public health and education priorities. The Transform-us! Study, set in Australia, is an example of an intervention that has targeted a reduction in daily sitting time in children by implementing behaviour change techniques within both the school and home setting (327). Intervention components with the school setting included standing easels (similar to a standing desk), scheduled active breaks during class time, classroom-based behaviour change messages and standing lessons. Within the family setting the intervention included homework tasks and newsletters promoting methods to reduce sitting time and increase PA (327). The Transform-Us! Intervention is currently being implemented across schools in Victoria, Australia (328), and it would be of benefit for a project of similar design to be delivered and evaluated in UK children.

7.1.4. How much of a reduction in class time and total daily sitting is enough in children?

Chapter 5 clearly suggested that the sit-stand desk intervention within the FDA class influenced reductions in total sitting time and prolonged bouts of sitting during class time and during waking hours at 4 months and 8 months. Class time sitting reduced by 32% (96 mins) and 20% (60 mins) at respective follow ups within the FDA class and by 11% and 9% respectively during waking hours on a week day. These reductions were highly statistically significant (P <0.0005) and larger than previously observed in standing desk studies set within the primary school classroom, as detailed in Chapter 2. This was a small-scale pilot study that did not include a power calculation to determine a necessary sample size to assess changes in sitting behaviour. Therefore, only tentative conclusions can be made from the evidence provided and they should not be generalised widely. Nevertheless, in adults, reducing 30 mins/day of total sedentary time with either sleep or PA has demonstrated improvements in cardio-metabolic biomarkers of 2-4% from isotemporal substitution analysis (329). However, current evidence in children is too inconsistent to produce conclusive dose-response evidence such as those observed in adults (42,43). Consequently, while the FDA intervention in Chapter 5 appeared to influence a positive direction of change, it is difficult to interpret what the observed reductions in sitting time really mean from a population health perspective. In other words, would these reductions in total daily sedentary time if observed in larger populations be enough for benefits to regional or national targets for obesity and other health-related outcomes? Chapter 5 highlighted that the large reductions observed in the FDA group did not result in significant reductions in adiposity indicators in the intervention group relative to the control group, despite the group being highly sedentary at baseline. The sample were also predominantly of South Asian ethnicity which is an ethnic group of higher body fat percentage at a given BMI compared to white European children (132). However, despite these findings there was a trend towards a reduction in BMI and waist circumference z-scores within the intervention group which may have become meaningful either with more time (e.g. over a 2-year period) or in a larger sample of children with greater statistical power.

Chapter 1 section 1.8 detailed that SB interventions have demonstrated the greatest reductions in BMI in overweight populations (135). Consequently, it may be that while healthy children may not experience immediate benefits, higher health risk groups may benefit from reductions in sitting time similar to those observed in Chapter 4. Future research should explore responses to reduced sitting time in health outcomes in high health risk (e.g. South Asian ethnic groups, overweight and obese, low socio-economic position (SEP) children) and lower health risk groups. The potential presence of a dose-response effect between daily sitting time and health outcomes in children also needs investigating in large sample prospective studies. These studies should determine sitting time via posture monitors, include different daily categories of sitting time in total (e.g. 4-6, 6-8, 8-10h/day) and different bout lengths (e.g. 5-10, 10-20, 20-30, 30+ mins) in the analysis, measure a broad range of health indicators and also explore sub group effects between different demographics. If a dose-response effect can be established it may provide specific sitting time reduction targets for standing desk and other SB interventions, and for public health guidelines.

7.1.5. Is standing time as a replacement for sitting time sufficient for health benefits?

Chapter 5 outlines that the large reductions in sitting time observed during class time and total waking hours in the FDA group was predominantly replaced with standing time. This was somewhat expected since sit-stand desks naturally provide standing as a replacement to sitting. While these large reductions in sitting time suggest that sit-stand desks may influence a reduction in sitting, should a shift towards standing and with little increase in other forms of PA be interpreted as a positive outcome? In

Chapter 4, correlation analysis demonstrated that standing time was not associated with adiposity indicators. The systematic review within Chapter 2 highlighted that standing desk interventions have consistently demonstrated an increase in energy expenditure during two hours of class time in USA children compared to traditional classroom furniture. However, time spent sitting or standing was not reported, and increases in energy expenditure were largely attributed to an increase in steps (257,260). There is currently a distinct lack of evidence of the health benefits of time spent standing when replacing sitting time in children and adolescents. Conversely, there is some evidence that prolonged standing in children carries some health risks of its own (228,295). In Chapter 1 section 1.6.1, it was explained that sitting may have its own unique physiology via the suppression of lipoprotein lipase activity and consequently any type of PA, including standing, that stimulates muscle contraction in the postural muscles should be sufficient for avoiding the attenuated effect (i.e. reduced HDL cholesterol) of sitting time. However, this concept is based on studies with rats and mice only and needs to be replicated in human trials, including child populations if ethically possible.

Chapter 4 suggested that sit-to-stand transitions and steps-per-minute, although not entirely consistently, were negatively associated with adiposity outcomes. This suggests that movement-based physical activities, not standing time, are required for benefits in adiposity. Within the FDA class we observed an increase in the number of sit-to-stand transitions at both follow ups compared to the control group (Chapter 5). Consequently, it may be more beneficial to encourage children to interrupt sitting periods with regular transitions towards standing and stepping behaviour, if practical during lesson time. These are only cautious suggestions based on preliminary study evidence that would need to be confirmed within fully powered large-scale randomised control trials in future. Nevertheless, Light intensity PA (LPA) in children has been favourably associated with cardio-metabolic outcomes (11) including lower systolic and diastolic blood pressure and higher HDL cholesterol from cross-sectional data (160). However, evidence from isotemporal substitution has found no benefit in health and fitness outcomes in children from replacing sitting time with LPA (330). Despite this, UK and Canadian PA guidelines promote replacing sitting time with LPA (28,37). The UK guidelines state that LPA will provide benefits for energy expenditure and a healthy weight (28). The evidence base of studies exploring the relationship between

LPA and health and development-related outcomes in children is limited, inconsistent and of very low to moderate quality (11). Consequently, an increase in light ambulation at and around a sit-stand desk may provide some benefits to health and other important development related outcomes but this cannot be stated with any confidence at this stage of the evidence available. It is perhaps unrealistic to expect improvements in learning and development-related outcomes over time based on the small physiological stimuli that standing provides. It may be more likely that some tasks are more suited to a standing posture compared to sitting and therefore a child can work more effectively. Thus, it would wrong to expect a general improvement in development and learning-related outcomes with time due to a child spending an additional 60 mins/day standing instead of sitting. Instead, such outcomes could improve because children are provided with the opportunity to stand during tasks in which they favour this posture and can therefore perform better. This in turn could improve classroom behaviour since children are liberated to choose between postures that favour different activities. Evidence from semi-structured interviews in Chapter 6 suggested that children may prefer to sit or stand during different classroom tasks. Certainly, more qualitative and quantitative research is needed in this area.

7.1.6. Are standing desks within the primary school classroom a realistic national education and public health policy?

Findings from Chapters 2 and 5 demonstrate that standing desk interventions may influence reductions in class time sitting. However, these findings are from a handful of small-scale pilot studies. For this type of classroom restructuring to be established as local or national educational or public health policy, far more evidence will be required. The key question is, what evidence would be needed for senior school management, local authorities or the government to buy into standing desk interventions within the classroom? First and foremost, larger scale randomised control trials set within different regions of the UK and in children of diverse socio-economic position and ethnic background will need to demonstrate meaningful reductions in class time sitting over the mid and longer-term (e.g. a full academic year). Educational stakeholders and policy makers will most likely need to observe positive intervention effects within learning and development-related outcomes. Key health policy developers will need to be convinced that standing desks within the school classroom can improve health outcomes across a range of demographics, but perhaps mostly in high health risk groups. It may be unlikely that the concept of health gains in later life by influencing a reduction in sitting time during early stages of life will be a convincing enough message, particularly if key stakeholders depend on annual returns of effectiveness. Evidence from the cross-sectional study in Chapter 4 suggested that some UK children are highly sedentary and accumulate sitting time in prolonged bouts to a level comparable to current generations of adult office workers (10-30% of waking hours spent sitting in bouts of 30+ mins) (282). However, this is a single small sample cross-sectional study with modest wear time compliance, implemented during the autumn and winter seasons only. Consequently, sitting levels and patterns may differ considerably within a larger sample of children in a different setting, with different demographics (i.e. higher socio-economical position) and during different times of the year. More inclinometer determined sedentary evidence from longitudinal surveillance studies with follow up assessment during different seasons, conducted within different UK regions, would help better determine the current prevalence and trends of sedentary behaviour in UK children. Nevertheless, when considering that current trends of SB suggest a continual increase in daily sedentary time from childhood into adulthood (96), it is possible that future generations of adult workers could be far more sedentary than office workers of today as economic advances and industrial innovations continue. The need for investment into early intervention to offset these trends may therefore be compelling enough for health policy makers. Perhaps benefits during or beyond an academic year to either learning-related outcomes or health outcomes, and not both, would ultimately be sufficient enough to persuade key local or national decision makers to act and commit to classroom-based standing desks.

If key decision makers can be persuaded, the next important stage is to consider the logistics of restructuring primary school classrooms in this way on a large scale. As stated by Michie et al. (233), intervention design is about more than effectiveness. The APEASE (Affordability, Practicality, Effectiveness/cost Effectiveness, Acceptability, Side effects and Equity) criteria for designing and evaluating interventions can help interpret standing desks as a potential national intervention policy. Standing desks are a potentially expensive intervention, particularly if providing one per child. Compared to traditional classroom furniture it has been estimated that standing desks may be between 40% cheaper and 20% more expensive, depending on the specific model (295). However, the popular Ergotron LearnFit may be somewhat more expensive than these estimates. If a newly built classroom requires furniture, then standing desks may be a modest net expenditure compared to traditional alternatives. However, replacing a classroom of traditional desks with standing desks, as in Chapter 5 and several studies reviewed in Chapter 2, will require considerable budgets and is a limitation of this intervention type. However, it is very possible that if standing desks are purchased on a large scale (i.e. town or city level) then manufacturers will be able to reduce prices (228).

Furthermore, as stated in Chapter 1 section 1.1, it has been estimated that just 4% of UK government health spending has been directed at primary prevention strategies (157). Financial support for school furniture budgets to enable schools to purchase standing desks may be one way in which government could positively increase the investment in primary prevention strategies. Practically, the intervention is very strong because of the self-service design if provided to every child in a classroom. If a rotation system is required, then the practicality reduces dramatically. Evidence for effectiveness (reduced class time sitting) is based on small number of low-quality pilot studies and clear conclusions cannot be made, however for this example we are assuming that there is already sufficient evidence to convince policy makers. While these interventions may be relatively expensive, the longevity of a standing desk means that over several years, large numbers of primary school children will have had high daily exposure to the desks over an entire academic year. Consequently, the long-term cost-effectiveness of each sit-stand desk could be very reasonable. Acceptability could be an issue with some teaching professionals since classroom restructuring may impede traditional teaching methods. Chapter 6 demonstrated that a lack of classroom space was an issue in a classroom full of sit-stand desks (FDA) and the teacher was required to adapt their teaching methods. Even within a PDA system, the teacher suggested that presence of sit-stand desks caused behavioural issues. Consequently, a sit-stand desk policy could result in resistance from some teaching professionals at least at first. Perhaps with time, support and training, teaching staff will learn to adopt and accept the new classroom infrastructure. To date the potential side effects of standing desks is largely unknown due to a lack of longer-term studies and volume of studies overall measuring different outcome measures. In

Chapter 5 it was evident that behaviour-related mental health deteriorated with time in the FDA group exposed to a full allocation system but also in the PDA group after 4 months of exposure. These were the first evidence of negative side effects when considering the studies reviewed in Chapter 2, although the evidence base is still within its infancy. It is certainly critical that academic achievement or other learning-related outcomes are not attenuated as a side effect if these interventions are to become part of local or national policy. Equity is one of the major strengths of a standing desk; all children who attend school and are physically able to shift between sitting and standing can equally benefit from the intervention. Consequently, if implemented on a large scale, all children exposed to the intervention have a great opportunity to reduce sitting time in the classroom. Overall, standing desks appear potentially strong in Practicality, Effectiveness/cost Effectiveness and Equity. Large barriers could be in Affordability and Acceptability by teaching professionals. Side effects are perhaps not obvious but there is limited evidence to draw upon to date.

7.1.7. When should standing desk interventions be implemented during the life course?

Since evidence suggests that early childhood (e.g. age 7 years) is the time in which UK children begin to increase in daily sedentary time (96), it may be important to first introduce standing desks during the early years of primary school (i.e. reception). If standing desks become traditional classroom furniture during the early stages of primary school, children will be accustomed to learning within this environment once they reach the later years of primary school. This would therefore reduce the risk of behavioural issues or novelty effects by the time academic performance becomes more important. However, currently available standing desk models would appear to be too large or inadequate for young children (i.e. >8 years old) (228). It has been identified that a particularly sharp rise in sitting time in total and in more prolonged bouts occurs between the age of 9 and 12 years of age in UK children (96). This would therefore seem an opportune age to start if standing desk models cannot be provided for younger ages. If children are exposed to standing desks at this age and develop more positive sitting habits during class time, it would seem likely that once re-exposed to traditional classroom furniture during secondary school, common sitting patterns will resume, and an increase of sitting time continues and further develops into adulthood. Consequently, it is important that environmental restructuring is implemented for populations at all stages of the life course to offset contemporary sedentary time trends and potentially minimise the life years exposed to excessive sitting time. This includes implementing standing desks within secondary schools, higher education, and workplace settings. Adolescents and adults, like children, will spend large proportions of a waking week at their place of learning or work and therefore high intervention exposure time is important. Furthermore, sit-stand desks, with their self-service design, will place minimal demand on education and workplace staff, therefore boosting the chance of success.

7.1.8. Should other lifestyle-related behaviours be targeted in addition to a standing desk intervention?

Chapter 1 section 1.2 details that recent research efforts have moved towards a 24-h movement continuum to consider the combined health effects of PA, SB and sleep. Compositional analysis indicates that in all children, high PA (particularly moderate to vigorous (MVPA)), low SB and high sleep should be targeted for optimal health (36). The positive changes that may have been brought about by the sit-stand desks with the FDA group in Chapter 5, a reduction in sitting time but also increase PA (via standing, sit-to-stand transitions and light PA) suggests the sit-stand desk may influence two of three aspects of the 24-h movement continuum. However, sit-stand desks are not designed to increase MVPA. Since MVPA provides the greatest health benefits for children compared to lower intensities of PA, reducing sedentary time or increasing sleep (36), it may be necessary to include an additional component to these interventions to target MVPA. Logistically it may be challenging to incorporate MVPA, particularly over a sustained period (e.g. >5 mins), within the classroom. However, there is evidence that PA, (including MVPA) when incorporated into the classroom through either short activity breaks or when used as a teaching tool can be feasible and effective in increasing PA, based on studies set in the USA, Europe and Australia (242). Using PA in this way has also demonstrated improved classroom management across age groups and increased student on task focus and attention (242).

Consequently, promoting PA within the classroom as an intervention technique to supplement standing desks could be highly beneficial. There are of course other periods of the day and week that could be targeted to promote MVPA engagement, but it would be advantageous to utilise the school setting which contains large populations in controlled conditions. While children in the FDA group in Chapter 5 demonstrated sufficient MVPA for UK guidelines from accelerometer data (>60 mins/day) at all three measurement points, the sample were largely South Asian which is an ethnic group of higher cardio-metabolic health risk during childhood and beyond compared to White Europeans (133,150,152). Therefore, targeting additional MVPA may be highly beneficial in samples such those in Chapters 4 to 6.

Sleep behaviour is the one component of the 24-h movement continuum that was not accounted for in Chapters 2 to 6. Higher amounts of daily sitting time reduce the time available for sleep and PA within a 24-h period. A reduction in class time sitting, even if resulting in reduced total day sitting time, will be replaced with PA and therefore not directly increase sleep time. It is logical to think that a reduction in sitting time and an increase in PA in total is likely to influence better sleep in children. However, standing desks typically demonstrate a replacement in sitting time with increased standing time, (as reported in Chapter 5) and it is unlikely that an additional hour or so of standing time per day will have meaningful effects on sleep behaviour. The promotion of MVPA in addition to standing desk provision as a multi-component intervention may again be prudent. Standing desk research is in its infancy; once studies have progressed more towards larger scale trials, it would be wise to at least measure sleep behaviour (using a combination of accelerometry and sleep logs) to explore the potential effect that changes in daily sitting and PA patterns, influenced by standing desk interventions, may have on sleep outcomes.

If standing desk effectiveness in reducing daily sitting time can be established in larger scale studies, then future interventions, whether targeting single or multi-lifestyle behaviour, will depend on the primary outcome, available budgets and considerations for sustainability. Different combinations of lifestyle behaviours may be required for optimal effects in health or learning-related outcomes. However, the more intervention components added to a standing desk intervention, the more demands there may be on researchers, parents and teaching professionals to implement the intervention, reducing the likelihood of sustainability. As introduced in Chapter 1 section 1.8, it may be wise to adopt a ‘proportionate universalism’ approach in this instance; all children are exposed to standing desks within the school environment but additional intervention techniques and resources, such as class time PA breaks (MVPA), nutritional strategies (i.e. educational classes for parents and children on healthy eating) and screen time reduction techniques (TV turn off time) are directed at higher health risk groups (e.g. obese, South Asian ethnicities, children of low SEP). Before multiple lifestyle factors are considered as additional intervention components however, the effectiveness of standing desks in reducing sitting time during class and during total waking hours in large scale studies must be confirmed first and foremost.

7.2. Thesis strengths

One of the major strengths of the research within this thesis is the consistent use of an activPAL monitor to measure sitting time. The vast majority of SB research in children to date is based on self/proxy report or hip-worn accelerometry (42). Consequently sitting time has often been measured somewhat inaccurately, with consistent demands within the research field for the use of posture monitors (60). Therefore, the research evidence in this thesis provides important objectively-determined sitting data evidence related to sedentary time prevalence, health associations and responses to a SB intervention in UK children.

The populations that have been explored in Chapters 4 to 6 are also a major strength to this thesis. The samples were based at schools set within neighbourhoods of low SEP. During childhood, SEP is inversely associated with childhood adiposity (310) and low SEP during childhood is associated with an increased risk of cardiovascular disease morbidity and mortality during adulthood (311). Furthermore, large proportions of study samples were of South Asian ethnicity. British South Asian children (aged 9-10 years) have demonstrated higher glycated haemoglobin, fasting insulin, triglyceride, and C-reactive protein and lower HDL-cholesterol compared to white British children (133). Consequently, many of the children studied in this thesis will have been of higher health risk and are therefore an important demographic for exploring SB and healthy behaviour change. Lastly, the Stand Out In Class study detailed in Chapters 5 and 6 is the first in Europe and second world-wide to evaluate a classroom-based standing desk intervention over the longer-term (>5 months). Consequently, the findings from this study add novel evidence to the standing desk literature.

7.3. Thesis weaknesses

Despite the important evidence produced in this thesis, there are some notable weaknesses. The study samples within Chapters 4 to 6 were all from just two schools within close proximity of one another. Furthermore, study samples were small, limiting statistical power and transferability of the evidence to northern UK cities of lower SEP. It has been pointed out that the SB literature in children is dominated by small scale cross-sectional studies (42) which the study in Chapter 4 contributes to. Although the use of activPAL devices were a strength of the research, data compliance was poor in the cross-sectional study (58%) in Chapter 4 and at both follow ups in the FDA group (63% and 56%) and at 8 months in the PDA group (48%) in Chapter 5. Consequently, important data may have been missed relating to primary outcomes. Reasons for poor compliance were discussed in Chapter 5 section 5.4.12 and it may be beneficial to utilise a garter device attachment reported in previous studies (91) rather than adhesive medical dressing used in Chapters 4 and 5 when using the activPAL with children in future studies. While it is assumed that the children within the cross-sectional study (Chapter 4) and intervention study (Chapters 5 and 6) were of low SEP, this was only based on the postcode addresses of the schools in which the children were recruited from. Consequently, some children may not have been of low SEP. Individual level data such as household income, parental education level, or household address would have better determined SEP and should be used in future research. More emphasis could have been placed on recording intervention implementation within the FDA and PDA classes discussed in Chapters 5 and 6. While an element of trust was used and the research team were weary of imposing administration on the teaching staff, daily or at least weekly record sheets of standing classes (FDA) and rotational plan adherence (PDA) would have been beneficial. Instead the extent to which these components were implemented is only known from infrequent conversations with teachers and children or retrospective interview data measured on a single occasion.

7.4. Future research

7.4.1. Standing desk studies

Within standing desk research, the primary objective should be to provide more evidence into the effectiveness of standing desks within the school classroom for reducing sitting time during class time and during total waking hours. This should include a fully powered randomised controlled trial, with randomisation taking place at the school level (228). Such studies should be implemented in different regions of the UK and within neighbourhoods of varied SEP and diverse ethnicities. These studies should clarify how effective sit-stand desks are in reducing sitting time across a range UK demographics and locations. More longer-term studies are required that at least span a full academic year. If feasible it would also be beneficial to span two school years to better determine sitting behaviour over time and if long-term reductions in sitting time can influence positive effects in important health outcomes such as adiposity.

Impacts on academic achievement are essential for intervention acceptability. This was attempted within the intervention study in Chapters 5 and 6 but due to incompatible assessment criteria between school sites and for within group pre-post comparisons, academic achievement could not be included. These issues need to be considered in future studies before intervention implementation occurs. Cost-effectiveness analysis is also required in future studies, considering daily, weekly and annual time frames for standing desk exposure time, within group pre-post changes in sitting minutes and changes relative to controls in sitting minutes per unit cost of a standing desk. Cost effectiveness should also be considered beyond a single academic year since these interventions can be utilised for several years if remaining operational.

Since evidence within Chapter 5, within the FDA arm at least, suggested that children choose to stand when given the opportunity but were resistant to enforced standing during a daily mathematics class, future qualitative research should try to explore whether children prefer to sit or stand during specific tasks or school subjects. If a clear pattern emerges, additional research could explore the impact of sitting and standing during different lessons in which children favour sitting or standing to determine whether different effects in cognitive or development-related performance are observed. If children perform better when allowed to stand during tasks in which they favour that posture compared to sitting, this could have major implications for standing desk acceptability.

Studies implementing standing desks within secondary schools are currently emerging. The evidence base needs to continue to develop to determine whether standing desks can feasibly be integrated into a system that involves student lessons taking place in different rooms and buildings. Impacts on standing desk exposure time, teacher and pupil experiences and effects on class time sitting should be prioritised.

7.4.2. Sitting patterns and levels during different seasons and over several years

Since evidence using posture monitors to determine sitting patterns in children are currently limited to a small number of cross-sectional studies, longitudinal research is needed into changes in sitting patterns over time. Several measurement phases implemented during different UK seasons would help determine whether the high levels of sitting time in total and in prolonged bouts observed in Chapter 4 during the autumn/winter seasons, particularly during after school and weekend days, change during different periods of the year. It would also be beneficial to recruit children from different regions of the UK, in areas of varied SEP and of diverse ethnicities. Findings from these studies would help inform the most important settings and domains for SB interventions to target. Longitudinal studies would also benefit from self-report measures (i.e. diary logs and surveys) to provide information on the mode, dose, and setting of SB during different periods of the waking day. This information can be used to understand when more harmful SBs take place, how this time is accumulated (bouts and breaks) and how these patterns may differ between demographics. This would in turn help inform SB interventions that may supplement standing desks at and away from the school setting.

7.5. Final conclusions

This PhD Thesis ultimately aimed to enhance the field of SB research in children with particular focus on SB prevalence and intervention design. The thesis includes a comprehensive systematic review, a cross-sectional surveillance study, and a longitudinal intervention study (split into two chapters). Chapters 4 to 6 included samples based in the City of Bradford, UK and mostly comprising children of South Asian ethnicities from low SEP neighbourhoods. These are high health risk groups and a priority for SB and public health research. The systematic review in Chapter 2 reported that standing desk interventions implemented within the school classroom is a rapidly emerging area of research. There were some promising early findings from pilot studies in some important outcomes related to health, feasibility and development. However, the evidence base consists of low quality and predominantly small-scale studies. More long-term studies measuring sitting behaviour are needed. Chapter 3 disclosed the data reduction methods applied within Chapters 4 and 5 to activPAL and ActiGraph data. A critical overview of the decisions made and the impact this may have on the data were provided. Chapter 4 reported on inclinometer-determined surveillance during a 7-day period and found that children were highly sedentary during different periods of the week. This included high proportions of waking hours spent in prolonged sitting bouts not observed in European children previously. These findings should be followed up with a larger sampled longitudinal surveillance study. Chapters 5 and 6 detailed the impact of the Stand Out In Class study, the first longer-term standing desk study based in the primary school classroom in Europe. The intervention within the FDA class suggested positive directions of change in a number of sitting and PA outcomes during class time and during total waking hours at two follow ups. The intervention within the PDA class was inadequately implemented in that weekly rotations of the children did not take place. Consequently, it is difficult to interpret the results with any clarity. This will probably be a common challenge for this standing desk intervention design. Some negative effects were observed in behaviour and feasibility-related outcomes in both intervention groups. These chapters suggest sit-stand desks in the classroom may have a positive influence on reducing sitting time over the longer-term but careful consideration is needed for implementation strategies and day-to-day teaching practicalities. Ultimately this thesis provides important evidence for SB patterns, intervention design and public health and education policy for UK children. The evidence is particularly pertinent in children of South Asian and White British ethnicity of lower SEP.

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Appendices

Appendix A: published systematic review paper (chapter 2)

Preventive Medicine Reports 3 (2016) 338-347

Contents lists available at ScienceDirect

Preventive Medicine Reports

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Review Article

The effects of standing desks within the school classroom: A systematic review

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article info

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abstract

Background. The school classroom environment often dictates that pupils sit for prolonged periods which may be detrimental for children's health. Replacing traditional school desks with standing desks may reduce sitting time and provide other benefits. The aim of this systematic review was to assess the impact of standing desks within the school classroom.

Method. Studies published in English up to and including June 2015 were located from online databases and manual searches. Studies implementing standing desks within the school classroom, including children and/or adolescents (aged 5-18 years) which assessed the impact of the intervention using a comparison group or pre—post design were included.

Results. Eleven studies were eligible for inclusion; all were set in primary/elementary schools, and most were conducted in the USA (n = 6). Most were non-randomised controlled trials (n = 7), with durations ranging from a single time point to five months. Energy expenditure (measured over 2 h during school day mornings) was the only outcome that consistently demonstrated positive results (three out of three studies). Evidence for the impact of standing desks on sitting, standing, and step counts was mixed. Evidence suggested that implementing standing desks in the classroom environment appears to be feasible, and not detrimental to learning.

Conclusions. Interventions utilising standing desks in classrooms demonstrate positive effects in some key outcomes but the evidence lacks sufficient quality and depth to make strong conclusions. Future studies using randomised control trial designs with larger samples, longer durations, with sitting, standing time and academic achievement as primary outcomes, are warranted.

Contents

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Appendix B: In/out form from the systematic review study (Chapter 2) to screen identified papers for study inclusion/exclusion

Standing desks within the school classroom
In/Out Form

Author and year	....	Today's date	____________
Study ID Number	....	Reviewer	....

Question	Yes	Not Clear	No	Further information:
An intervention based study with baseline and follow up measures?				State the type of study:
Includes the use of a standing desk as the experiment/treatment within a school classroom setting?				Type of standing desk:
Include children aged <u><</u>11 years, and/or adolescents aged 12–18 years (or a mean within these ranges) as subjects of study at baseline?				Age group:
be published in peer-reviewed journals in the English language				
Be published up to and including April 2015				
Is the association time-stamped (e.g. food eaten while in-front of screens?)				

IF THE ANSWER TO ANY OF THE ABOVE IS SHADED BOX, EXCLUDE THE STUDY (FROM THIS INITIAL SCREENING)

This study is:	**Included**	☐	**Excluded**	☐	**Not sure**	☐
	Details:					
Other information						

Appendix C: Partial allocation and full allocation Professional Development manuals for the Stand Out In Class intervention study (Chapters 5 and 6).

Bradford Teaching Hospitals NHS
NHS Foundation Trust

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Loughborough University

Stand out in Class!

Teacher Project Manual

A program to reduce sedentary behaviour in Year 5 Children

Class 5N (Partial allocation)

Stand out in Class

Teacher Project Manual

Important definitions

What is physical activity?

Physical activity is defined as 'bodily movement produced by the contraction of skeletal muscle that increases energy expenditure above resting levels'.
Physical activity can therefore be in many forms. For example, during PE, play at break times or in free time, sports, active transport or domestic chores.

Research has shown that when children engage in PA it is often spontaneous and sporadic, resulting in intermittent short bursts of activity that are followed by periods of rest.

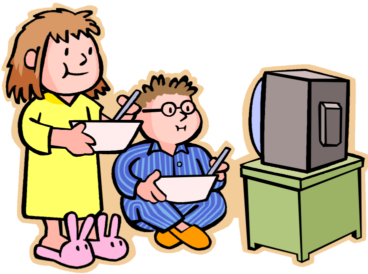
What is physical inactivity?

Physical inactivity is a term used to identify people who do not meet national physical activity guidelines. The UK government recommendations that children are moderate-to-vigorously active for at least 60 minutes and up to several hours every day. Children would be classified as inactive if they do less than 60 minutes of moderate-to-vigorous physical activity each day.

What are sedentary behaviours?

Sedentary Behaviours, not the same as physical inactivity, are a "distinct class of behaviours characterised by low energy expenditure that occur whilst sitting or lying down during waking hours" and can include:

- Television (TV) viewing
- Computer use
- Internet use
- Electronic game use
- Reading
- School class work



The time that children spend in these sedentary behaviours is often termed 'sedentary time' or 'sitting time'. Screen based sedentary behaviours (i.e. TV viewing, computer use, electronic game use) are often grouped together and termed 'screen time'.

The Stand out in Class project will target children's sedentary time through modification to the classroom environment. It will last for almost a full school year (8 months) to see if there are any changes in children's sitting and standing behaviour, classroom behaviour, cognitive ability and physical wellbeing. It will also provide valuable information about the feasibility of delivering class lessons using the sit/stand workstation desks.

Sedentary behaviour and children's health

The majority of evidence exploring the health impact of sedentary behaviours has focused on television viewing. However, other sedentary behaviours are beginning to be identified as independent factors that may impact children's immediate health. In addition, studies conducted over 5- 6 years suggest that adolescent and adult health may be related to the time spent in sedentary behaviour during childhood.

Physical health

Sedentary behaviour in children has demonstrated an increased risk of:

- *Higher body fatness*
- *overweight/obesity*
- *poor oral health* (screen time)
- *Reduced physical activity*
- *increased calorie intake* (screen time)
- *Poorer diet quality* (screen time)

Furthermore, adults who are sedentary as children may have increased risk of:

- *obesity*
- *skinfold thickness*
- *waist/hip ratio* measurements
- *Elevated cholesterol*
- *poor fitness*
- Increased chance of *smoking*.

Psychosocial health

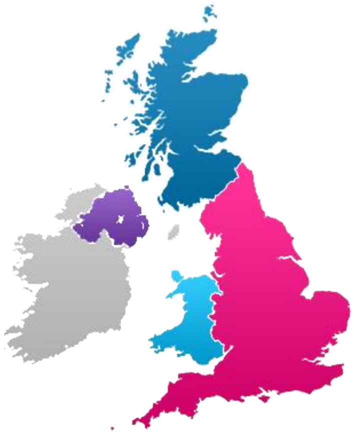
Research has shown that sedentary behaviour during childhood reduces children's *self-esteem* and *social competence*. It also increases children's *social-emotional problems* and children who watch more TV are more likely to engage in *illegal drug use, violence* and have *poorer academic performance*.

Research also suggests that increased sedentary time is positively associated with poor health outcomes in adults (e.g. overweight and obesity, impaired glucose tolerance, type 2 diabetes, heart disease), independent of physical activity levels, suggesting that PA and SB are two distinct behaviours that need to be targeted individually.

Children at risk

Estimates suggest that up to one in four children in the UK, the US and Australia are currently overweight or obese. In the UK, evidence suggests that primary school-aged children are typically sedentary for 8 hours per day, with children spending >65% of waking hours in sedentary behaviour. Over the last two decades, time spent in computer use and electronic games use has substantially increased.

The development of strategies to reduce time spent sedentary is critical for the present and future health of children.



UK physical activity guidelines for children

In 2011, the Chief Medical Officers of England, Wales, Scotland and Northern Ireland endorsed recommendations for the amount of physical activity and sedentary behaviour children (5-18 years) should have to obtain health benefits.

The following recommendations apply to children and young people (aged 5-18 years):

1. All children and young people should engage in moderate to vigorous intensity physical activity for at least 60 minutes and up to several hours every day.

2. Vigorous intensity activities, including those that strengthen muscle and bone, should be incorporated at least three days a week.

3. All children and young people should minimise the amount of time spent being sedentary (sitting) for extended periods.

Aim of the Stand out in Class project

The primary aim of this study is to collect pilot data to test the feasibility and effectiveness of using height adjustable desks, also known as sit/stand workstations, on the time children spend sitting on an average school day and also on their general health, well-being and learning.

Emerging international studies have shown that sit/stand desks in school classrooms are effective in increasing children's energy expenditure and standing and movement during the school day, without disruption to children's learning and behaviour. Studies have also shown sit/stand desks in classrooms lead to improvements in children's posture and levels of academic engagement and achievement. Little research however has examined the use of sit/stand desks in UK schools.

The Stand out in Class project

The Stand out in Class project aims to target reductions in children's sedentary behaviour in the school environment. During the intervention, which will last until the end of this school year, the project will involve the following:

- **Provision of height-adjustable desks:** the classroom will be provided with one height-adjustable desk per student. These can easily be adjusted so that children can stand or sit while completing their work. A height adjustable desk will also be provided to the teacher. Appropriate postures that should be adopted when children are using the desks are shown below:

Classroom strategies – rotation plan: Teachers will be encouraged to rotate the children as they see fit and via methods they may already use for general station-based learning activities. For example, one group of students could be rotated to the sit/stand desks for a specific lesson, giving them the option to stand during the lesson. We will support teachers with the development of a rotation plan. A sample rotation plan is shown overleaf, this plan is based on students allocated to one of 5 groups (A-E), with a maximum of 6 students per group. Another example would be to rotate groups of children to the sit/stand desks for a morning or afternoon period.

Example sit-stand desk rotation plan

	9.00 – 10.45	11.00 – 12.30	1.30 – 3.15
Monday	Literacy Group A 9 – 10 Group B 10-10.45	Numeracy Group C 11 – 12 Group D 12-12.30	Themed curriculum Group D 1.30-2.00 Group E 2.00-3.15
Tuesday	Numeracy Group C 9 – 10 Group E 10-10.45 Desk use alternated between groups across weeks	Swimming (desks not in use)	Themed curriculum Group A 1.30-2.00 Group B 2.00-3.15 Desk use alternated between groups across weeks
Wednesday	Numeracy Group D 9 – 10 Group C 10-10.45	Literacy Group B 11 – 12 Group E 12-12.30	Themed curriculum Group E 1.30-2.00 Group A 2.00-3.15
Thursday	Numeracy Group E 9 – 10 Group A 10-10.45	Literacy Group B 11 – 12 Group C 12-12.30	Science Group C 1.30-2.00 Group D 2.00-3.15
Friday	Literacy Group B 9 – 10 Group D 10-10.45 Desk use alternated between groups across weeks	Numeracy Group C 11 – 12 Group E 12-12.30 Desk use alternated between groups across weeks	PE (desks not in use)

Privacy, Confidentiality and Disclosure of Information

information collected from the Stand out in Class project will remain strictly confidential and any publications arising from the study will not contain names or other identifying information. Hardcopies of all records will be stored in secure filing cabinets at the Bradford Institute for Health Research and Loughborough University and data stored on computers will be accessible to the chief investigators and research staff only.

Projected study timeline

November, 2015	Baseline measurements across the two Year 5 classes.
18th November, 2015	Sit/stand desks installed in two Year 5 classrooms. One classroom to receive 6 sit/stand desks, while the other classroom receives one sit/stand desk per student.
February, 2016	Follow-up measurements taken across the two classes
June/July, 2016	Follow-up measurements taken across the two classes

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Further reading

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Stand out in Class!

Teacher Project Manual

A program to reduce sedentary behaviour in Year 5 Children

Class 5Y (Full allocation)

Stand out in Class

Teacher Professional Development

Important definitions

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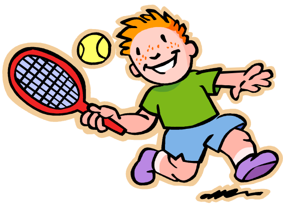

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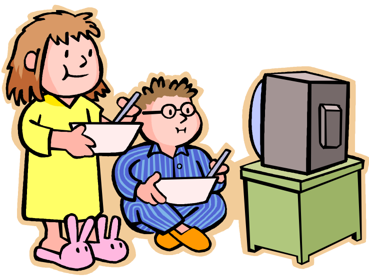


The time that children spend in these sedentary behaviours is often termed 'sedentary time' or 'sitting time'. Screen based sedentary behaviours (i.e. TV viewing, computer use, electronic game use) are often grouped together and termed 'screen time'.

The Stand out in Class project will target children's sedentary time through modification to the classroom environment. It will last for almost a full school year (8 months) to see if there are any changes in children's sitting and standing behaviour, classroom behaviour, cognitive ability and physical wellbeing. It will also provide valuable information about the feasibility of delivering class lessons using the sit/stand workstation desks.

Sedentary behaviour and children's health

The majority of evidence exploring the health impact of sedentary behaviours has focused on television viewing. However, other sedentary behaviours are beginning to be identified as independent factors that may impact children's immediate health. In addition, studies conducted over 5- 6 years suggest that adolescent and adult health may be related to the time spent in sedentary behaviour during childhood.

Physical health

Sedentary behaviour in children has demonstrated an increased risk of:

- *Higher body fatness*
- *overweight/obesity*
- *poor oral health* (screen time)
- *Reduced physical activity*
- *increased calorie intake* (screen time)
- *Poorer diet quality* (screen time)

Furthermore, adults who are sedentary as children may have increased risk of:

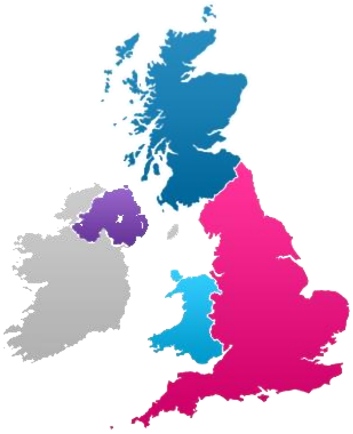
- *obesity*
- *skinfold thickness*
- *waist/hip ratio* measurements
- *Elevated cholesterol*
- *poor fitness*
- Increased chance of *smoking*.

Psychosocial health

Research has shown that sedentary behaviour during childhood reduces children's *self-esteem* and *social competence*. It also increases children's *social-emotional problems* and children who watch more TV are more likely to engage in *illegal drug use, violence* and have *poorer academic performance*.

Research also suggests that increased sedentary time is positively associated with poor health outcomes in adults (e.g. overweight and obesity, impaired glucose tolerance, type 2 diabetes, heart disease), independent of physical activity levels, suggesting that PA and SB are two distinct behaviours that need to be targeted individually.

Children at risk



Estimates suggest that up to one in four children in the UK, the US and Australia are currently overweight or obese. In the UK, evidence suggests that primary school-aged children are typically sedentary for 8 hours per day, with children spending >65% of waking hours in sedentary behaviour. Over the last two decades, time spent in computer use and electronic games use has substantially increased.

The development of strategies to reduce time spent sedentary is critical for the present and future health of children.

UK physical activity guidelines for children

In 2011, the Chief Medical Officers of England, Wales, Scotland and Northern Ireland endorsed recommendations for the amount of physical activity and sedentary behaviour children (5-18 years) should have to obtain health benefits.

The following recommendations apply to children and young people (aged 5-18 years):

1. All children and young people should engage in moderate to vigorous intensity physical activity for at least 60 minutes and up to several hours every day.

2. Vigorous intensity activities, including those that strengthen muscle and bone, should be incorporated at least three days a week.

3. All children and young people should minimise the amount of time spent being sedentary (sitting) for extended periods.

Aim of the Stand out in Class project

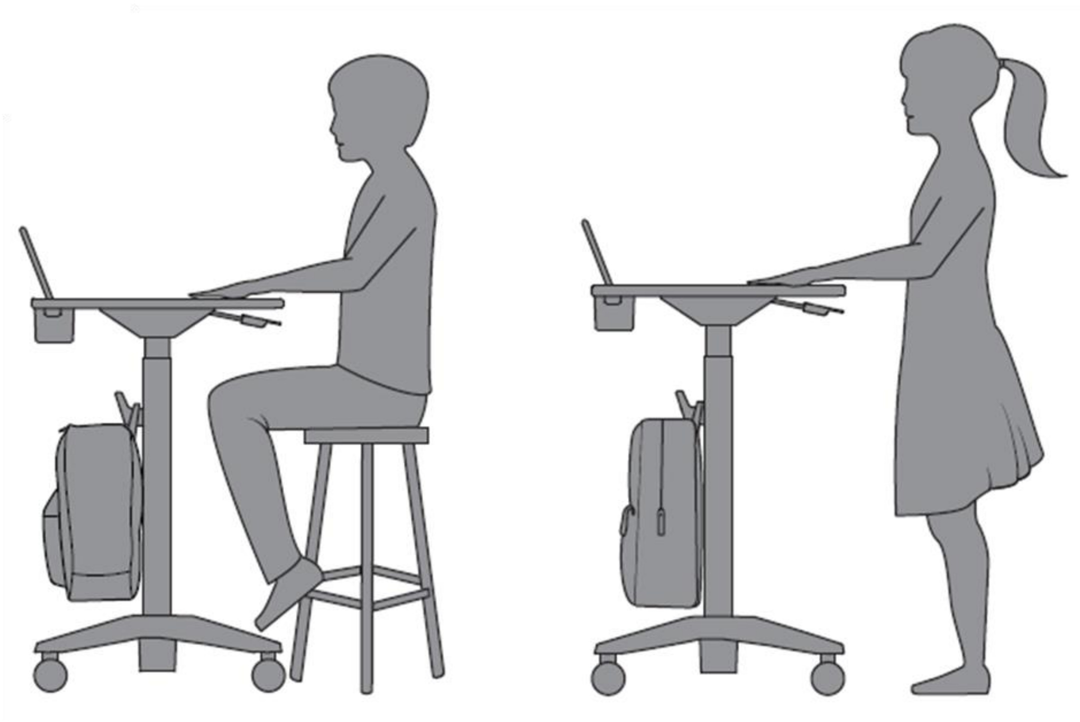
The primary aim of this study is to collect pilot data to test the feasibility and effectiveness of using height adjustable desks, also known as sit/stand workstations, on the time children spend sitting on an average school day and also on their general health, well-being and learning.

Emerging international studies have shown that sit/stand desks in school classrooms are effective in increasing children's energy expenditure and standing and movement during the school day, without disruption to children's learning and behaviour. Studies have also shown sit/stand desks in classrooms lead to improvements in children's posture and levels of academic engagement and achievement. Little research however has examined the use of sit/stand desks in UK schools.

The Stand out in Class project

The Stand out in Class project aims to target reductions in children's sedentary behaviour in the school environment. During the intervention, which will last until the end of this school year, the project will involve the following:

- **Provision of height-adjustable desks:** the classroom will be provided with one height-adjustable desk per student. These can easily be adjusted so that children can stand or sit while completing their work. A height adjustable desk will also be provided to the teacher. Appropriate postures that should be adopted when children are using the desks are shown below:



- **Classroom strategies - standing lessons:** standing lessons are designed to reduce prolonged periods of sitting during class time. As part of this intervention, teachers are asked to modify the delivery but not the content of at least one lesson each day so that children complete the lesson standing (a standing lesson). Simple changes such as a daily 30 minute standing lesson will reduce children's sitting time by 2.5 hours per week!

- Standing lessons are easily incorporated into almost any subject/learning task and require minimal equipment or preparation time.

- It is up to the teacher's discretion as to how the standing lessons are delivered. For example, all children stand at once or children rotate their standing time.

- It is recommended that the teacher encourages the children to stand for a period of 30 minutes per day initially, during the first 2 weeks of desk use, and to then gradually encourage increases in standing time. The research team can help support the teacher with the integration of standing lessons.

Project Timeline

November, 2015	Baseline measurements across the two Year 5 classes.
18th November, 2015	Sit/stand desks installed in two Year 5 classrooms. One classroom to receive 6 sit/stand desks, while the other classroom receives one sit/stand desk per student.
February, 2016	Follow-up measurements taken across the two classes
June/July, 2016	Follow-up measurements taken across the two classes

Privacy, Confidentiality and Disclosure of Information

All information collected from the Stand out in Class project will remain strictly confidential and any publications arising from the study will not contain names or other identifying information. Hardcopies of all records will be stored in secure filing cabinets at the Bradford Institute for Health Research and Loughborough University and data stored on computers will be accessible to the chief investigators and research staff only.

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Appendix D: Strength and Difficulties questionnaire (Chapter 5)

Strengths and Difficulties Questionnaire

For each item, please mark the box for Not True, Somewhat True or Certainly True. It would help us if you answered all items as best you can even if you are not absolutely certain or the item seems daft! Please give your answers on the basis of the child's behaviour over the last six months or this school year.

Child's Name .... Male/Female

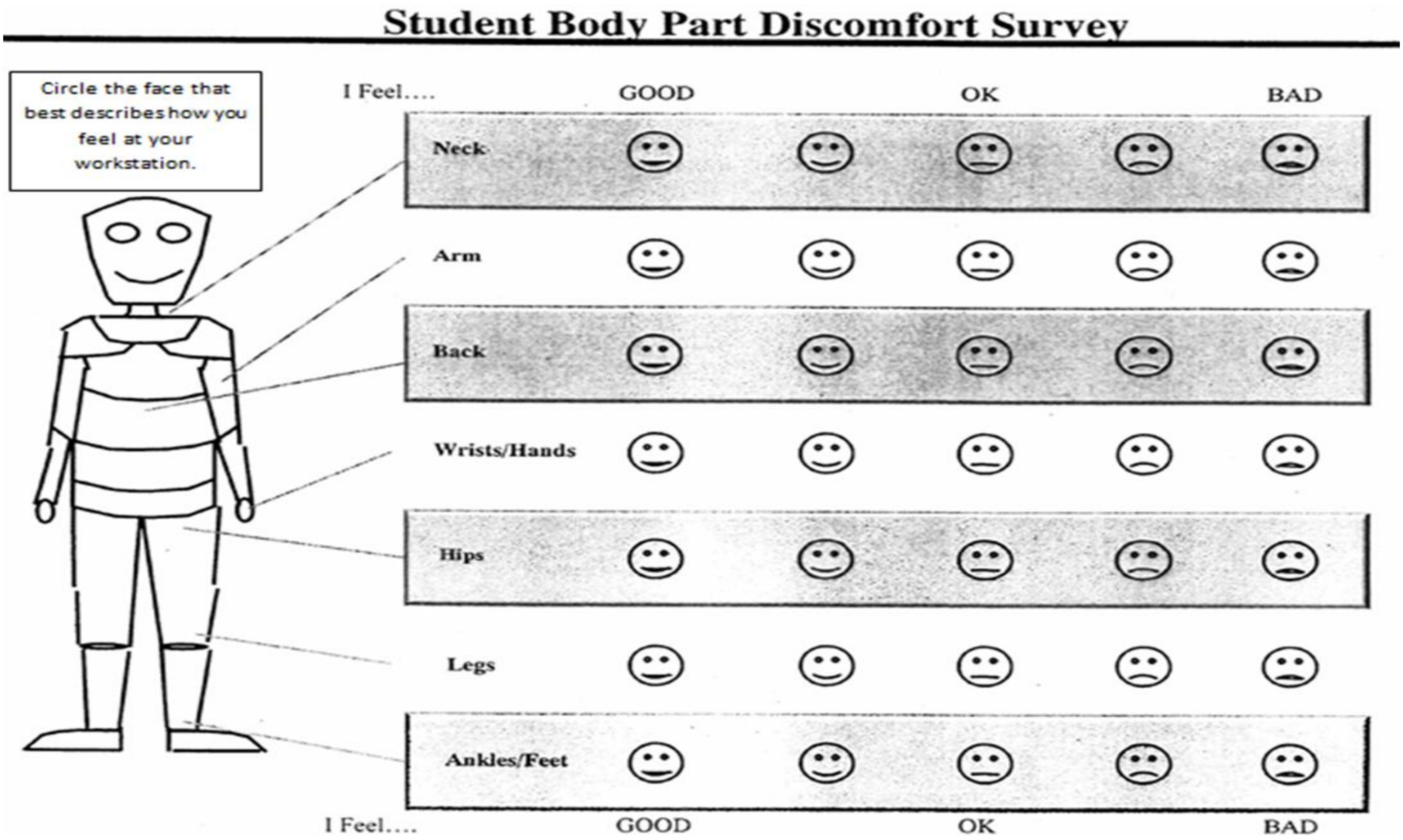
Date of Birth..

	Not True	Somewhat True	Certainly True
Considerate of other people's feelings	☐	☐	☐
Restless, overactive, cannot stay still for long	☐	☐	☐
Often complains of headaches, stomach-aches or sickness	☐	☐	☐
Shares readily with other children (treats, toys, pencils etc.)	☐	☐	☐
Often has temper tantrums or hot tempers	☐	☐	☐
Rather solitary, tends to play alone	☐	☐	☐
Generally obedient, usually does what adults request	☐	☐	☐
Many worries, often seems worried	☐	☐	☐
Helpful if someone is hurt, upset or feeling ill	☐	☐	☐
Constantly fidgeting or squirming	☐	☐	☐
Has at least one good friend	☐	☐	☐
Often fights with other children or bullies them	☐	☐	☐
Often unhappy, down-hearted or tearful	☐	☐	☐
Generally liked by other children	☐	☐	☐
Easily distracted, concentration wanders	☐	☐	☐
Nervous or clingy in new situations, easily loses confidence	☐	☐	☐
Kind to younger children	☐	☐	☐
Often lies or cheats	☐	☐	☐
Picked on or bullied by other children	☐	☐	☐
Often volunteers to help others (parents, teachers, other children)	☐	☐	☐
Thinks things out before acting	☐	☐	☐
Steals from home, school or elsewhere	☐	☐	☐
Gets on better with adults than with other children	☐	☐	☐
Many fears, easily scared	☐	☐	☐
Sees tasks through to the end, good attention span	☐	☐	☐

Signature ....

Parent/Teacher/Other (please specify:
Date ....

Appendix E: musculoskeletal discomfort questionnaire (Chapter 5)



Student Body Part Discomfort Survey

Circle the face that best describes how you feel at your workstation.

I Feel....	GOOD		OK		BAD
Neck	☺	☺	☺	☹	☹
Arm	☺	☺	☺	☹	☹
Back	☺	☺	☺	☹	☹
Wrists/Hands	☺	☺	☺	☹	☹
Hips	☺	☺	☺	☹	☹
Legs	☺	☺	☺	☹	☹
Ankles/Feet	☺	☺	☺	☹	☹

I Feel.... GOOD OK BAD

Appendix F: Implementation evaluation planned focus group and interview questions (Chapter 6)

Implementation evaluation

Semi-structure interview and focus group questions based on Durlak and Dupree's (2008) summary of factors that affect program implementation. The item labels correspond with the items within the Durlack and Dupree (2008) summary list.

II

A – Do you think the new desks are needed? Why?

B (teachers) – How relevant are the desks to the school needs?

B – What do you think the potential benefits of the desks are?

C (Teachers) – How well do you think you are able to teach with these desks?

(Partial desk allocation class) How well are you able to rotate the class?

III

A – How well do the desks fit with the school and pupils needs?

B – To what extent can the desks be used/adapted to fit with the school and pupils needs?

IV

A1 – How have the desks affected the class atmosphere?

A2 (teachers) – How have the pupils adapted to the desks? How willing are the pupils to change their sitting and standing behaviour?

A3 (Pupils) – How have the desks changed your learning and class experience?

A4 – Are you (teacher/pupil) aware of the purpose of the desks? Do you see this as important or relevant for to?

B1 (teachers) – Have other teaching staff been consulted on the implementation of teaching with these desks and how to increase standing time (i.e. sedentary behaviour reduction strategies).

B3 – Have sedentary behaviour reduction strategies been discussed with you (pupil)/teaching assistants (teacher) as well as correct posture?

B4 (partial desk allocation teacher) – Do pupils know of the standing desk rotation plan and how it works?

C1 – Are there class champions for sedentary behaviour reduction strategies, desk rotation (partial desk allocation teacher) or correct posture?

V

A (teachers) – Do you think you have had sufficient instruction and training with the standing desks to successfully use them in your class?

B (teachers) – Is there sufficient support from research team members for you to implement the desks effectively?

Durlack and Dupree (2008): factors that affect program implementation in which the focus group and interview questions were developed from.

Table 2 Factors affecting the implementation process

I. Community Level Factors

- A. Prevention Theory and Research[c]
- B. Politics[a,b]
- C. Funding[a,b,c]
- D. Policy[a,b]

II. Provider Characteristics

- A. Perceived Need for Innovation[b,c]
  Extent to which the proposed innovation is relevant to local needs
- B. Perceived Benefits of Innovation[b]
  Extent to which the innovation will achieve benefits desired at the local level
- C. Self-efficacy
  Extent to which providers feel they are will be able to do what is expected
- D. Skill Proficiency[a,b,c]
  Possession of the skills necessary for implementation

III. Characteristics of the Innovation

- A. Compatibility (contextual appropriateness, fit, congruence, match)[b,c]
  Extent to which the intervention fits with an organization's mission, priorities, and values.
- B. Adaptability (program modification, reinvention)[b]
  The extent to which the proposed program can be modified to fit provider preferences, organizational practices, and community needs, values, and cultural norms

IV. Factors Relevant to the Prevention Delivery System: Organizational Capacity

- A. General Organizational Factors
  1. Positive Work Climate[a,b,c]
     Climate may be assessed by sampling employees' views about morale, trust, collegiality, and methods of resolving disagreements
  2. Organizational norms regarding change (a k a, openness to change, innovativeness, risk-taking)[b]
     This refers to the collective reputation and norms held by an organization in relation to its willingness to try new approaches as opposed to maintaining the status quo
  3. Integration of new programming[b,c]
     This refers to the extent to which an organization can incorporate an innovation into its existing practices and routines
  4. Shared vision (shared mission, consensus, commitment, staff buy-in)[b]
     This refers to the extent to which organizational members are united regarding the value and purpose of the innovation
- B. Specific Practices and Processes
  1. Shared decision-making (local input, community participation or involvement, local ownership, collaboration)[a,b,c]
     The extent to which relevant parties (e.g., providers, administrators, researchers, and community members) collaborate in determining what will be implemented and how
  2. Coordination with other agencies (partnerships, networking, intersector alliances, multidisciplinary linkages)[a,b,c]
     The extent to which there is cooperation and collaboration among local agencies that can bring different perspectives, skills, and resources to bear on program implementation
  3. Communication[b]
     Effective mechanisms encouraging frequent and open communication
  4. Formulation of tasks (workgroups, teams, formalization, internal functioning, effective human resource management)[a,b,c]
     Procedures that enhance strategic planning and contain clear roles and responsibilities relative to task accomplishments
- B. Specific Staffing Considerations
  1. Leadership[a,b,c]
     Leadership is important in many respects, for example, in terms of setting priorities, establishing consensus, offering incentives, and managing the overall process of implementation
  2. Program champion (internal advocate)[a,b,c]
     An individual who is trusted and respected by staff and administrators, and who can rally and maintain support for the innovation, and negotiate solutions to problems that develop
  3. Managerial/supervisory/administrative support[a,b,c]
     Extent to which top management and immediate supervisors clearly support and encourage providers during implementation

Appendix G: sensitivity analysis – using South Asian ethnicity as a covariate in multi-level models for sittng outcomes (Chapter 5).

The proportion of children that were of South Asian ethnicity in the intervention compared to the control groups was significantly lower at baseline (-43%, *P* <0.01). The table below is a comparison of multi-level models with and without South Asian ethnicity as a covariate. Only 10/45 *P*-values did not match between models according to the *P* <0.05 threshold. A difference was not observed in class time total sitting, the primary outcome variable.

Table F1. A comparison of sitting, standing and stepping outcomes during different times of a week day between multi-level models with and without South Asian ethnicity as a covariate.

	Time point								
	Baseline			4 Months			8 Months		
Outcome	β	95% CI	*P*	β	95% CI	*P*	β	95% CI	*P*
Class time									
Sitting time, % of wear time	-3.57	(-9.83, 2.70)	0.265	-25.34	(-32.25, -18.43)	0.000	-19.99	(-27.05, -12.94)	0.000
South Asian covariate	-1.71	(-8.29 4.87)	0.611	-21.72	(-28.90 -14.54)	0.000	-16.33	(-23.64 -9.01)	0.000
Standing time, % of wear time	4.36	(-0.96, 9.68)	0.108	25.74	(19.91, 31.58)	0.000	17.82	(11.88, 23.76)	0.000

South Asian covariate	2.90	(-2.73	8.53)	0.312	21.35	(15.57	27.14)	0.000	13.39	(7.49	19.29)	0.000
Stepping time, % of wear time	-0.81	(-2.62,	1.01)	0.384	-0.26	(-2.28,	1.75)	0.798	2.21	(0.15,	4.27)	0.035
South Asian covariate	-1.20	(-3.12	0.71)	0.218	0.54	(-1.65	2.74)	0.629	2.99	(0.75	5.23)	0.009
Sitting time in 10+min bouts, % of wear time	-3.31	(-9.40,	2.79)	0.288	-17.35	(-24.04,	-10.66)	0.000	-28.96	(-35.81,	-22.10)	0.000
South Asian covariate	-1.87	(-8.24	4.50)	0.565	-14.02	(-22.00	-6.03)	0.001	-25.55	(-33.65	-17.46)	0.000
Sitting time in 5-10min bouts, % of wear time	2.39	(0.02,	4.75)	0.048	-5.29	(-7.87,	-2.70)	0.000	-0.61	(-3.25,	2.04)	0.653
South Asian covariate	2.47	(-0.03	4.97)	0.053	-7.67	(-10.69	-4.66)	0.000	-2.99	(-6.05	0.07)	0.056
Steps, p/min of wear time	-1.16	(-2.41,	0.09)	0.068	-1.64	(-3.04,	-0.24)	0.021	0.86	(-0.57,	2.29)	0.238
South Asian covariate	-1.36	(-2.68	-0.04)	0.044	-0.48	(-2.07	1.11)	0.552	2.01	(0.39	3.63)	0.015
Sit-to-stand transitions, p/hr wear time	1.37	(-0.05,	2.80)	0.058	2.92	(1.33,	4.51)	0.000	4.62	(2.99,	6.24)	0.000
South Asian covariate	1.17	(-0.34	2.68)	0.127	1.55	(-0.23	3.33)	0.088	3.23	(1.42	5.04)	0.000
After school												
Sitting, % of wear time	0.97	(-4.74,	6.68)	0.739	3.70	(-2.50,	9.90)	0.242	1.29	(-5.17,	7.75)	0.696
South Asian covariate	0.27	(-5.82	6.35)	0.932	2.76	(-3.87	9.38)	0.415	0.28	(-6.59	7.15)	0.937
Full Day												

Sitting time, % of wear time	-1.00	(-5.69,	3.69)	0.675	-7.67	(-12.77,	-2.57)	0.003	-5.52	(-10.84,	-0.19)	0.042
South Asian covariate	-0.39	(-5.37	4.60)	0.880	-6.68	(-12.23	-1.13)	0.018	-4.47	(-10.23	1.29)	0.128
Standing time, % of wear time	1.30	(-2.07,	4.68)	0.450	5.78	(2.03,	9.53)	0.003	8.78	(5.16,	12.40)	0.000
South Asian covariate	0.60	(-3.01	4.20)	0.746	7.49	(3.99	10.99)	0.000	4.45	(0.81	8.08)	0.017
Stepping time, % of wear time	-0.29	(-2.62,	2.03)	0.805	-0.87	(-3.38,	1.65)	0.498	-0.20	(-2.81,	2.42)	0.883
South Asian covariate	-0.21	(-2.71	2.28)	0.866	-0.58	(-3.17	2.01)	0.662	0.10	(-2.59	2.79)	0.070
Sitting time in 10+min bouts, % of wear time	-0.53	(-4.85,	3.79)	0.811	-3.96	(-8.63,	0.72)	0.097	-7.40	(-12.28,	-2.52)	0.003
South Asian covariate	-1.87	(-8.24	4.50)	0.565	-14.02	(-22.00	-6.03)	0.001	-25.55	(-33.65	-17.46)	0.000
Sitting time in 5-10min bouts, % of wear time	0.93	(-0.60,	2.45)	0.234	-1.78	(-3.42,	-0.15)	0.032	-0.33	(-2.03,	1.36)	0.699
South Asian covariate	2.47	(-0.03	4.97)	0.053	-7.67	(-10.69	-4.66)	0.000	-2.99	(-6.05	0.07)	0.056
Steps, p/min of wear time	-0.45	(-2.39,	1.49)	0.647	-0.90	(-3.08,	1.28)	0.419	-0.35	(-2.54,	1.84)	0.753
South Asian covariate	-0.48	(-2.56	1.60)	0.650	-0.45	(-2.75	1.85)	0.703	0.10	-2.21	2.41)	0.933
Sit-to-stand transitions, p/hr wear time	0.60	(-0.36,	1.56)	0.222	1.44	(0.36,	2.52)	0.009	1.36	(0.29,	2.43)	0.013
South Asian covariate	0.39	(-0.63	1.41)	0.452	0.83	(-0.31	1.97)	0.152	0.75	(-0.37	1.88)	0.190

p/min, per minute; p/hr, per hour