Physical activity, sedentary time, and fatness in a biethnic sample of young children

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Physical Activity, Sedentary Time, and Fatness in a Biethnic Sample of Young Children

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1Bradford Institute for Health Research, Bradford NHS Foundation Trust, Bradford, UNITED KINGDOM; 2MRC Epidemiology Unit, University of Cambridge, Cambridge, UNITED KINGDOM; 3School of Sport, Exercise and Health Sciences, Loughborough University, Leicestershire, UNITED KINGDOM; and 4UKCRC Centre for Diet and Activity Research (CEDAR), School of Clinical Medicine, University of Cambridge, Cambridge, UNITED KINGDOM

ABSTRACT

COLLINGS, P. J., S. BRAGE, D. D. BINGHAM, S. COSTA, J. WEST, R. R. MCEACHAN, J. WRIGHT, and S. E. BARBER. Physical Activity, Sedentary Time, and Fatness in a Biethnic Sample of Young Children. Med. Sci. Sports Exerc., Vol. 49, No. 5, pp. 930–938, 2017. Purpose: This study aimed to investigate associations of objectively measured physical activity (PA) and sedentary time with adiposity in a predominantly biethnic (South Asian and White British) sample of young children. Methods: The sample included 333 children age 11 months to 5 yr who provided 526 cross-sectional observations for PA and body composition. Total PA volume (vector magnitude counts per minute), daily time at multiple intensity levels (the cumulative time in activity 333 children age 11 months to 5 yr who provided 526 cross-sectional observations for PA and body composition. Total PA volume (vector magnitude counts per minute), daily time at multiple intensity levels (the cumulative time in activity (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 favoring to concentrate exclusively on associations

Recent reviews have emphasized 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 characterized by unplanned and unsustained bursts of movement that are unreliable recalled by young children with developing cognition, and which are nonconducive to accurate parent reports (27).

A small evidence base has emerged that has utilized 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 favoring to concentrate exclusively on associations

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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 underresearched 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 remain largely unknown, national guidelines recommend that children younger than 5 yr participate in 180 min·d⁻¹ of PA at any intensity (15,16,37).

Investigating the effects of displacing one intensity of PA for equal time in another or for ST (isotemporal substitution analysis) is also a novel methodological approach that has only once been implemented in young children (29). That study however, like most others that have incorporated components, such as light PA, be it at the low or high end of the spectrum of PA may help to elucidate patterns of association (26). Investigating the entire range of PA (RCT) (30), the BiB-1000 observational cohort study (13), the Preschoolers in the Playground 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% to 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 analyzed by trial arm. All data (up to four repeated measurements) from the Preschoolers in the Playground 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 between 11 months and 5 yr of age (contributing 526 activity records, hereafter called observations) were included in this complete-case analysis. Because of the selection criteria of two studies (1,30), our sample was more deprived than the overall BiB cohort, but there were no differences in sex or ethnic composition, and no difference in the sum of triceps and subscapular skinfolds, compared with participants of the population-based BiB-1000 study (P ≥ 0.21 for all; BiB-1000 includes 1707 children considered representative of the city of Bradford [4]). All studies in this pooled analysis received

### TABLE 1. Description of studies.

<table>
<thead>
<tr>
<th>Study</th>
<th>Design/Objective</th>
<th>Population</th>
<th>Measurements</th>
</tr>
</thead>
<tbody>
<tr>
<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 PA antenatally and postnatally by mother and child</td>
<td>85 1-yr-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>7 d awake-time accelerometry; height and weight; measurements performed between July 2013 and March 2014</td>
</tr>
<tr>
<td>PiP</td>
<td>A cluster RCT piloting a playground-based PA intervention. Data were collected at baseline, 10, 30, and 52 wk</td>
<td>164 1.5- to 4-yr-olds recruited from 10 primary schools (five intervention schools, n = 83 intervention children)</td>
<td>7 d awake-time accelerometry; height, weight, and waist circumference; measurements performed between September 2012 and May 2014</td>
</tr>
<tr>
<td>BB-1000</td>
<td>An obesity etiology substudy embedded within the observational BiB project</td>
<td>A subsample of 97 2- to 4-yr-olds participating in BiB-1000; parents were initially recruited when attending routine oral glucose tolerance tests in pregnancy</td>
<td>7 d awake-time accelerometry; height, weight, waist circumference, triceps and subscapular skinfolds; measurements performed between June 2011 and July 2012</td>
</tr>
<tr>
<td>LEAP</td>
<td>An observational study comparing children’s PA, gross motor skills, and body composition between playground settings</td>
<td>105 3- to 5-yr-olds (76% South Asian) recruited from two primary schools</td>
<td>7 d continuous (24 h) accelerometry; parent-reported sleep diaries; height, weight, waist circumference, triceps and subscapular skinfolds; measurements performed September to November 2015</td>
</tr>
</tbody>
</table>

Intraobserver reliability
Waist circumference (n = 78): TEM = 0.49 cm; r = 0.97
Triceps skinfolds (n = 26): TEM = 0.25 mm; r = 0.99
Subscapular skinfolds (n = 26): TEM = 0.41 mm; r = 0.99

Interobserver reliability
Triceps skinfolds (n = 14): TEM = 0.66 mm; r = 0.79
Subscapular skinfolds (n = 12): TEM = 0.66 mm; r = 0.86

r values are Pearson product–moment correlation coefficients.
PiP, Preschoolers in the Playground; TEM, technical error of measurement.
either National Research Ethics Service or institutional ethical approval. Parental written informed consent and child assent were obtained before measurements.

**Exposure measurement: PA and ST.** Movement data were collected in all studies at a sampling frequency of 60 Hz, using the same batch of accelerometers (ActiGraph GT3X+; ActiGraph, Pensacola, FL), worn under or over clothing at the hip on an elasticated belt for six to eight consecutive days. Raw acceleration data files were processed using Actilife (v6.13, ActiGraph) in 15-s epochs. Monitor nonwear and daytime napping were inferred from continuous zero vertical activity counts ≥10 min 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 24 h, similar to the protocol used in the LEAP study (Table 1). To remove sleep from all acceleration records, a hierarchy of methods was 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 scrutinized, 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; and 3) if there was high-level movement after a parent-reported sleep onset, sleep times from the acceleration data were prioritized. This multimethod approach to eliminating sleep from 24-h accelerometry resembles a method previously used (12), and all judgments 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 h of data after removal of sleep were considered valid. To maximize 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 three or more valid days of data, an amount that 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 behaviors 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 h 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 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–1) above specific vector magnitude intervals (the total time in activity >500, >1000, >1500, ..., >6000 counts per minute). Data were further processed “classically” by using validated thresholds to estimate time spent sedentary (<820 vector magnitude counts per minute), in light PA (820–3907 counts per minute), and MVPA (≥3908 counts per minute) (6). Adherence (defined as performing on average ≥180 min PA per day) to activity guidelines was also quantified (15,16,37).

**Outcome measurement: adiposity data.** With the exceptions of length (measured by a rollometer 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 ≥3 cm; all data were used to calculate means. The BiB-1000 and the 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 subsamples of LEAP study participants also underwent repeated skinfold measurements to permit calculation of intra- and interobserver technical error of measurement for waist circumference, triceps, and subscapular skinfolds (Table 1); relative technical error of measurement values 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 to create deciles of area-level deprivation (which were grouped into the lowest 10%, 10%–30%, and ≥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 summarized using means with SD (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 modeled 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)
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 (50.8)</td>
<td>14 (51.9)</td>
<td>88 (47.5)</td>
<td>67 (54.9)</td>
<td></td>
</tr>
<tr>
<td>Girls</td>
<td>164 (49.2)</td>
<td>13 (48.1)</td>
<td>96 (52.2)</td>
<td>55 (45.1)</td>
<td>0.23</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>

Ethnic group comparisons were performed using multilevel logistic regression for gender and multilevel ordered logistic regression for IMD and weight status; multilevel models were used to account for school clustering. IMD, index of multiple deprivation.

*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 Preschoolers in the Playground study.

RESULTS

A total of 333 children (50.7% boys) with a mean age of 3.3 ± 0.9 yr 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 from more deprived areas and exhibited lower BMI compared with White British children (Tables 2 and 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 two (12%), three (17%), or four (4%) occasions. The number of valid observations totaled 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⁻¹. 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% of all activity observations were characterized by ≥180 min PA per day. 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 (Fig. 2A) or waist circumference (Fig. 2B), but time

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spent above 3500 counts per minute (i.e., high light-intensity PA to adopt terminology used by others [8]) was inversely associated with skinfold thickness, with every 20 min\(^{-1}\) related to 0.60 mm lower sum of skinfolds (Fig. 2C; \(P = 0.042\)). This relationship was characterized by a dose-dependent graded association, as the magnitude of association strengthened with increasing activity intensity, such that every 20 min\(^{-1}\) spent above 6000 counts per minute was associated with a 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 inverse association between MVPA and the sum of skinfolds, and revealed that replacing 20 min\(^{-1}\) 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 toward significance \((P = 0.068)\).

All of the results were materially similar and conclusions remained unchanged when analyses were performed with accelerometry data that were diurnally well balanced and derived from automated exclusion of sleep. The same applies to analyses that only included children with \(\geq 3\) d of accelerometry and models that were rerun with exclusion of intervention (nonbaseline) data, the results of which are presented as supplementary material (see Table, Supplemental Digital Content 1, Associations of categories for ST and PA with adiposity indicators (exclusive of all nonbaseline intervention data), http://links.lww.com/MSS/A838).

**DISCUSSION**

This is the first study to comprehensively investigate the relations between PA, ST, and adiposity in a predominantly biethnic group of young children. Our results contribute to a

### TABLE 3. Characteristics of study participants: continuous variables.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Total ((N = 333); Observations = 526)</th>
<th>Other/Mixed ((n = 27); Observations = 48)</th>
<th>South Asian ((n = 184); Observations = 315)</th>
<th>White British ((n = 122); Observations = 171)</th>
<th>(P) Ethnicity, South Asian vs White British</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</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>0.088</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 (\text{kg/m}^2)</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>ST (\text{min}^{-1})</td>
<td>292.3 ± 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 (\text{min}^{-1})</td>
<td>242.0 ± 54.0</td>
<td>232.9 ± 47.9</td>
<td>244.2 ± 55.3</td>
<td>239.9 ± 52.8</td>
<td>0.12</td>
</tr>
<tr>
<td>MVPA (\text{min}^{-1})</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 (counts per minute)</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(^{-1}))</td>
<td>575.6 ± 93.0</td>
<td>578.1 ± 72.9</td>
<td>576.8 ± 97.8</td>
<td>572.6 ± 88.4</td>
<td>0.006</td>
</tr>
<tr>
<td>Triceps skinfold (mm)</td>
<td>10.1 ± 2.6</td>
<td>11.2 ± 2.9</td>
<td>10.4 ± 2.7</td>
<td>9.4 ± 2.2</td>
<td>0.094</td>
</tr>
<tr>
<td>Subscapular skinfold (mm)</td>
<td>6.6 ± 2.6</td>
<td>7.7 ± 4.0</td>
<td>7.0 ± 2.9</td>
<td>5.8 ± 1.2</td>
<td>0.58</td>
</tr>
<tr>
<td>Sum of skinfolds (mm)</td>
<td>16.6 ± 4.7</td>
<td>18.8 ± 6.2</td>
<td>17.4 ± 5.2</td>
<td>15.2 ± 3.1</td>
<td>0.47</td>
</tr>
</tbody>
</table>

All variables were approximately normally distributed, and all values are presented as mean ± SD. 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 index of multiple deprivation.

*Based on British growth reference data.

**DISCUSSION**

This is the first study to comprehensively investigate the relations between PA, ST, and adiposity in a predominantly biethnic group of young children. Our results contribute to a

**FIGURE 1**—Daily cumulative awake time spent above vector magnitude intervals. Data are mean values, and error bars represent ± SD. Light PA (820–3908 counts per minute) corresponds to the light shaded region and MVPA (≥3908 counts per minute) to the dark shaded region. The inset shows a magnified plot for >4000 counts per minute. A multivariate test of means provided no evidence for a difference between South Asian and White British \((P = 0.76)\). CPM, counts per minute.
growing body of evidence for inverse cross-sectional associations between MVPA and measures of adiposity in children aged 5 yr and younger (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 triaxial 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 9.6 h 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 Fig. 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

FIGURE 2—Associations between the cumulative awake time above vector magnitude intervals with BMI (A), waist circumference (B), and sum of skinfolds (C). 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 counts per minute) corresponds to the light shaded region and MVPA (≥3908 counts per minute) to the dark shaded region. CPM, counts per minute.
TABLE 4. Associations of categories for ST and PA with adiposity indicators.

<table>
<thead>
<tr>
<th></th>
<th>BMI (kg m⁻²) (N = 333; Observations = 526)</th>
<th>Waist Circumference (cm) (n = 310; Observations = 457)</th>
<th>Sum of Skinfolds (mm) (n = 156; Observations = 156)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>β (95% CI)</td>
<td>β (95% CI)</td>
<td>β (95% CI)</td>
</tr>
<tr>
<td>Model 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ST</td>
<td>−0.0069 (−0.040 to 0.027)</td>
<td>0.056 (−0.075 to 0.19)</td>
<td>0.21 (−0.12 to 0.53)</td>
</tr>
<tr>
<td>Light PA</td>
<td>−0.00021 (−0.043 to 0.042)</td>
<td>−0.066 (−0.22 to 0.11)</td>
<td>−0.059 (−0.47 to 0.35)</td>
</tr>
<tr>
<td>MVPA</td>
<td>0.045 (−0.040 to 0.13)</td>
<td>−0.14 (−0.46 to 0.19)</td>
<td>0.76 (−1.43 to −0.085)</td>
</tr>
<tr>
<td>Total PA (counts per minute)</td>
<td>0.042 (−0.037 to 0.12)</td>
<td>0.072 (−0.39 to 0.24)</td>
<td>0.64 (−1.46 to 0.19)</td>
</tr>
<tr>
<td>Model 2—Isotemporal substitution</td>
<td></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>
<td>0.048 (−0.37 to 0.47)</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>
<td>−0.77 (−1.46 to −0.084)</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>
<td>−0.82 (−1.71 to 0.062)</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 min of ST or PA for different PA intensities. For example, shifting 20 min of ST to MVPA was associated with 0.77 mm lower sum of skinfolds. We found no evidence for associations between PA and adiposity as defined by BMI or waist circumference, which may explain the novel findings. Like 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 (Fig. 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 suboptimal indicators of body fatness in children (2). Our observation that for every TABLE 4. Associations of categories for ST and PA with adiposity indicators. 20 min d⁻¹ 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⁻¹ 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⁻¹ of PA exceeding an intensity of 6000 counts per minute 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 postactivity 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 per day of any intensity (15,16,37), as we did find a significant inverse association between 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 preschoolers (23). Nevertheless, in the current sample although 95% of activity observations exceeded the recommended volume of PA per day (chiefly satisfied by engaging in low light-intensity PA as shown in Fig. 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 per day alongside an unspecified volume of vigorous PA (on at least 3 d·wk⁻¹) is endorsed for ≥5-yr-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 harmonized data from four studies to achieve a relatively large sample size and capitalized on repeated measures for one-third of the cohort, thereby reducing the regression dilution effect. Habitual PA was also estimated objectively using triaxial accelerometer and a population-specific wear criterion (3). It is unfortunate that data for the sum of skinfolds were only available for a subsample of participants, but we advantageously retained all adiposity indicators in their continuous forms for analyses thereby raising statistical power and avoiding decisions regarding categorization. With regard 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 because of 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 favorable 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.

The authors are grateful to all the schools, families, and children that took part in each of the studies and to the BiB community team for assisting with recruitment and data collection. The studies used in this research have been financially supported by the National Institute for Health Research (NIHR) program grant for applied research (RP-PG-0407-10044), the NIHR Public Health Research (PHR 11/3001/16), and the NIHR CLAHRC Yorkshire and the Humber. The views expressed are those of the authors and not necessarily those of the NHS, the NIHR, or the Department of Health. The results of the study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation. The results of the present study do not constitute endorsement by the American College of Sports Medicine.

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 or institutional ethical approval. Parental written informed consent and child assent were obtained before measurements.

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The authors’ responsibilities were as follows: P. J. C. designed and conducted the research, analyzed data, wrote the article, and had primary responsibility for the final content of the manuscript. S. B. assisted in the design of the statistical analysis and critiqued the manuscript. D. D. B. assisted in the process of accelerometer data.

D. D. B., S. C., J. We., R. R. C. M., J. Wr., and S. E. B. designed individual studies, organized and managed data collections, and critiqued the manuscript; all authors approved the final manuscript as submitted.

ClinicalTrials Registry number and website: The HAPPY (ISRCTN56735429) and PiP (ISRCTN54165860) pilot randomized controlled trials are both registered with the ISRCTN (http://www.isrctn.com).

**REFERENCES**


