Physical activity intensity, sedentary time, and body composition in preschoolers

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ABSTRACT

Background: Detailed associations between physical activity (PA) subcomponents, sedentary time, and body composition in preschoolers remain unclear.

Objective: We examined the magnitude of associations between objectively measured PA subcomponents and sedentary time with body composition in 4-y-old children.

Design: We conducted a cross-sectional study in 398 preschool children recruited from the Southampton Women’s Survey. PA was measured by using accelerometry, and body composition was measured by using dual-energy X-ray absorptiometry. Associations between light physical activity, moderate physical activity (MPA), vigorous physical activity (VPA), and moderate-to-vigorous physical activity (MVPA) intensity; sedentary time; and body composition were analyzed by using repeated-measures linear regression with adjustment for age, sex, birth weight, maternal education, maternal BMI, smoking during pregnancy, and sleep duration. Sedentary time and PA were also mutually adjusted for one another to determine whether they were independently related to adiposity.

Results: VPA was the only intensity of PA to exhibit strong inverse associations with both total adiposity ($P < 0.001$ for percentage of body fat and fat mass index (FMI)) and abdominal adiposity ($P = 0.002$ for trunk FMI). MVPA was inversely associated with total adiposity ($P = 0.018$ for percentage of body fat; $P = 0.022$ for FMI) but only because of the contribution of VPA, because MPA was unrelated to fatness ($P \geq 0.077$). No associations were shown between the time spent sedentary and body composition ($P \geq 0.11$).

Conclusions: In preschoolers, the time spent in VPA is strongly and independently associated with lower adiposity. In contrast, the time spent sedentary and in low-to-moderate–intensity PA was unrelated to fatness ($P \geq 0.077$). No associations were shown between the time spent sedentary and body composition ($P \geq 0.11$).

INTRODUCTION

In England, more than one-fifth of children between 4 and 5 y of age are overweight or obese (1). It is expected that a considerable fraction of these over-fat children will become obese adults (2). Therefore, early childhood is an important time frame that should be targeted by preventive strategies intended to reduce body fat accumulation.

Increased physical activity (PA)\(^4\), which is the largest modifiable component of energy expenditure, is frequently prioritized alongside dietary restriction for the prevention or treatment of obesity (3, 4). It is logical that PA may assist the attainment of healthy weight by encouraging energy balance. However, there have been only a small number of investigations that have examined the association between preschool PA and body composition (5). At least in part, the small number of studies can be attributed to past difficulties in the measurement of the PA of young children. Uniquely, young children participate in low-intensity movement that is rapidly interspersed with brief, sporadic, and often unmemorable episodes of moderate-to-vigorous physical activity (MVPA) (6, 7). Children <10 y of age are unable to recall their own activity with accuracy and surrogate reports courtesy of caregivers have exhibited low validity (8). Alternative methodologies, such as accelerometry, are now available, and they can be feasibly used in large-scale studies to provide objective measurements of the free-living PA of young children (9). Accelerometers have been validated in preschoolers.

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\(^4\)Abbreviations used: DXA, dual-energy X-ray absorptiometry; FM, fat mass; FMI, fat mass index; LM, lean mass; LMI, lean mass index; LPA, light physical activity; MPA, moderate physical activity; MVPA, moderate-to-vigorous physical activity; PA, physical activity; SWS, Southampton Women’s Survey; TFM, trunk fat mass; TFM, trunk fat mass index; VPA, vigorous physical activity.

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under a variety of conditions and by using different criterion methods. The vast majority of studies reported strong correlations between techniques (10, 11).

Accelerometers provide rich data about total activity and can further be used to measure subcomponent PA (eg, the time spent in light physical activity (LPA), moderate physical activity (MPA), and vigorous physical activity (VPA) intensity, and sedentary time (12)). With the use of accelerometers, studies in young children have established inverse cross-sectional associations between PA and adiposity (5, 13–15). The studies have also indicated that high-intensity PA may be more strongly associated with adiposity than PA of a low-to-moderate intensity. However, it remains unknown if PA of greater intensity is associated with preschool adiposity independent of the time spent sedentary, which, itself, is a potential risk factor for obesity (16). Answering this is important for public health purposes, in terms of refining obesity interventions that are aimed at increasing PA, or reducing sedentary time, in young children.

The aim of the current study was to examine independent associations between a range of accelerometer-derived PA intensities and sedentary time (accomplished by mutually adjusting for one another) with body composition in a reasonably large, free-living population cohort of preschool children.

SUBJECTS AND METHODS

Subjects

The study was a cross-sectional investigation embedded within the Southampton Women’s Survey (SWS). Details of the SWS, which is a longitudinal birth cohort study, have been previously published (17). Briefly, between 1998 and 2002, all nonpregnant women aged 20–34 y who were registered with a general practitioner in Southampton, United Kingdom, were invited to participate in the SWS. Women who accepted and subsequently became pregnant (n = 3159) were studied during gestation, and their offspring were followed through childhood. At 4 y of age 1013 children underwent an assessment of body composition by using dual-energy X-ray absorptiometry (DXA); some children also underwent an assessment of habitual PA. This study constituted a complete-case analysis of participants with full data for body composition, PA, and important covariates at 4 y of age (n = 398). Approval for all components of the SWS was granted by the local research ethics committee, and parental written informed consent was obtained for all children.

Assessment of PA intensity and sedentary time

Free-living PA was measured by using the Actiheart combined heart rate and movement sensor (CambridgeNtech Ltd) attached to the chest (18). In young children, methods required for the interpretation of both heart rate and movement from the Actiheart sensor are still being developed, and thus for this study, accelerometer data were used in isolation.

Children were asked to wear the accelerometer continuously (including overnight wear) for 7 consecutive days including during swimming, bathing, and sleeping. Movement data were collected in 60-s epochs and, after upload to a computer, were reduced by means of a custom-designed program (MahUffe version 1.9.0.3; http://www.mrc-epid.cam.ac.uk). As part of data-reduction, periods of continuous zero counts ≥100 min in duration were used to indicate monitor removal from the torso and were erased. First and last days of observation were also discarded. We have previously observed that the SWS cohort (at 4 y of age) exhibited similar PA levels on both week and weekend days (KR Hesketh, AM McMinn, U Ekelund, et al, unpublished observations, May 2012). Therefore, weekend observations were deemed nonessential to providing reliable estimates of PA, and all children with at least one valid day of activity data were included in analyses. A valid day was defined as ≥600 min of nonsleeping data.

To derive the time (min/d) spent sedentary and in a range of PA intensities, age-specific cut-points commonly employed in the preschool age group were used (19–21). The cutoffs (sedentary: <37.5 counts; LPA: 38–419 counts; MPA: 420–841 counts; and VPA: ≥842 counts) were originally developed by using the Actigraph accelerometer (Manufacturing Technologies Inc) with 15-s epochs. To accommodate our data, we first reintegrated thresholds to 60 s (×4) and calculated Actiheart sensor equivalent cutoffs (×5). The conversion factor was based on a comparison of counts in adolescents when both devices were worn simultaneously in the laboratory during treadmill walking and running and during free living (22, 23). It seems that accelerometer counts indicative of sedentary behavior and MVPA are largely independent of age and body size (24); thus, there is some reassure that our conversion factor, although developed in adolescents, was suitable for application in preschoolers.

Daily sedentary time courtesy of the 24-h monitoring protocol was a combined record of true awake sedentary time and sleep. To eliminate sleep (a sedentary behavior albeit necessary for normal growth and functioning), distributions of registered sedentary time on an hourly basis were inspected. Overnight between 2300 and 0600, the median sedentary time was high (60 min/h; IQR: 3 min/h) and was presumed to reflect sleep; all data related to this 7-h period were removed. To account for interindividual and intra-individual variabilities in sleep patterns and durations, an additional exclusion rule was formulated. If a sedentary time >45 min was recorded within one of the hours between 0600–0800 and 2100–2300, the child was considered to have been sleeping, and the corresponding hour or hours were discarded from analyses (Figure 1). Napping has a low purported prevalence in this age group (25, 26), and hence, all periods of high sedentary time (>45 min/h) between the hours of 0800 and 2100 were considered true sedentariness and not daytime sleeping. With the use of our dismissal criteria, the average time of sleep onset for children was shown to be 2112, the sleep termination time was established as 0707, and the average (±SD) daily sleep duration was 9.9 ± 0.9 h. These times were reflective of objectively-measured sleep patterns and durations in 4-y-olds (25, 26) and indicated the credibility of our method. After the removal of sleep, daily averages for sedentary time and time spent in each of the PA intensities were constructed. Information concerning the number of bouts of MVPA (MPA + VPA) and VPA ≥5 min in duration was also extracted.

Assessment of body composition

Children were invited for an assessment of body composition by using DXA (Hologic Discovery; Hologic Inc) at Southampton General Hospital. To encourage child compliance, a sheet with...
was used to calculate LM index (LMI; kg/m$^2.5$). Regression of
TFMI: height raised to the power of 2 was used to calculate fat mass index (FMI; kg/m$^2$) and
appropriate colored cartoons was laid on the scanning bed before
measurement, and suitable DVD cartoons were shown during
scans. The DXA instrument was calibrated by using a spine
phantom daily and a step phantom weekly. The total radiation
dose for whole-body measurement by using the pediatric scan
mode was 4.7 μSv.

Scans were analyzed by a trained technician with automated
pediatric software (Vertec Scientific Ltd). Chosen body-composition
variables for this study included 2 measures of total adiposity,
namely the percentage of body fat and fat mass (FM), a single
measure of lean mass (LM), and, as an indicator of truncal ad-
osity, trunk fat mass (TFM). TFM was estimated by using a
region defined by a horizontal line below the chin, vertical
borders lateral to the ribs, and oblique lines that passed through
femoral necks. Subsequent to the measurement of child height (by using a Leicester height measurer), height-adjusted indexes
of FM, LM, and TFM were computed (27). Height raised to the
power of 2 was used to calculate fat mass index (FMI; kg/m$^2$) and
trunk fat mass index (TFMI; kg/m$^2.5$). Height to the power of 2.5
was used to calculate LM index (LMI; kg/m$^2.5$). Regression of
these indexes against height at 4 y confirmed that they were no
longer associated with stature (FMI: $r^2 = 0.0001$, $P = 0.88$; 
TFMI: $r^2 = 0.0000$, $P = 0.95$; LMI: $r^2 = 0.0008$, $P = 0.58$).
Weight was measured by using standard procedures with cali-
ibrated digital scales (Seca Ltd) and, together with height, was
used to calculate BMI [in kg/m$^2$ (weight divided by the square
of height)]. For descriptive purposes, children were classified as
normal weight, overweight, or obese according to International
Obesity Task Force age- and sex-specific BMI growth charts
(28).

Potential confounders

Data about several covariates known to be associated with PA
or body composition were collected, including information about
maternal education on enrollment to the SWS. These data were
used to categorize mothers into 3 socioeconomic groups (low,
moderate, and high) partitioned according to similarities in ed-
ucational level [low: no qualifications and General Certificate of
Secondary Education grades D or below (national school exams
at age 16 y); moderate: General Certificate of Secondary Edu-
cation grade C or above and A-level (national school exams at age
18 y); high: Higher National Diploma (higher education qualifi-
cation considered equivalent to the first 2 y of a 3-y degree) and
degree]. Maternal height and weight were measured with a stadi-
meter and calibrated digital scales, respectively, and were used to
calculate maternal prepregnancy BMI. Infant sex and birth weight
were abstracted from obstetric records, and maternal smoking
was reported at 11 and 34 wk of gestation with responses being
combined to indicate any smoking during pregnancy. Sleep du-
ration was derived from the Actiheart sensor according to the
method described in Figure 1. Finally, information about the du-
ration of breastfeeding (weeks since birth) was maternally reported
and available for a large subsample of participants ($n = 383$).

Statistical analysis

To determine the normality of continuous variables, histo-
grams were viewed in conjunction with skewness and kurtosis
statistics. The nonnormality of skewed dependent variables (FMI
and TFMI) was rectified by using natural logarithmic trans-
formations. Descriptive statistics for all variables were sub-
sequently calculated for the total group and by sex after collapsing
daily activity data to the average level (average data were used for the descriptive analysis only). To summarize
normally distributed continuous variables, means and SDs were
calculated, and sex differences were tested by using ANOVA.
For skewed variables, median and IQRs were determined, and sex
differences were examined by using Wilcoxon’s rank-sum test.
For categorical variables, proportions were used, and sex dif-
ferences were analyzed by using the chi-square test. Identical
statistical tests were used to compare characteristics of children
who contributed and did not contribute to the analysis (because
of incomplete data).

To examine associations between PA intensity, sedentary time,
and body-composition variables, Pearson’s correlation analysis
was initially used followed by linear regressions with repeated
measures. Repeated measures were used to account for clustered
data that resulted from children who contributed >1 d of PA. All
potential confounders including age, sex, birth weight, maternal
education, maternal BMI, smoking during pregnancy, and sleep
duration were initially added to regressions (model 1). Model 2
was further adjusted for sedentary time to see if the associations
between PA intensity and body composition were independent
of time spent sedentary. Similarly, when sedentary time was the
exposure of interest, model 2 was further adjusted for MVPA.
All finally adjusted models were examined for nonlinear varia-
tion by introducing quadratic terms and checking for an im-
proved model fit by using likelihood ratio testing. The effect
modification by sex was also inspected. Regression coefficients
from models that included log-transformed dependent variables
(FMI and TFMI) were converted for ease of interpretation.
Coefficients were modified to represent the average percentage
change in the outcome per unit increase in the independent
variable by using the following formula:

\begin{align*}
\text{Coefficient adjusted for sex} &= \text{Coefficient} \\
&\quad \times \frac{1}{1 - \text{Coefficient}}
\end{align*}

\textbf{FIGURE 1}. Derivation of sedentary time. Sedentary time between 2300 and 0600 was assumed to reflect (in)activity during sleep; all corresponding data were removed (dark-gray shading). To account for interindividual and intraindividual variabilities in the sleep pattern, high sedentary times (>45 min/h; solid horizontal line) between 0600 and 0800 and between 2100 and 2300 were further assumed to reflect (in)activity during sleep, and all corresponding data were removed (light-gray shading). Remaining data provided an indication of sleep termination and onset times as well as sleep duration [0700 and 2100 (diamonds) and 10 h, respectively, in this scenario]. LPA, light physical activity; MPA, moderate physical activity; VPA, vigorous physical activity.
Independent variables were also scaled according to guidelines for PA in children (ie, 60 min MVPA/d, which is the former guideline for young children) or according to durations that might be considered realistic ambitions for intervention studies (eg, 15 min VPA/d).

Subsequent to finalizing regression models 1 and 2, a number of sensitivity analyses were conducted to determine the robustness of coefficients. To enable adjustment for breastfeeding history, regression models were repeated in a marginally reduced sample size (n = 383; sensitivity analysis 1). Models were also rerun to allow for possible errors in the derivation of sedentary time (sensitivity analysis 2). This analysis was accomplished by replacing both sedentary time and sleep-duration variables with the one combined measure of awake sedentary time and sleep provided by the complete 24-h monitoring record. With appreciation that 1 d of observation may not accurately reflect the habitual PA pattern of children, we further used the intraclass correlation coefficient for accelerometer variables, in conjunction with the Spearman-Brown prophecy formula, to calculate the number of days needed to obtain 80% reliability in PA and sedentary time estimates. In close agreement with published recommendations (29), we showed that 6 d of accelerometer were needed to optimize reliability (data not shown). Models were thereby restricted to participants with at least this level of activity data and reanalyzed (sensitivity analysis 3). A significance level of P < 0.05 was chosen a priori, and all analyses were performed with Stata 12.0 software (StataCorp).

RESULTS

Descriptive characteristics of the sample are shown in Table 1. There was an equal sex contribution (51% of the sample were boys), but the sample was predominantly white (97% of mothers were white). Approximately 9% of children were born to mothers who smoked during pregnancy, and a similar proportion (7.8%) was born to mothers with no or few academic qualifications. At the time of the 4-y measurement, boys were marginally older than girls (P = 0.028). With reference to body composition, all indexes of adiposity (percentage of body fat, FM, FMI, TFM, and TFMI) were significantly higher in girls (P < 0.001), but there was no sex difference in the proportion of children categorized as normal weight, overweight, or obese (P = 0.34).

### Table 1

**Descriptive characteristics of the study population**

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Total (n = 398)</th>
<th>Boys (n = 202)</th>
<th>Girls (n = 196)</th>
<th>P-sex difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>4.10 (0.08)</td>
<td>4.11 (0.08)</td>
<td>4.10 (0.08)</td>
<td>0.028</td>
</tr>
<tr>
<td>Maternal ethnicity (% white)</td>
<td>96.9</td>
<td>97.5</td>
<td>96.9</td>
<td>0.72</td>
</tr>
<tr>
<td>Maternal education (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>7.84</td>
<td>6.9</td>
<td>8.6</td>
<td>0.51</td>
</tr>
<tr>
<td>Moderate</td>
<td>59.6</td>
<td>57.9</td>
<td>61.2</td>
<td></td>
</tr>
<tr>
<td>High</td>
<td>32.7</td>
<td>35.2</td>
<td>30.1</td>
<td></td>
</tr>
<tr>
<td>Maternal BMI (kg/m²)</td>
<td>24.3 (5.4)</td>
<td>24.3 (4.9)</td>
<td>24.0 (5.8)</td>
<td>0.62</td>
</tr>
<tr>
<td>Smoked during pregnancy (%)</td>
<td>9.3</td>
<td>8.9</td>
<td>9.7</td>
<td>0.86</td>
</tr>
<tr>
<td>Birth weight (kg)</td>
<td>3.5 ± 0.5</td>
<td>3.6 ± 0.5</td>
<td>3.5 ± 0.5</td>
<td>0.054</td>
</tr>
<tr>
<td>Breastfeeding (wk)</td>
<td>13.0 (29.4)</td>
<td>13.0 (25.9)</td>
<td>13.0 (31.3)</td>
<td>0.30</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.04 ± 0.04</td>
<td>1.05 ± 0.04</td>
<td>1.04 ± 0.04</td>
<td>0.21</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>17.8 (2.7)</td>
<td>17.7 (2.8)</td>
<td>17.8 (2.7)</td>
<td>0.64</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>16.3 (1.6)</td>
<td>16.4 (1.6)</td>
<td>16.3 (1.6)</td>
<td>0.82</td>
</tr>
<tr>
<td>Percentage of body fat</td>
<td>26.8 ± 4.9</td>
<td>24.2 ± 3.7</td>
<td>29.5 ± 4.5</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Fat mass (kg)</td>
<td>4.6 (1.4)</td>
<td>4.2 (1.1)</td>
<td>5.2 (1.5)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Fat mass index (kg/m²)</td>
<td>4.2 (1.3)</td>
<td>3.9 (0.9)</td>
<td>4.7 (1.3)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Trunk fat mass (kg)</td>
<td>1.6 (0.6)</td>
<td>1.5 (0.5)</td>
<td>1.8 (0.7)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Trunk fat mass index (kg/m²)</td>
<td>1.5 (0.6)</td>
<td>1.3 (0.4)</td>
<td>1.7 (0.7)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Lean mass (kg)</td>
<td>12.6 ± 1.5</td>
<td>13.1 ± 1.4</td>
<td>12.1 ± 1.4</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Lean mass index (kg/m²)</td>
<td>11.2 ± 0.87</td>
<td>11.6 ± 0.81</td>
<td>10.8 ± 0.73</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Weight status (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>79.9</td>
<td>82.7</td>
<td>77.0</td>
<td></td>
</tr>
<tr>
<td>Overweight</td>
<td>15.6</td>
<td>13.9</td>
<td>17.4</td>
<td></td>
</tr>
<tr>
<td>Obese</td>
<td>4.5</td>
<td>3.5</td>
<td>5.6</td>
<td>0.34</td>
</tr>
<tr>
<td>LPA (min/d)</td>
<td>423.6 ± 63.0</td>
<td>428.6 ± 64.8</td>
<td>418.5 ± 60.8</td>
<td>0.11</td>
</tr>
<tr>
<td>MPA (min/d)</td>
<td>58.6 (28.2)</td>
<td>61.8 (33.3)</td>
<td>56.8 (23.2)</td>
<td>0.0073</td>
</tr>
<tr>
<td>VPA (min/d)</td>
<td>23.6 (21.3)</td>
<td>24.8 (22.9)</td>
<td>22.9 (19.7)</td>
<td>0.48</td>
</tr>
<tr>
<td>MVPA (min/d)</td>
<td>84.7 (46.4)</td>
<td>89.0 (53.8)</td>
<td>82.3 (39.3)</td>
<td>0.042</td>
</tr>
<tr>
<td>Sedentary time (min/d)</td>
<td>329.3 ± 72.7</td>
<td>327.1 ± 77.5</td>
<td>331.6 ± 67.5</td>
<td>0.54</td>
</tr>
<tr>
<td>Sleep duration (min/d)</td>
<td>598.2 ± 30.2</td>
<td>591.4 ± 39.9</td>
<td>605.2 ± 35.7</td>
<td>0.0003</td>
</tr>
</tbody>
</table>

1. LPA, light physical activity; MPA, moderate physical activity; MVPA, moderate-to-vigorous physical activity; VPA, vigorous physical activity.
2. Median; IQR in parentheses (all such values). Median (IQR) and sex comparisons were made by using Wilcoxon’s rank sum tests.
3. Sex comparisons were made by using chi-square tests for categorical variables.
4. Mean ± SD (all such values). Mean ± SD and sex comparisons were made by using ANOVA.
There were no sex differences in the number of days of PA measurement \( (P = 0.47) \). Children were monitored for 1 (4%), 2 (4%), 3 (7%), 4 (7%), 5 (16%), 6 (60%), or 7 (2%) valid days (operationalized as \( \geq 600 \) min nonsleeping data). Before removing sleep, the average recorded observation time from the Actiheart sensor was 1425.6 \( \pm 63.6 \) min/d, and \( >92\% \) of days contained 1440 min (24 h) data. These values indicate a high adherence to the accelerometer protocol and low variability in wear time. An average of 5.2 d of accelerometer per child was collected and culminated in a total of 2045 d PA, which served as the unit of analysis in this investigation. As reported in Table 1, these activity data revealed that boys participated in more MPA and MVPA than girls did \( (P = 0.0073 \) and \( P = 0.042 \), respectively). Boys also conducted more bouts of MVPA that lasted \( \geq 5 \) min in length \( \{\text{boys: } 3.7 \ (IQR: 3) \}; \text{girls: } 3.0 \ (IQR: 2.4); P = 0.0037\} \). Girls slept longer than boys \( (P = 0.0003) \), but there was no sex difference in LPA, VPA, or time spent sedentary \( (P \geq 0.11); \) Table 1). The median number of VPA bouts that lasted \( \geq 5 \) min in duration was comparably low across sexes \( \{\text{boys: } 0.7 \ (IQR: 1.3) \}; \text{girls: } 0.6 \ (IQR: 1.0); P = 0.076\} \), which alluded to the sporadic nature of preschool PA.

Compared with children followed-up at 4 y of age with incomplete data, children who contributed to the analysis \( (n = 398) \) were, on average, 0.13 mo younger \( (P = 0.0085) \), 0.10 kg heavier at birth \( (P = 0.0054) \), and 0.9 cm taller at 4 y of age \( (P = 0.0019) \). In addition, the prevalence of maternal smoking in pregnancy was lower in children who contributed to the analysis than in children with incomplete data \( (9% \% \text{compared with } 16\% , \text{respectively}; P = 0.005) \). In terms of body composition, 345 children underwent DXA at 4 y, but did not contribute to the analysis because data for PA or covariates were not collected. These children did not differ from the analysis sample in any aspect of body composition \( (P \geq 0.43) \) or in the proportion classified as normal, overweight, or obese \( (P = 0.62) \). Similarly, 194 children had valid data for PA but did not contribute to the analysis because data for body composition or covariates were not available. Compared with these children, children who formed the analysis sample slept longer \( (589.5 \text{ compared with } 598.2 \text{ min/d, respectively}; P = 0.0063) \) and were less active because they performed fewer average minutes of LPA per day \( (434.9 \text{ compared with } 423.6; P = 0.039) \), fewer average minutes of MPA per day \( (66.6 \text{ compared with } 58.6; P = 0.0020) \), and fewer average minutes of MVPA per day \( (95.9 \text{ compared with } 84.7; P = 0.032) \).

Bivariate correlations between independent and dependent variables are shown in Table 2. Moderate to strong correlations between most activity variables meant that, in an effort to avoid collinearity-induced errors, a series of individual linear regressions were performed for each PA intensity. Adiposity variables were also strongly correlated \( (P < 0.001 \text{ for all}) \) and were all negatively correlated with LMI \( (P < 0.001) \). Correlations between activity and body-composition variables showed that all intensities of PA were negatively related to adiposity, but strengths of coefficients were higher for VPA \( (P < 0.001 \text{ for all}) \) than the lower intensities of activity. In contrast, sedentary time was positively correlated with adiposity \( (P \leq 0.01) \). Activity variables were positively correlated with LMI but unlike coefficients for adiposity, there was no discernible pattern toward stronger correlations for higher-intensity PA. Sedentary time was significantly negatively correlated with LMI \( (P < 0.001) \).

Adjusted associations for PA intensity and sedentary time with each adiposity measurement are shown in Table 3. Because there was no evidence of an effect modification by sex \( (P \geq 0.14) \), data are related to the whole sample adjusted for sex. The most-consistent results were established for VPA, which was significantly inversely associated with all indicators of adiposity, independent of covariates including sedentary time \( (P < 0.001) \) for percentage of body fat and FMI; \( P = 0.002 \) for TFMI). A total of 15 min VPA/d was associated with a 0.36 lower percentage of body fat, 1.75% lower FMI, and 1.90% lower TFMI. Data were analyzed in continuous form, but for presentation purposes, adjusted means of the percentage of body fat, FMI, and TFMI stratified by quarters of VPA are shown in Figure 2. An inverse dose-response relation with lower adiposity as a function of increasing VPA is illustrated in Figure 2 \( (P\text{-trend } \leq 0.011) \).

Greater MVPA was associated both with a lower percentage of body fat and FMI \( (P = 0.018 \text{ and } P = 0.022, \text{respectively}) \) but not lower TFMI \( (P = 0.095; \text{Table 3}) \). Because MPA was unrelated to all measures of adiposity \( (P \geq 0.077) \), by process of elimination, the observed associations between MVPA, percentage of body fat, and FMI were exclusively explained by the contribution of VPA. LPA was positively associated with the percentage of body fat and FMI after adjustment for sedentary time \( (P = 0.018 \text{ and } P = 0.022, \text{respectively}) \), but no associations were

### Table 2

<table>
<thead>
<tr>
<th></th>
<th>LPA</th>
<th>MPA</th>
<th>VPA</th>
<th>MVPA</th>
<th>Sedentary time</th>
<th>Percentage of body fat</th>
<th>FMI</th>
<th>TFMI</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPA</td>
<td>0.36</td>
<td>0.61</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VPA</td>
<td>0.018</td>
<td>0.61</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MVPA</td>
<td>0.25</td>
<td>0.94</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sedentary time</td>
<td>-0.75</td>
<td>-0.64</td>
<td>-0.39</td>
<td>-0.60</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percentage of body fat</td>
<td>-0.046</td>
<td>-0.11</td>
<td>-0.13</td>
<td>-0.13</td>
<td>0.080</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FMI</td>
<td>-0.020</td>
<td>-0.073</td>
<td>-0.12</td>
<td>-0.10</td>
<td>0.058</td>
<td>0.94</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TFMI</td>
<td>-0.033</td>
<td>-0.059</td>
<td>-0.10</td>
<td>-0.084</td>
<td>0.062</td>
<td>0.88</td>
<td>0.94</td>
<td></td>
</tr>
<tr>
<td>LMI</td>
<td>0.095</td>
<td>0.12</td>
<td>0.066</td>
<td>0.11</td>
<td>-0.084</td>
<td>-0.39</td>
<td>-0.087</td>
<td>-0.082</td>
</tr>
</tbody>
</table>

\( P < 0.001 \) unless otherwise indicated. Data were analyzed by using Pearson’s product-moment correlation. FMI, fat mass index; LMI, lean mass index; LPA, light physical activity; MPA, moderate physical activity; MVPA, moderate-to-vigorous physical activity; PA, physical activity; TFMI, trunk fat mass index; VPA, vigorous physical activity.

\( *P \geq 0.05. \)

\( *P < 0.05. \)

\( *P < 0.01. \)
shown between sedentary time and adiposity \( (P \geq 0.35) \). Variance inflation factors and tolerance statistics were within acceptable limits \( (\text{variance inflation factors} = 10 \text{ and tolerances} = 0.1) \) for all regressions, but these tests can not verify the absence of collinearity within models. Indicators of collinearity include large shifts in coefficients and theoretically questionable changes in signs of the effect on the introduction of a correlated variable. LPA and sedentary time were strongly negatively correlated \( (r = -0.75) \), and after we compared models 1 and 2 for LPA, as shown in Table 3, it appeared that the positive associations between LPA and adiposity were probably spurious artifacts because LPA and sedentary time were heavily collinear.

Adjusted associations for PA intensity and sedentary time with LMI are shown in Table 4. There was no evidence for an effect modification by sex \( (P \geq 0.094) \), and thus, data are presented for the whole sample with adjustment for sex. Initially, there was borderline evidence for a positive relation between MPA \( (P = 0.066) \) and MVPA \( (P = 0.063) \) with LMI, but adjustment for sedentary time weakened these associations \( (P \geq 0.45) \). Similarly, there was some evidence to indicate that greater sedentary time was associated with lower LMI \( (P = 0.056) \), but after adjustment for MVPA, there was no longer evidence of an association \( (P = 0.25) \).

In sensitivity analyses 1 and 2, coefficients for all body-composition variables remained materially unchanged. When analyses were restricted to children with \( \geq 6 \) valid PA data, point estimates strengthened by a small amount, but changes in significance did not occur \( \text{(data not shown)} \). There was no evidence to indicate nonlinear associations in any models \( \text{(data not shown)} \).

DISCUSSION

The results from this study suggested that inverse associations exist between VPA and both total and abdominal adiposity. In contrast, sedentary time and low-to-moderate PA intensities (when the statistical artifact was accounted for) appeared to be unrelated to adiposity. Fifteen minutes of accumulated VPA per day was associated with 0.36 lower percent of body fat, 1.75% lower FMI, and 1.90% lower TFMI. There are no established health-related reference values for adiposity in preschoolers, and thus, it is difficult to decipher the clinical importance of these data. However, overweight and obesity track over time, and adiposity increases with age, and thus, any reduction in adiposity at 4 y is unlikely to be trivial \( (30) \). Furthermore, truncal adipose tissue is strongly related to various cardiovascular and metabolic risk factors \( (31, 32) \). The inverse association between VPA and TFMI may point toward a role for high-intensity movement in the determination of the metabolic health of young children.

We are aware of only one other study that has examined the association between objectively measured sedentary time and adiposity in preschoolers \( (33) \). Similar to our adjusted associations, the investigation showed no correlation between sedentary behavior and weight status. Television viewing, which is a specific type of sedentary behavior, has been shown to exhibit positive associations with adiposity and overweight/obesity in preschoolers \( (34) \). However, dietary factors could mediate this relation because television viewing seems to be associated with a higher energy intake and poorer diet quality \( (35, 36) \). Observations in older children by using objective measures of sedentary time have offered the same inference as in the current study, that the total time spent sedentary may not be associated with adiposity \( \text{(37–40)} \).

Differences in accelerometer models and methodologies, the derivation of activity variables, and measures of body composition preclude a direct comparison of our PA data with other investigations. Nonetheless, our results are in agreement with other cross-sectional studies conducted in preschoolers. Janz et al \( (13) \) showed that VPA was negatively correlated with the percentage of body fat, FM, and TFMI in 434 US children aged 4–6 y.
Children in the lowest one-quarter for VPA had a higher percentage of body fat and 1 kg greater FM than did children in the topmost one-quarter. Similarly, in an ethnically and socially diverse group of 245 American preschoolers, overweight boys, compared with normal weight boys, were shown to participate in less MVPA and fewer hourly intervals of MVPA and VPA (14). In another diverse US cohort, it was further shown that odds of early childhood overweight were reduced by 6% and 32%, respectively, with each additional minute of VPA and very vigorous PA per day (5). Finally, in 281 Portuguese children aged 4–6 y, it was reported that children in the lowest one-third for VPA, relative to children in the highest third for VPA, had ~4-fold higher odds of being overweight (15). Our results contribute to the literature by showing that VPA is strongly inversely associated with both total and abdominal adiposity, irrespective of the time spent sedentary, and regardless of whether sedentary time is measured as awake-time only or total sedentary time including sleep. Together, the available data imply that weight interventions and PA guidelines may attain greater success in combating early childhood obesity if a paradigm shift toward VPA occurred. This recommendation concurs with the closing remarks of a recent systematic review that summarized the available evidence of weight-management schemes in young children (41). Currently, UK guidance states that children younger than 5 y should be active 180 min/d while simultaneously minimizing sedentary behaviors, but there is no recommendation regarding activity intensity (42).

Mechanistically, the inverse relation between VPA and adiposity may be due to maximal fat oxidation, which occurs during intense exercise (43). It has also been suggested that high-intensity PA may stimulate a preference for fat as an energy source, create greater elevations in postactivity energy expenditure (when the body returns to a condition of homeostasis), and transiently suppress (or elevate to a lesser extent compared with low-to-moderate-intensity PA) postactivity energy intake (44, 45). Because high-intensity activities often involve large ground-reaction forces and repetitive or forceful muscular contractions, it has further been hypothesized that vigorous movement may encourage stem cell differentiation into muscle and bone to the detriment of adipose tissue formation (46). However, we showed no association between VPA and LMI independently of sedentary time. Evidence for each of the aforementioned mechanisms that theoretically links VPA with reduced fatness remains limited. Whether VPA performed habitually by young children (ie, vigorous activity that is sporadic and unsustained) can stimulate these pathways remains to be determined.

**TABLE 4**

<table>
<thead>
<tr>
<th></th>
<th>LMI (95% CI) (kg/m^2.5)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPA (60 min/d)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model 1</td>
<td>0.036 (−0.014, 0.086)</td>
<td>0.16</td>
</tr>
<tr>
<td>Model 2</td>
<td>−0.033 (−0.12, 0.053)</td>
<td>0.45</td>
</tr>
<tr>
<td>MPA (30 min/d)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model 1</td>
<td>0.05 (−0.0035, 0.11)</td>
<td>0.066</td>
</tr>
<tr>
<td>Model 2</td>
<td>0.022 (−0.046, 0.089)</td>
<td>0.53</td>
</tr>
<tr>
<td>VPA (15 min/d)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model 1</td>
<td>0.030 (−0.0067, 0.066)</td>
<td>0.11</td>
</tr>
<tr>
<td>Model 2</td>
<td>0.014 (−0.023, 0.052)</td>
<td>0.45</td>
</tr>
<tr>
<td>MVPA (60 min/d)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model 1</td>
<td>0.070 (−0.0038, 0.14)</td>
<td>0.063</td>
</tr>
<tr>
<td>Model 2</td>
<td>0.033 (−0.053, 0.12)</td>
<td>0.45</td>
</tr>
<tr>
<td>Sedentary time (120 min/d)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model 1</td>
<td>−0.080 (−0.16, 0.0022)</td>
<td>0.056</td>
</tr>
<tr>
<td>Model 2</td>
<td>−0.058 (−0.16, 0.040)</td>
<td>0.25</td>
</tr>
</tbody>
</table>

*Model 1 was adjusted for age, sex, birth weight, maternal education, maternal BMI, smoking during pregnancy, and sleep duration. For LPA, MPA, VPA, and MVPA, model 2 was adjusted as for model 1 and for sedentary time. For sedentary time, model 2 was adjusted as for model 1 and for MVPA. Data were analyzed by using repeated-measures linear regression. LMI, lean mass index; LPA, light physical activity; MPA, moderate physical activity; MVPA, moderate-to-vigorous physical activity; PA, physical activity; VPA, vigorous physical activity.
In contrast to the results for adiposity, we showed no association between PA with LMI. Elsewhere, a positive association between MVPA and fat-free mass in girls was observed (13), but this study did not adjust for sedentary time. Furthermore, fat-free mass includes lean mass and the sum of bone mineral content. We have previously shown that MVPA is positively associated with hip-bone size and density (47). Thus, the results from the SWS indicated that, although objectively measured PA in youth may be influential in terms of bone density, it does not seem to be associated with more lean tissue independent of sedentary time. Similarly, we did not show an association between sedentary time and LMI. There are few comparable data, but Janz et al (13) failed to find an association between parental-reported television viewing and fat-free mass. Moreover, in children ≥10 y of age, self-reported sedentary behaviors appear to be unrelated to follow-up fat-free mass index (48).

Strengths of the current study included the (relatively) large and homogenous sample, objective measures of PA and body composition, and adjustment for several potential confounders. However, the sample signified a population with low minority representation, and thus, the generalizability of findings may be limited. We also incorporated a complete-case analysis in which children with missing data were excluded; this approach can yield biased variable estimates. Although we could not rule out bias as a result of missing data, we did compare associations that were both adjusted and unadjusted for predictors of missingness. Results were comparable (data not shown) and, thus, provided some indication against systematic error because of missing information. As regards the measurement of PA, accelerometers placed on the torso struggle to adequately capture static activities that involve movement of the limbs. Such activities include bicycling, lifting and pushing, climbing, swinging, and throwing. Many children spend time performing these types of activities, and, as recently indicated, they are more prevalent in high-active children (49). The failure to register these kinds of activities to a greater extent in high- than low-active children may have resulted in an attenuation of associations. Smaller epochs (<60 s) would have also been advantageous because they have been shown to provide greater distinctions in daily VPA between more- and less-active children by minimizing systematic measurement error (50). The likely outcome of the use of an extended epoch duration is analogous to the error incurred by missing certain types of activities; a dilution in effect estimates may have occurred, and thus, coefficients displayed for VPA and MVPA were plausibly underestimates of their true associations with body composition. However, residual confounding by unknown and unmeasured factors such as energy intake and diet composition could not be excluded. To finish, our cross-sectional study precluded us from making a strong inference about causality, let alone its direction; low participation in VPA may be a consequence and not a cause of higher adiposity because of physical limitations, psychological factors, and social barriers (51). To aid causality, prospective studies or randomized controlled trials are needed.

In conclusion, in young children aged 4 y, the time engaged in VPA appears to be strongly and independently associated with lower adiposity. In contrast, sedentary time and time spent in low-to-moderate intensity PA were unrelated to adiposity. Thus, the data suggest that, if the obesity epidemic is to be successfully curbed, interventions and PA guidelines alike may need to encourage VPA from an early age. Prospective study designs are needed to determine the direction of the association between PA intensity and adiposity in early childhood.

We are grateful to the women of Southampton and their children who took part in the study and the research nurses and other staff who collected and processed data. We also thank Stephen Sharp and Jian’an Luan for their statistical advice.

The authors’ responsibilities were as follows—SB, NCH, KMG, HMI, CC, NJW, and UE: designed the research; CLR: helped to conduct the research; PJC: analyzed data, performed the statistical analysis, and wrote the manuscript; PJC and UE: were responsible for the final content of the manuscript; and all authors: agreed on the content of the final manuscript. None of the authors had a conflict of interest.

REFERENCES