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Physical activity, sedentary time and fatness in a bi-ethnic sample of young children

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Compliance with Ethical Standards: Paul Collings, Soren Brage, Daniel Bingham, Silvia Costa, Jane West, Rosemary McEachan, John Wright, and Sally Barber declare that they have no conflict of interest. All studies involved in this manuscript received either National Research Ethics Service (NRES) or institutional ethical approval. Parental written informed consent and child assent were obtained prior to measurements.

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Running head: Activity and body composition in childhood

Abbreviations: BiB, Born in Bradford; BMI, Body mass index; CI, Confidence interval; HAPPY, Healthy and Active Parenting Programme for early Years; LEAP, Learning Environment and Active Play study; MVPA, Moderate-to-vigorous physical activity; PA, Physical activity; PiP, Preschoolers in the Playground study; SD, standard deviation; ST, Sedentary time
Clinical Trial Registry number and website: The HAPPY (ISRCTN56735429) and PiP (ISRCTN54165860) pilot randomised controlled trials are both registered with the ISRCTN (http://www.isrctn.com)

Abstract

Purpose: To investigate associations of objectively-measured physical activity (PA) and sedentary time (ST) with adiposity in a predominantly bi-ethnic (South Asian and White British) sample of young children. Methods: The sample included 333 children aged 11 months to 5 years who provided 526 cross-sectional observations for PA and body composition. Total PA volume (vector magnitude counts per minute (cpm)), daily time at multiple intensity levels (the cumulative time in activity >500 cpm, >1000 cpm, >1500 cpm and so on up to >6000 cpm), and time spent sedentary (<820 cpm), in light PA (820-3907 cpm) and moderate-to-vigorous PA (MVPA: ≥3908 cpm) were estimated with tri-axial accelerometry. Indicators of adiposity included BMI, waist circumference, and the sum of subscapular and triceps skinfold thicknesses. Statistical analyses were performed using multilevel regression and isotemporal substitution models adjusted for confounders. Effect modification by ethnicity was examined. Results: There was no evidence for effect modification by ethnicity (p-interaction≥0.13). In the whole sample, the accumulated time spent above 3500 cpm (i.e. high light-intensity PA) was inversely associated with the sum of skinfolds (β (95% CI) = -0.60 (-1.19 to -0.021) mm per 20 min/d) and the magnitude of association increased dose-dependently with PA intensity (peaking for time spent >6000 cpm: -1.57 (-3.01 to -0.12) mm per 20 min/d). Substitution of 20 min/d of ST with MVPA was associated with a lower sum of skinfolds (-0.77 (-1.46 to -0.084) mm). Conclusions: High light-intensity PA appears to be beneficial for body composition in young South Asian and White British children, but higher-intensity PA is more advantageous.
Keywords: Exercise, Sedentariness, Movement, Obesity, Growth, Pediatrics
Introduction

Recent reviews have emphasised that early childhood is a critical period for physical activity (PA) promotion and obesity prevention (20, 36). However it is acknowledged that the amount and type of PA that is needed for healthy growth and development remains unclear. Part of this uncertainty stems from challenges in measuring young children’s habitual PA, which is characterised by unplanned and unsustained bursts of movement that are unreliably recalled by young children with developing cognition, and which are non-conducive to accurate parent-reports (27).

A small evidence-base has emerged that has utilised accelerometry to estimate habitual PA and sedentary time (ST) in young children, with cross-sectional findings consistently supporting the notion that objectively-measured high-intensity PA is inversely associated with adiposity (17). However, the studies performed to date vary in quality and scope. For instance, most have failed to explore the breadth of intensity data provided by accelerometry, instead favouring to concentrate exclusively on associations for moderate-to-vigorous PA (MVPA) in what has been termed ‘paradigm paralysis’ (26). Investigating the entire spectrum of PA may help to elucidate patterns of association and will help to ascertain if under-researched components, such as light PA be it at the low or high end of the light-intensity domain (8), are related to body composition. This is of particular importance in this age group because much of young children’s daily activity is performed within the light intensity region (23), and although the merits of light PA largely remain unknown, national guidelines recommend that children aged <5 years participate in 180 min/d of PA at any intensity (15, 16, 37).

The effects of displacing one intensity of PA for equal time in another or for ST (isotemporal substitution analyses) is also a novel methodological approach that has only once been implemented in young children (29). That study, however, like most others which have
incorporated traditional approaches (10, 25, 38), was uniform with regards to ethnicity, being conducted in young white children with low prevalence of overweight and obesity and highly educated parents, thus limiting generalisability. For these reasons, despite some evidence for effect modification by ethnicity in primary school-aged children (21, 39), accompanied by reports that South Asian children are less active and possess higher risk of obesity and related comorbidities (33), it remains unknown if PA and ST are differently associated with adiposity in South Asian and White British young children (aged ≤5 years).

The aim of this investigation was to examine cross-sectional associations of objectively-measured PA volume and intensity distribution, and ST, with adiposity in a predominantly bi-ethnic sample of young South Asian and White British children from a deprived city in the north of England.

Subjects and methods

Description of study population

Participants were recruited from a range of studies related to the Born in Bradford birth cohort study (40) and research programme (www.borninbradford.nhs.uk). This included the Healthy and Active Parenting Programme for early Years (HAPPY) feasibility randomised controlled trial (RCT) (30), the Born in Bradford (BiB-1000) observational cohort study (13), the Preschoolers in the Playground (PiP) pilot cluster RCT (1), and the Learning Environment and Active Play (LEAP) observational study. Recruitment rates for each of the individual studies ranged from 31-48%. Because overall intervention attendances were low in both pilot feasibility RCTs (1, 30) and there was no evidence for interaction by trial arm in the proceeding multivariate analyses (all $p$-interaction ≥0.10), data from both RCTs were treated as cohort and were not analysed by trial arm. All data (up to four repeated measurements) from the PiP study were used. Table 1 provides specific details of each of the studies, all of
which were conducted in the city of Bradford, the sixth largest and one of most deprived and ethnically diverse metropolitan boroughs in England (14, 40).

From an overall total of 451 study participants, 333 children aged between 11 months and 5 years (contributing 526 activity records, hereafter referred to as observations) were included in this complete-case analysis. Due to the selection criteria of two studies (1, 30) our sample was more deprived than the overall Born in Bradford cohort, but there were no differences in sex or ethnic composition, and no difference in the sum of triceps and subscapular skinfolds compared to participants of the population-based BiB-1000 study ($p \geq 0.21$ for all; BiB-1000 includes 1,707 children considered representative of the city of Bradford (4)). All studies in this pooled analysis received either National Research Ethics Service (NRES) or institutional ethical approval. Parental written informed consent and child assent were obtained prior to measurements.

**Exposure measurement: physical activity and sedentary time**

Movement data were collected in all studies at a sampling frequency of 60Hz, using the same batch of accelerometers (Actigraph GT3X+, ActiGraph, Florida, USA), worn under or over clothing at the hip on an elasticated belt for 6-8 consecutive days. Raw acceleration data files were processed using Actilife (v6.13, ActiGraph, Florida, USA) in 15 second epochs. Monitor non-wear and daytime napping were inferred from continuous zero vertical activity counts ≥10 minutes and were removed (7); traces were further visually scanned for implausible data. Scans revealed that approximately 20% of children who were asked to wear monitors only during waking hours actually wore the monitor continuously for 24h, similar to the protocol used in the LEAP study (Table 1). To remove sleep from all acceleration records a hierarchy of methods were used: 1) Parent-reported sleep diary data were used to identify daily sleep onset and termination times, 2) In the absence of sleep diary data, daily plots of acceleration data were scrutinised, with the beginnings of persistent low movement
registration in the evening considered a sign of sleep onset and movement initiation on
mornings identified as sleep termination; 3) If there was high-level movement after a parent-
reported sleep onset, sleep timings from the acceleration data were prioritised. This multi-
method approach to eliminating sleep from 24h accelerometry resembles a method previously
used (12) and all judgements were made by a single experienced reviewer who was entirely
blinded to participant characteristics other than acceleration data and sleep diaries. In
sensitivity analyses, the accelerometry data were also processed using an automated and
objective method that has face validity for sleep identification (10).

All days with ≥6 hours of data after removal of sleep were considered valid. To maximise
power and mitigate selection biases, all children with ≥1 valid day were included in this
analysis. Sensitivity analyses were also performed that included only children with ≥3 valid
days of data, an amount which has been shown to provide reliable activity estimates in the
source population (3). These days were not required to include weekends, but as young
children’s movement behaviours appear to vary throughout a day (23) another sensitivity
analysis was performed that imparted a time-distribution caveat; here a valid day was
required to possess ≥1 hour of observed time in the morning (06:00 – 12:00), afternoon
(12:00 – 17:00) and evening (17:00 – 23:00). For each definition of valid wear, the average
daily vector magnitude counts per minute (cpm) was calculated as an indicator of total PA
volume, and the time distribution of PA intensity was generated by calculating the
accumulated time (min/d) above specific vector magnitude intervals (the total time in activity
>500 cpm, >1000 cpm, >1500 cpm and so on up to >6000 cpm). Data were further processed
‘classically’ by using validated thresholds to estimate time spent sedentary (<820 vector
magnitude cpm), in light PA (820-3907 cpm) and MVPA (≥3908 cpm) (6). Adherence
(defined as performing on average ≥180 min PA/d) to activity guidelines was also quantified
(15, 16, 37).
Outcome measurement: adiposity data

With the exceptions of length (measured by a rollameter in the HAPPY study) and weight (measured in BiB-1000 by Tanita scales, BC-418MA, Tokyo, Japan), all studies measured height (Holtain Ltd, UK) and weight (Seca 877, UK) with the same calibrated equipment used by the same trained personnel. The data were used to calculate body mass index (BMI, kg/m$^2$) which was converted to $z$-scores and weight status categories for description (9).

Waist circumferences were measured with Seca anthropometrical tape at the level of the exposed naval, in duplicate or triplicate if the first two measures differed by $\geq$3cm; all data were used to calculate means. The BiB-1000 and LEAP studies included single measurements of triceps and subscapular skinfolds on the left side of the body using standard procedures (Tanner/Whitehouse Calipers, Holtain Ltd, UK). Random sub-samples of LEAP study participants also underwent repeated skinfold measurements to permit calculation of intra- and inter-observer technical error of measurement (TEM) for waist circumference, triceps and subscapular skinfolds (Table 1); relative TEMs were acceptable and indicative of ‘skilful’ anthropometrists (34).

Covariables

Parent-reports or school records were used to provide participant age, sex, home postcode and ethnicity. Children of unmixed ethnic origin were classified as either South Asian (including Pakistani, Bangladeshi or ‘other’ South Asian origin) or White British, whereas children of ‘other’ or mixed ethnicity were allocated to a separate category. Home postcodes were used alongside the English Index of Multiple Deprivation (IMD) to create deciles of area-level deprivation (which were grouped into the lowest 10%, 10-30%, and $\geq$30%) (14).

Time-stamped information from accelerometers identified the season of measurements (winter: December to February; spring: March to May; summer: June to August; autumn: September to November) and wear time was captured.
Statistical analysis

Descriptive characteristics were summarised using means with standard deviations (SDs; all variables were approximately normally distributed) or frequencies. Comparisons between South Asian and White British children were made using linear (continuous variables) or logistic (categorical variables) multilevel regression; the mixed ethnic group was too small for comparison. A multivariate test of means was used to investigate differences between South Asian and White British children in regard to the cumulative awake time spent above vector magnitude intervals. Pearson product-moment correlation coefficients quantified relations between PA and ST variables as well as between adiposity indicators.

Associations between components of PA and ST (exposures) with adiposity indicators (outcomes; all modelled continuously) were estimated by linear multilevel regression analysis. Multilevel models were used to account for repeated-measures data (level 1) nested within children (level 2) clustered within schools (level 3; HAPPY and BiB-1000 children were not recruited from schools and were assigned a dummy variable). Crude models were initially performed followed by adjustment for age, sex, ethnicity, IMD, monitor wear time (not in models with total PA volume as the exposure), and season of assessment. When waist circumference and sum of skinfolds were outcomes, additional adjustment for height was made. Models were specified with random intercepts at child level but not random slopes as they explained little to no variation in outcomes.

The above described models were first used to investigate associations of the cumulative time above specific vector magnitude intervals (time in activity >500 cpm, >1000 cpm, >1500 cpm and so on up to >6000 cpm; each intensity occupied a single model) with outcomes. Models were then used to investigate associations of the classical PA and ST categories, and total PA volume, with the same outcomes. In this second analysis, two primary models were constructed: Model 1 was adjusted for all aforementioned factors; Model 2 (not applicable to
total PA volume) was built in the same manner, but entailed mutual adjustment for each of
the PA intensities by simultaneously including light PA and MVPA categories in the linear
predictor. As this model was constrained to invariant time by adjusting for monitor wear time
and leaving out only ST, the results represent isotemporal substitution, in other words the
effect on the outcome of exchanging a unit of ST for PA (inverting the results is the effect of
exchanging a unit of PA for ST) (31). To cover all isotemporal eventualities the omitted
category was subsequently changed from ST to light PA and models were re-run.

In all analyses nonlinear variation was examined by introducing quadratic terms for
exposures, and interactions by ethnicity were explored (effect modification by ethnicity was
limited to a comparison of associations between South Asian and White British children due
to the diminutive mixed ethnic group). All results are presented per 20 min/d increments for
time-based exposures and 300 cpm increments for total PA volume, which are approximate
standard deviation values of the activity data or multiples thereof. Statistical analyses were
conducted in Stata/SE 13.1 (StataCorp, College Station, Texas, USA). P-values <0.05 were
deemed statistically significant.

**Results**

Three hundred and thirty three children (50.7% boys) with a mean age of 3.3 (± 0.9) years
were included in the analysis, of whom 37% were of White British and 55% were of South
Asian origin (Table 2); the South Asian group was predominantly Pakistani origin (74%).
Overall, 20% of children were overweight or obese, and South Asian children were more
deprived and exhibited lower BMI compared to White British children (Table 3). Although
most children (67%) possessed valid accelerometry and anthropometry at only one time-
point, repeated-measures were available for 110 children who provided data on 2 (12.3%), 3
(16.5%), or 4 (4.2%) occasions. The number of valid observations totalled 526 (the unit of
analysis in this investigation) which were spread across all seasons (winter: 15%; spring:
26%; summer: 23%; autumn: 36%). Observations were informed by 1-2 (15%), 3-5 (28%), or ≥6 (57%) valid days of accelerometry, and the mean monitor wear time was 575.6 ± 93.0 min/d. There were no differences in time spent in any PA or ST category between South Asian and White British children (Table 3) and no difference in adherence to PA guidelines (p=0.14); 95.4% of all activity observations were characterised by ≥180 min PA/d. Figure 1 illustrates the cumulative awake time above discreet vector magnitude thresholds. In every ethnic group an exponential decline as a function of increasing PA intensity was observed; again there was no difference in means between South Asian and White British children (p=0.76). Pearson’s correlation analysis showed that the strongest correlation for time-based exposures was between ST and light PA (r=-0.65), and that BMI was more strongly correlated with waist circumference (r=0.76) than the sum of skinfolds (r=0.61), which were also themselves correlated (r=0.70 between waist circumference and sum of skinfolds; p<0.001 for all).

There was no evidence for interaction by ethnicity in any of the main analyses (p≥0.13) and hence results for all models are presented for the total sample adjusted for ethnicity. Figure 2 shows associations between the cumulative time above increasing vector magnitude intensity thresholds with adiposity indicators. There were no significant associations for BMI (Figure 2a) or waist circumference (Figure 2b), but time spent above 3500 cpm (i.e. high light-intensity PA to adopt terminology used by others (8)) was inversely associated with skinfold thickness, with every 20 min/d related to 0.60 mm lower sum of skinfolds (Figure 2c; p=0.042). This relationship was characterised by a dose-dependent graded association, as the magnitude of association strengthened with increasing activity intensity such that every 20 min/d spent above 6000 cpm was associated with 1.57 mm lower sum of skinfolds (p=0.034). These dose-dependent results were largely consistent with categorical analyses (Table 4) which showed a significant association between MVPA and the sum of skinfolds, and
revealed that replacing 20 min/d of ST with MVPA was associated with 0.77 mm lower sum of skinfolds. Shifting the same amount of time from the light PA category to MVPA had a similar effect, tending towards significance (p=0.068).

All of the results were materially similar and conclusions remained unchanged when analyses were performed with accelerometer data that were diurnally well balanced and derived from automated exclusion of sleep. The same applies to analyses that only included children with ≥3 days of accelerometry and models that were re-run with exclusion of intervention (non-baseline) data, the results of which are presented as supplementary material.

**Discussion**

This is the first study to comprehensively investigate the relation between PA, ST and adiposity in a predominantly bi-ethnic group of young children. Our results contribute to a growing body of evidence for inverse cross-sectional associations between MVPA and measures of adiposity in children aged ≤5 years (5, 10, 25, 29, 32, 38). However, our investigation provides new and unique evidence; by investigating the entire spectrum of activity intensities we found a dose-dependency between PA and adiposity which first appeared below the threshold for MVPA in both South Asian and White British children.

A particular strength of this study was the use of tri-axial accelerometry and short sampling intervals to account for the diverse and erratic movement patterns of young children. We identified that regardless of ethnicity the waking day was dominated by ST (accounting for 49% of the average 9.6h daily wear time) and light PA (42% of wear time), with relatively little time spent in MVPA (9% of wear time). These estimates closely match those from Butte et al. (5) who provide the only closely comparable data by using the same cut-points. Despite considerable engagement in light activity (particularly at the low end of the light-intensity spectrum as shown in Figure 1), we found little evidence for associations between our light
PA category and measures of healthier body composition, which is in line with the few existing data in this age group (10, 29, 32). A key limitation of all studies nonetheless has been a reliance on purely accelerometer-based (and often only uni-axial) measures. The capability of such devices to accurately register what may be a more diverse and varied movement profile at the lowest end of the intensity spectrum (most MVPA even in young children is walking or running (19, 24)), coupled with misclassification errors between ST and light PA (behaviours hypothesised to be oppositely related to adiposity), might be one explanation why most studies have found little evidence of an association for light PA, particularly when that category represents the full light-intensity range as tends to be the case. Recently in adolescents the light intensity continuum has been divided into low (e.g. standing) and high light-intensity PA (e.g. slow walking) categories, both of which exhibited different associations with cardiometabolic risk markers (8). Similarly, our novel cumulative analysis of intensity distributions revealed an inverse association between light PA and adiposity, but only at the high end of the light-intensity continuum (>3500 cpm); for every 20 min/d of PA exceeding this intensity the sum of skinfolds was lower by 0.60 mm. This observation is in partial agreement with at least two studies in older children which have reported inverse associations between light PA and adiposity (11, 28). Notably, one of those studies incorporated uninterrupted (24h) combined heart-rate and movement sensing to better characterise ST and all categories of PA (including light activity), which may explain the findings. Similarly to the results reported herein, that study also found an inverse dose-dependent association between intensity distribution and adiposity, starting in the light intensity region (11).

Although we witnessed some indication of an inverse trend between higher-intensity PA and waist circumference (Figure 2b) we only found significant results for the sum of skinfolds. Other studies have similarly found null associations between PA and adiposity as defined by
BMI or waist circumference, but inverse associations using more direct measures of adiposity (18, 29). Our findings support the notion that BMI and the sum of skinfolds provide different measures of adiposity (18) and that height-for-weight indices and circumferences may be sub-optimal indicators of body fatness in children (2). Our observation that for every 20 min/d of MVPA the sum of skinfolds was lower by 0.76 mm may seem modest in scale, but the average MVPA exceeded 50 min/d and measurement error may have attenuated the association. Furthermore, previous studies in young children have reported that inverse associations with laboratory-measured adiposity are only apparent (10, 25) or are strongest (29) for vigorous PA. Our cumulative analysis of intensity supports the idea that PA is related to adiposity dose-dependently in early childhood, and that time-for-time higher-intensity PA is most strongly related to adiposity (11): 20 min/d of PA exceeding an intensity of 6000 cpm was associated with 1.57 mm lower sum of skinfolds. We found no evidence for associations between total PA and adiposity, which might suggest that our observed associations for higher-intensity PA were not driven by total activity volume. While it is biologically plausible that vigorous activity may be important for adiposity over and above activity volume (for reasons related to appetite regulation and increased post-activity energy expenditure) whether or not young children’s sporadic and unsustained habitual PA can stimulate such pathways remains to be determined (10).

Our findings partially support current activity guidelines for young children which endorse minimal ST and 180 min PA/d of any intensity (15, 16, 37), as we did find a significant inverse association light PA and adiposity, albeit at the higher end of the light continuum. Studies in older children (some with improved exposure measurement (11)) have reported inverse associations between the full intensity range of light PA and adiposity (11, 28), and light activity could also be beneficial for child health independent of body fat status (8) as well as essential for motor skill acquisition which requires substantial active time; in this
study light PA accounted for >80% of all active minutes which is consistent with a study of
pre-schoolers (23). Nevertheless, in the current sample despite 95% of activity observations
exceeding the recommended volume of PA/d (chiefly satisfied by engaging in low light-
intensity PA as shown in Figure 1), approximately 20% of children were still overweight or
obese. Given this, coupled with our dose-dependent negative associations between PA
intensity and adiposity, our data imply that guidelines might better acknowledge the merit of
higher-intensity PA for lower adiposity. Higher-intensity PA has also been demonstrated to
have wider benefit for fitness and improved cardiometabolic risk (11, 22, 29). A subtle
change in focus from exclusively PA volume would further appear reasonable in terms of
preparing young children for the guideline change, when 60 min MVPA/d alongside an
unspecified volume of vigorous PA (on at least three days per week) is endorsed for ≥5 year-
olds (15). Because we found no interaction by ethnicity, it appears that a recommendation for
some higher-intensity PA performed in early childhood would be equally beneficial for the
body composition of young South Asian and White British children. This is important in the
context of health equality, and because South Asians are a high-risk group for obesity and
cardiometabolic disease.

Strengths/limitations

Our study benefits from a well-described sample that is young, ethnically diverse and from a
deprived urban setting. This reflects a population at particularly high risk of childhood
obesity and subsequent adverse health consequences. We harmonised data from four studies
to achieve a relatively large sample size and capitalised on repeated-measures for one-third of
the cohort, thereby reducing the regression dilution effect. Habitual PA was also estimated
objectively using tri-axial accelerometry and a population-specific wear criterion (3). It is
unfortunate that data for the sum of skinfolds was only available for a sub-sample of
participants, but we advantageously retained all adiposity indicators in their continuous forms
for analyses thereby raising statistical power and avoiding decisions regarding categorisation. With regards to confounding, similar studies (10, 11, 35) have found little evidence for a confounding influence by factors such as household income, maternal education, maternal obesity, smoking in pregnancy, and birth weight, which is reassuring as we could not account for them, but energy intake and diet patterns remain possible prominent confounders of our associations. It is also a weakness that the direction of association between variables, let alone causality, is indeterminable due to the cross-sectional study design. For instance, bidirectional associations may exist between exposures and outcomes, and thus our results may equally imply that less fat children have more favourable ST and PA profiles.

To conclude, this study found that for improved body composition in young children of different ethnicity at least high light-intensity PA is necessary, but higher-intensity PA is more beneficial. Public health bodies might consider basing recommendations around the concept of dose-dependent relationships; by occasionally choosing MVPA over light PA and particularly ST, health benefits can be expected, and greater benefit may arise from higher doses.
Acknowledgements

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Conflicts of Interest and Source of Funding: This work has been financially supported by a National Institute for Health Research (NIHR) programme grant for applied research (RP-PG-0407-10044), NIHR Public Health Research (PHR 11/3001/16), and the NIHR CLAHRC Yorkshire and the Humber. Authors PJC, DDB, JWe, RRCM, JWr, and SEB are part of the Healthy Children, Healthy Families Theme of the NIHR CLAHRC Yorkshire and the Humber. Author SB is supported by the UK Medical Research Council [grant MC_UU_12015/3]. None of the authors reported a conflict of interest related to the study.

Authors' Contributions

The authors’ responsibilities were as follows - PJC: designed and conducted the research, analyzed data, wrote the paper, and had primary responsibility for the final content of the manuscript; SB assisted design of the statistical analysis and critiqued the manuscript; DDB assisted processing of accelerometer data; DDB, SC, JWe, RRCM, JWr, and SEB: designed individual studies, organized and managed data collections, and critiqued the manuscript; all authors approved the final manuscript as submitted.
References


Figure 1. Daily cumulative awake time spent above vector magnitude intervals. Data are mean values and error bars represent ± SD. Light PA (820-3908 cpm) corresponds to the light shaded region and MVPA (≥3908 cpm) to the dark shaded region. The inset shows a magnified plot for >4000 cpm. A multivariate test of means provided no evidence for a difference between South Asian and White British (p=0.76). SD, standard deviation; cpm, counts per minute.

Figure 2. Associations between the cumulative awake time above vector magnitude intervals with a) BMI, b) Waist circumference, and c) Sum of skinfolds. Statistical analyses performed using multilevel models adjusted for age, sex, ethnicity, index of multiple deprivation, monitor worn time, and season of assessment. Models for waist circumference (n=310; observations=457) and the sum of skinfolds (n=156; observations=156) were further adjusted for height. BMI: n=333 & observations=526. All results are beta-coefficients with 95% confidence intervals and are scaled to represent the association between exposures and outcomes per 20 min difference in exposures. Light PA (820-3908 cpm) corresponds to the light shaded region and MVPA (≥3908 cpm) to the dark shaded region. BMI: body mass index; cpm: counts per minute.
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<th>Study</th>
<th>Design/objective</th>
<th>Population</th>
<th>Measurements</th>
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<td>HAPPY</td>
<td>Pilot feasibility RCT investigating obesity risk reduction in infants born to overweight or obese mothers by encouraging breast feeding, healthy food choices and physical activity antenatally and postnatally by mother and child</td>
<td>85 1y olds (n=39 intervention); mothers were recruited when attending routine hospital appointments in pregnancy; only children that could stand and walk unaided were included in the current analysis</td>
<td>7d awake-time accelerometry; height and weight; measurements performed between July 2013 and March 2014</td>
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<td>PiP</td>
<td>A cluster RCT piloting a playground-based physical activity intervention. Data were collected at baseline, 10-, 30-, and 52-weeks</td>
<td>164 1.5-4y olds recruited from 10 primary schools (five intervention schools, n=83 intervention children)</td>
<td>7d awake-time accelerometry; height, weight, and waist circumference; measurements performed between September 2012 and May 2014</td>
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<td>BiB-1000</td>
<td>An obesity aetiology sub-study embedded within the observational Born in Bradford (BiB) project</td>
<td>A sub-sample of 97 2-4y olds participating in BiB-1000; parents were initially recruited when attending routine Oral Glucose Tolerance Tests in pregnancy</td>
<td>7d awake-time accelerometry; height, weight, waist circumference, triceps and subscapular skinfolds; measurements performed between June 2011 and July 2012</td>
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<td>LEAP</td>
<td>An observational study comparing children’s physical activity, gross motor skills, and body composition between playground settings</td>
<td>105 3-5y olds (76% South Asian) recruited from two primary schools</td>
<td>7d continuous (24h) accelerometer; parent-reported sleep diaries; height, weight, waist circumference, triceps and subscapular skinfolds; measurements performed September to November 2015</td>
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</tbody>
</table>

**Intra-observer reliability**

- Waist circumference (n=78): TEM=0.49 cm; r=0.97
- Tricep skinfolds (n=26): TEM=0.25 mm; r=0.99
- Subcapular skinfolds (n=25): TEM=0.41 mm; r=0.99

**Inter-observer reliability**

- Tricep skinfolds (n=14): TEM=0.66 mm; r=0.79
- Subcapular skinfolds (n=12): TEM=0.66 mm; r=0.86
BiB, Born in Bradford; HAPPY, Healthy and Active Parenting Programme for early Years; LEAP, Learning Environment and Active Play; PiP, Preschoolers in the Playground; RCT, Randomised Controlled Trial; TEM, Technical Error of Measurement; $r$-values are Pearson product-moment correlation coefficients.
Table 2. Characteristics of study participants: categorical variables

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Total (n=333)</th>
<th>Other/Mixed (n=27)</th>
<th>South Asian (n=184)</th>
<th>White British (n=122)</th>
<th>p-ethnicity South Asian vs. White British</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender (n (%))</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boys</td>
<td>169 (50.7)</td>
<td>14 (51.8)</td>
<td>88 (47.8)</td>
<td>67 (54.9)</td>
<td>0.23</td>
</tr>
<tr>
<td>Girls</td>
<td>164 (49.3)</td>
<td>13 (48.2)</td>
<td>96 (52.2)</td>
<td>55 (45.1)</td>
<td></td>
</tr>
<tr>
<td>IMD*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Most deprived 10%</td>
<td>200 (60.1)</td>
<td>15 (55.6)</td>
<td>135 (73.4)</td>
<td>50 (41.0)</td>
<td></td>
</tr>
<tr>
<td>10-30%</td>
<td>88 (26.4)</td>
<td>11 (40.7)</td>
<td>39 (21.2)</td>
<td>38 (31.1)</td>
<td></td>
</tr>
<tr>
<td>≥30%</td>
<td>45 (13.5)</td>
<td>1 (3.7)</td>
<td>10 (5.4)</td>
<td>34 (27.9)</td>
<td>0.003</td>
</tr>
<tr>
<td>Weight status†</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>268 (80.5)</td>
<td>21 (77.8)</td>
<td>150 (81.5)</td>
<td>97 (79.5)</td>
<td></td>
</tr>
<tr>
<td>Overweight</td>
<td>31 (9.3)</td>
<td>5 (18.5)</td>
<td>14 (7.6)</td>
<td>12 (9.8)</td>
<td></td>
</tr>
<tr>
<td>Obese</td>
<td>34 (10.2)</td>
<td>1 (3.7)</td>
<td>20 (10.9)</td>
<td>13 (10.7)</td>
<td>0.71</td>
</tr>
</tbody>
</table>

*Based on the national measure of relative deprivation for small areas in England; †Based on British growth reference data and using only the earliest available time-point from the PiP study. Ethnic group comparisons were performed using multilevel logistic regression for gender and IMD, and multilevel ordered logistic regression for weight status; multilevel models were used to account for school clustering. IMD, Index of multiple deprivation.
Table 3. Characteristics of study participants: continuous variables

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Total (n=333; obs=526)</th>
<th>Other/Mixed (n=27; obs=40)</th>
<th>South Asian (n=184; obs=315)</th>
<th>White British (n=122; obs=171)</th>
<th>p-ethnicity South Asian vs. White British</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>3.3 ± 0.9</td>
<td>3.0 ± 1.2</td>
<td>3.4 ± 1.0</td>
<td>3.2 ± 0.8</td>
<td>0.76</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>96.8 ± 8.6</td>
<td>93.7 ± 10.1</td>
<td>98.1 ± 8.6</td>
<td>95.1 ± 7.6</td>
<td>0.068</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>15.3 ± 3.0</td>
<td>14.6 ± 3.7</td>
<td>15.5 ± 3.2</td>
<td>15.0 ± 2.4</td>
<td>0.83</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>16.2 ± 1.7</td>
<td>16.3 ± 1.5</td>
<td>16.0 ± 1.8</td>
<td>16.6 ± 1.5</td>
<td>0.004</td>
</tr>
<tr>
<td>BMI z-score*</td>
<td>0.058 ± 1.2</td>
<td>0.089 ± 1.1</td>
<td>-0.11 ± 1.3</td>
<td>0.36 ± 1.0</td>
<td>0.004</td>
</tr>
<tr>
<td>Waist circumference (cm)†</td>
<td>50.5 ± 4.5</td>
<td>49.4 ± 3.5</td>
<td>50.6 ± 5.1</td>
<td>50.8 ± 3.5</td>
<td>0.84</td>
</tr>
<tr>
<td>Sedentary time (min/d)</td>
<td>282.3 ± 64.6</td>
<td>298.1 ± 70.9</td>
<td>280.1 ± 66.5</td>
<td>282.5 ± 59.2</td>
<td>0.108</td>
</tr>
<tr>
<td>Light PA (min/d)</td>
<td>242.0 ± 54.0</td>
<td>232.9 ± 47.9</td>
<td>239.9 ± 52.8</td>
<td>244.2 ± 55.3</td>
<td>0.12</td>
</tr>
<tr>
<td>MVPA (min/d)</td>
<td>51.4 ± 23.5</td>
<td>47.1 ± 25.6</td>
<td>52.5 ± 24.2</td>
<td>50.3 ± 21.5</td>
<td>0.080</td>
</tr>
<tr>
<td>Vector magnitude (cpm)</td>
<td>1371.2 ± 320.2</td>
<td>1278.3 ± 358.4</td>
<td>1389.1 ± 323.5</td>
<td>1359.9 ± 301.6</td>
<td>0.25</td>
</tr>
<tr>
<td>Monitor wear time (min/d)</td>
<td>575.6 ± 93.0</td>
<td>578.1 ± 72.9</td>
<td>576.8 ± 97.8</td>
<td>572.8 ± 88.4</td>
<td>0.006</td>
</tr>
</tbody>
</table>

*Based on British growth reference data; †Data available for 310 participants who provided 457 observations; All variables were approximately normally distributed and all values are mean ± standard deviation; Ethnic group comparisons were performed using multilevel linear regression to account for school clustering and (excluding skinfold comparisons) repeated-measures; there were no differences in p-values if comparisons were adjusted for IMD. BMI, Body mass index; PA: Physical activity; MVPA: Moderate-to-vigorous physical activity; cpm: counts per minute.
Table 4. Associations of categories for sedentary time and physical activity with adiposity indicators.

<table>
<thead>
<tr>
<th>BMI (kg/m²) (n=333; obs=526)</th>
<th>Waist circ. (cm) (n=310; obs=457)</th>
<th>Sum of skinfolds (mm) (n=156; obs=156)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sedentary time</td>
<td>-0.0069 (-0.040 to 0.027)</td>
<td>0.056 (-0.075 to 0.19)</td>
</tr>
<tr>
<td>Light PA</td>
<td>-0.00021 (-0.043 to 0.042)</td>
<td>-0.056 (-0.22 to 0.11)</td>
</tr>
<tr>
<td>MVPA</td>
<td>0.045 (-0.040 to 0.13)</td>
<td>-0.14 (-0.46 to 0.19)</td>
</tr>
<tr>
<td>Total PA (cpm)</td>
<td>0.042 (-0.037 to 0.12)</td>
<td>-0.072 (-0.39 to 0.24)</td>
</tr>
<tr>
<td>Model 2 – Isotemporal substitution</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ST → Light PA</td>
<td>-0.0096 (-0.055 to 0.036)</td>
<td>-0.034 (-0.21 to 0.15)</td>
</tr>
<tr>
<td>ST → MVPA</td>
<td>0.052 (-0.039 to 0.14)</td>
<td>-0.11 (-0.46 to 0.24)</td>
</tr>
<tr>
<td>Light PA → MVPA</td>
<td>0.061 (-0.054 to 0.18)</td>
<td>-0.077 (-0.53 to 0.37)</td>
</tr>
</tbody>
</table>

Statistical analyses performed using multilevel models adjusted for age, gender, ethnicity, index of multiple deprivation, monitor wear time (not in models with total PA as the outcome), and season of assessment. Models with waist circumference and sum of skinfolds as the outcomes were further adjusted for height. All results are scaled to represent the association between exposures and outcomes per 20 min difference in time-based exposures and 300 total PA counts per minute. Model 2 shows isotemporal substitution results and the effect of exchanging 20 minutes of ST or PA for different PA intensities. For example, shifting 20 minutes of ST to MVPA was associated with 0.77 mm lower sum of skinfolds, and vice versa shifting 20 minutes of MVPA to ST was associated with 0.77 mm higher sum of skinfolds. Statistically significant results are in bold. CI: Confidence interval; ST: Sedentary time; PA: Physical activity; MVPA: Moderate-to-vigorous physical activity; cpm: counts per minute.
Figure 2a

Click here to download Figure Figure2a_BMI.tif