

Targeting sedentary time or moderate- and vigorous-intensity activity: independent relations with adiposity in a population-based sample of 10-y-old British children^{1–3}

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ABSTRACT

Background: It is unclear whether subcomponents of physical activity (PA) are associated with adiposity independent of time spent while sedentary.

Objective: The objective was to examine associations between objectively measured PA and its subcomponents [ie, time spent at light-intensity PA, moderate-intensity PA (MPA), vigorous-intensity PA (VPA), and moderate-plus-vigorous-intensity PA (MVPA)], independent of sedentary time, and self-reported leisure screen time (television and electronic game use) with indexes of adiposity in a population-based sample of British children.

Design: A cross-sectional study was conducted in 1862 UK children aged 9–10 y. PA and sedentary activity were measured by accelerometry, and indicators of adiposity were waist circumference, body mass index (BMI), and fat mass index calculated from bioimpedance measurements. Screen time was assessed by self-report. We examined the associations between PA subcomponents and adiposity by multilevel linear models adjusted for birth weight, maternal BMI, energy intake, and sleep duration.

Results: Objectively measured sedentary time was positively associated with waist circumference ($P = 0.04$) and fat mass index ($P = 0.05$), independent of age and sex. However, this association was attenuated after adjustment for MVPA and other covariates. VPA (all $P < 0.0001$), combined MVPA (all $P < 0.01$), and total activity (counts/min) (all $P < 0.001$) were all inversely associated with each of the adiposity indexes, independent of sedentary time and other important covariates. Associations were weaker for MPA: $P = 0.05$, 0.87 , and 0.1 for waist circumference, BMI, and fat mass index, respectively.

Conclusions: Time spent in VPA appears to be more strongly associated with adiposity than sedentary time. Interventions may therefore need to incorporate higher intensity-based activities to curb the growing obesity epidemic. *Am J Clin Nutr* 2009; 90:1185–92.

INTRODUCTION

The increasing prevalence of overweight and obesity in children and adolescents is a major public health concern (1, 2). Obesity is a strong predictor of morbidity, with central obesity associated with insulin resistance, dyslipidemia, and hypertension—all independent risk factors for cardiovascular disease and features of the metabolic syndrome (3, 4). The specific causes of overweight and obesity are varied and complex but, at a population level, are consistent with sustained positive

energy balance. A sedentary lifestyle and low levels of physical activity (PA) participation have therefore been implicated in this trend.

Previous studies using objective methods for assessing PA have shown inverse associations or no association between total PA and various markers of obesity in youth (5, 6), without taking into account the differential effect of PA subcomponents (ie, time spent at different intensity levels, including light, moderate, and vigorous intensities). A few recent studies have reported lower body fat being significantly associated with vigorous-intensity PA (VPA), but not moderate-intensity PA (MPA) in adolescents (7); similar results were shown in children (8–11). However, these studies have not addressed whether subcomponents of PA are associated with adiposity independent of time spent sedentary. Furthermore, childhood obesity is influenced by a multitude of social, environmental, and physical variables. Many studies have not adjusted for important covariates such as energy intake, birth weight, sleep duration, and parental obesity, which are emerging as important determinants of adiposity in youth (12–15). Any consideration of the complex interrelations between PA and adiposity would be strengthened by quantifying and adjusting for their potential effects.

Current recommendations for children suggest participation in ≥ 60 min/d of MPA (16), with sedentary leisure time such as television (TV) viewing and screen-time use (computer and/or video games) limited to 2 h/d (17). Unfortunately, despite acknowledgment of the physiologic differences between activity and sedentary behavior and increasing interest in the physio-

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logic, medical, and public health effects of too much sedentary time (18), few studies have examined the independent effect of overall sedentary time, screen time, and increased nonexercise activity (ie, light activity) with adiposity.

A better understanding of the relations between PA components, sedentary behavior, and overall adiposity will aid the development of interventions to encourage healthy lifestyles in children. We aimed to examine the independent associations between subcomponents of objectively measured habitual PA (ie, time spent sedentary and at light, moderate, and vigorous intensities) and the self-reported amount of leisure screen time (TV and electronic game use) with various indexes of adiposity in a population-based sample of 9- and 10-y-old British school-children.

SUBJECTS AND METHODS

Participants

Year 5 children ($n = 2064$) were recruited from 92 rural and urban schools in Norfolk, United Kingdom, as part of the SPEEDY (Sport, Physical Activity and Eating behavior, Environmental Determinants in Young people) study. Data were collected through primary schools during the 12-wk summer term of 2007 (April to July). Study design, sampling procedures, selection criteria, participation rates, and the data collection procedures were reported elsewhere (19). The University of East Anglia local research ethics committee approved the study, and written consent was obtained from the children's parent or legal guardian.

Physical activity

Free-living PA was assessed with the Actigraph activity monitor (GT1M; Actigraph LLC, Pensacola, FL; <http://www.theactigraph.com>) over 1 wk, with a recording epoch of 5-s intervals. Participants were instructed to wear the monitor on an elastic waist band on the right hip during day time, except during bathing and other aquatic activities. Participants who did not manage to record ≥ 500 min/d of activity for ≥ 3 d were excluded from further analyses. Zero-activity periods of ≥ 10 min were interpreted as "not worn time," and these periods were removed from the summation of activity. A special written program (MAHUffe; www.mrc-epid.cam.ac.uk) was used for data cleaning, reduction, and further analyses. The outcome variables were time (min/d) spent at different activity-intensity categories averaged per day over the measurement period and total daily activity counts (counts/min)—an indicator of overall PA intensity. Intensity thresholds were defined as follows: sedentary, < 100 counts/min; light-intensity PA (LPA), between 101 and 1999 counts/min; MPA, 2000–3999 counts/min; and VPA, > 4000 counts/min. Our lower limit for the MPA threshold corresponds to a walking pace of ≈ 3 –4 km/h in children (20) and was previously used in this age group to study associations between PA intensity and adiposity (11). Finally, we combined MPA and VPA into one single variable: moderate-plus-vigorous-intensity PA (MVPA).

A total of 2030 (98%) children returned accelerometers after the measurement period, 45 children were excluded because of lost or faulty monitors. An additional 151 children did not

provide 3 d of valid data. No differences were observed between children with and without valid data for BMI, overweight status, or parental education.

Anthropometric and body-composition measures

Simple noninvasive anthropometric measures were undertaken by trained staff following standardized procedures. Portable Leicester height measures (Seca, Hamburg, Germany) were used to assess height to the nearest millimeter. Waist circumference (WC) was measured twice to the nearest millimeter at the midpoint between the lower costal margin and the level of the anterior superior iliac crests by using a calibrated measuring tape (Seca, Birmingham, United Kingdom). A third measurement was taken if a discrepancy of ≥ 3 cm was observed and an average was calculated; a 0.5-cm correction was applied to account for clothing (21). A nonsegmental bioimpedance scale (type TBF-300A; Tanita, Tokyo, Japan) was used to measure weight (to the nearest 0.1 kg) and impedance. Body fat percentage, fat mass (FM), and fat-free mass (FFM) were calculated from the impedance value (22). A fat mass index (FMI) was calculated as FM (in kg) divided by height squared. This measure has been used parallel to BMI, because it provides additional information about body compartmental FM, regardless of stature, and is expressed in units common to BMI (23). Obesity status was determined by using sex- and age-specific cutoffs previously published by Cole et al (24).

Screen time

Screen time during leisure time was assessed with a self-report child questionnaire—the Youth Physical Activity Questionnaire (25), which is based on the Children's Leisure Activities Study Survey (CLASS) (26). Children were asked to report their frequency and duration of sedentary leisure-based activity (ie, electronic games, computer, Internet, and TV use) over the past 7 d. They were required to record how many days they performed the activity (never, 1 d, 2–3 d, or ≥ 3 d) and report the duration in hours and minutes in response to "on the days you did this (e.g. played computer games) how long did you normally do it for?" The screen-time variable (total screen time) was then derived by multiplying the duration by the frequency, recorded in minutes per day.

Covariates

The SPEEDY study also collected information on many other important variables, which were used in the analyses to control for variation in these covariates. Data on maternal BMI (calculated from self-reported height and weight), child's birth weight (n for boys = 741 and girls = 955), and highest educational qualifications (in categories) were collected with a self-administered parental questionnaire. Average sleep duration was derived from the child's self-reported bedtime and wake time for school days and weekends, with the mean recorded as average sleep duration in hours. Children, with assistance from their parents, were asked to record everything they ate and drank over a 4-d period in a food and drink diary. For each item recorded the children were asked to provide information on what they consumed with an estimated portion size; the estimated weights of portions were then calculated by using published values (27).

Mean nutritional intakes were estimated by using the WISP nutritional analysis software version 3.0 (Tinuviel Software, Warrington, United Kingdom).

Statistical analysis

Statistical analyses were carried out by using STATA version 9 software (StataCorp, College Station, TX). All outcome variables were first assessed for normality. FMI was logarithmically transformed (log) because of its skewed distribution. Sex differences for continuous data were analyzed by analysis of variance, and a chi-square test was used for categorical data. Age- and sex-adjusted correlations between self-reported screen time with adiposity and objectively measured sedentary time were assessed. Multilevel linear regression models were used to examine the independent associations between total PA and PA subcomponents (time spent sedentary or in LPA, MPA, and VPA) with adiposity indicators (WC, FMI, and BMI). Our primary model (model 1) was adjusted for age and sex with school as a random effect. The second model (model 2) was additionally adjusted for parental socioeconomic status, birth weight, maternal BMI, sleep duration, height, and energy intake. Height was excluded from the models in which FMI and BMI were modeled as outcomes. As a result of missing data, the sample size for model 2 was lower; however, we also ran the analysis as adjusted per model 1 using the sample from model 2 and found no differences in the reported direction and magnitude of the regression coefficients (data not shown). In model 3 we additionally adjusted for objectively measured sedentary time (min/d) to examine whether the associations with time spent at LPA, MPA, and VPA were independent of time spent sedentary. We assessed for multicollinearity by calculating correlation coefficients between the different subcomponents of activity and the variance inflation factor. Correlations between sedentary time and PA intensity (LPA, MPA, and MVPA) were $r \leq 0.51$, and the variance inflation factor was <4 . Standardized z scores were also calculated for each PA measure, and linear regression analyses were conducted to examine the associations between these standardized measures of PA with each of the adiposity indexes.

Logistic regression was used to examine the odds of being overweight or obese by quartiles of MVPA and by current PA and screen-time recommendations. All regression models were tested for sex interactions (sex \times PA exposure). Overall there were no significant sex interactions (all P values > 0.1); therefore, the results are presented with boys and girls combined. Only the basic model adjusted for age and sex is shown, the fully adjusted model yielded similar results. Statistical significance was accepted at a level of $P < 0.05$.

RESULTS

Descriptive statistics for demographic and physical characteristics are shown in **Table 1**. Overall, 23% of children were classified as overweight or obese. Slightly more girls than boys ($P < 0.05$) were overweight. Sixty-nine percent of children, including significantly more boys than girls, met current recommendations for PA participation, defined as the accumulation of ≥ 60 min MVPA/d. Fifty-eight percent met guidelines for screen-time use of ≤ 2 h/d, with more girls meeting this recommendation. Approximately 14% of children did not meet

TABLE 1

Physical activity (PA) and descriptive characteristics of the study population by sex ($n = 1862$)¹

Characteristic	Boys ($n = 820$)	Girls ($n = 1042$)
Age (y)	10.2 \pm 0.03 ²	10.3 \pm 0.03
Ethnicity (% nonwhite)	3.8	4.0
Parental education (%)		
General Certificate of Secondary Education or lower	35.5	40.3
Up to Advanced-level General Certificate of Education	43.1	40.5
Higher education	21.4	19.3
Birth weight (g)	3443 \pm 595	3277 \pm 564 ³
Maternal BMI (kg/m ²)	25.2 \pm 5.2	25.1 \pm 4.9
Height (cm)	141.0 \pm 6.5	141.0 \pm 6.8
Weight (kg)	35.9 \pm 7.8	36.9 \pm 8.7 ³
Fat-free mass (kg)	25.6 \pm 3.3	24.2 \pm 3.5 ³
Fat mass (kg)	9.3 (9.0, 9.5) ⁴	11.7 (11.4, 12.0) ³
Fat mass index (kg/m ²)	4.7 (4.5, 4.8)	5.9 (5.7, 6.0) ³
Body fat (%)	27.3 \pm 7.5	33.1 \pm 7.2 ³
Waist circumference (cm)	64.2 \pm 7.8	64.0 \pm 8.9
Energy intake (kcal/d)	1796.4 \pm 380.4	1686.0 \pm 343.3 ³
Screen time (min/d)	109.7 (101.9, 118.0)	70.5 (65.8, 75.5) ³
BMI (kg/m ²)	17.9 \pm 2.9	18.4 \pm 3.3 ³
Sleep duration (min/d)	621.4 \pm 57.9	642.0 \pm 52.4 ³
Weight status (%)		
Overweight	15.9	19.4 ³
Obesity	3.9	6.0
Total PA (counts/min)	717.0 \pm 220	635 \pm 210 ³
Sedentary (min/d)	450 \pm 56.2	461 \pm 51.6 ³
LPA (min/d)	186.2 \pm 32.7	178.8 \pm 31.2 ³
MPA (min/d)	54.5 \pm 14.9	44.4 \pm 12.27 ³
VPA (min/d)	29.7 \pm 14.3	21.7 \pm 11.1 ³
MVPA (min/d)	84.2 \pm 25.9	66.1 \pm 20.8 ³
Met PA recommendations, ≥ 60 min/d MVPA (%)	81.5	59.4 ³
Met screen-time recommendations, ≤ 2 h/d (%)	48.3	66.7 ³

¹ LPA, light-intensity physical activity; MPA, moderate-intensity physical activity; VPA, vigorous-intensity physical activity; MVPA, moderate-plus-vigorous-intensity physical activity.

² Mean \pm SD (all such values).

³ Significantly different from boys, $P < 0.01$ (ANOVA for continuous data and chi-square test for categorical data).

⁴ Geometric mean; 95% CI in parentheses (all such values)

recommendations for combined activity and screen time, 40% achieved the combined recommendation, and 46% only met one recommendation. Overall, girls were significantly less active than boys and had a higher FM, body fat, and BMI. Self-reported screen time was not correlated with adiposity ($r = -0.006$ and $P = 0.78$ for WC, $r = -0.007$ and $P = 0.75$ for FMI, and $r = -0.21$ and $P = 0.36$ for BMI) and was only weakly positively correlated with objectively measured sedentary time ($r = 0.06$, $P = 0.013$).

Associations between total PA and PA subcomponents with obesity indicators are shown in **Table 2**. Objectively measured sedentary time was positively associated with WC and FMI but not with BMI, independent of age and sex. However, these associations were attenuated and no longer significant after further adjustment for covariates and time spent in MVPA. LPA was weakly and positively associated with all obesity markers, but

TABLE 2

Multilevel linear regression coefficients (and 95% CIs) for the association between obesity and total physical activity (PA), PA intensity, and time spent sedentary in 10-y-old children¹

	Waist circumference			Log-transformed fat mass index			BMI		
	β	95% CI	<i>P</i>	β	95% CI	<i>P</i>	β	95% CI	<i>P</i>
Sedentary (min/d)									
Model 1 ²	0.008	0.0004, 0.02	0.04	0.0003	0.000003, 0.001	0.05	0.001	-0.0002, 0.002	0.11
Model 2 ³	0.006	-0.001, 0.01	0.11	0.0004	0.00006, 0.0008	0.02	0.0006	-0.0004, 0.002	0.23
Model 3 ⁴	-0.002	-0.01, 0.01	0.7	0.00002	-0.003, 0.0004	0.93	-0.0003	-0.001, 0.001	0.96
LPA (min/d)									
Model 1 ²	-0.0004	-0.02, 0.01	0.93	0.0005	-0.00007, 0.001	0.08	0.002	0.0007, 0.004	0.004
Model 2 ³	-0.002	-0.01, 0.01	0.74	0.0002	-0.0005, 0.001	0.66	0.002	-0.0002, 0.004	0.07
Model 3 ⁵	0.0002	-0.01, 0.13	0.97	0.0003	-0.0004, 0.001	0.37	0.002	0.0001, 0.004	0.03
MPA (min/d)									
Model 1 ²	-0.048	-0.08, -0.02	0.003	-0.002	-0.004, -0.0007	<0.01	-0.003	-0.007, 0.002	0.23
Model 2 ³	-0.039	-0.07, -0.01	0.02	-0.002	-0.003, -0.0001	0.03	-0.001	-0.006, 0.003	0.57
Model 3 ⁵	-0.034	-0.07, 0.006	0.05	-0.002	-0.003, 0.0003	0.1	-0.0004	-0.005, 0.004	0.87
VPA (min/d)									
Model 1 ²	-0.12	-0.15, -0.10	<0.0001	-0.006	-0.008, -0.005	<0.0001	-0.013	-0.02, -0.009	<0.0001
Model 2 ³	-0.098	-0.12, -0.07	<0.0001	-0.005	-0.007, -0.004	<0.0001	-0.01	-0.04, -0.006	<0.0001
Model 3 ⁵	-0.10	-0.13, -0.07	<0.0001	-0.06	-0.07, -0.004	<0.0001	-0.01	-0.02, -0.006	<0.0001
MVPA (min/d)									
Model 1 ²	-0.053	-0.07, -0.04	<0.0001	-0.003	-0.004, -0.002	<0.0001	-0.005	-0.007, -0.002	<0.0001
Model 2 ³	-0.042	-0.06, -0.03	<0.0001	-0.002	-0.003, -0.001	<0.0001	-0.00	-0.006, -0.001	0.003
Model 3 ⁵	-0.044	0.06, -0.03	<0.0001	-0.002	-0.003, -0.001	<0.0001	-0.003	-0.006, -0.001	0.009
Total PA(counts/min)									
Model 1 ²	-0.005	-0.007, -0.003	<0.0001	-0.0002	-0.0003, -0.0002	<0.0001	-0.0005	-0.0007, -0.0001	<0.0001
Model 2 ³	-0.004	-0.006, -0.002	<0.0001	-0.0002	-0.0003, -0.0001	<0.0001	-0.0003	-0.0006, -0.0001	<0.0001
Model 3 ⁵	-0.004	-0.006, -0.002	<0.0001	-0.0002	-0.0003, -0.0001	<0.0001	-0.0004	-0.006, -0.0001	0.001

¹ LPA, light-intensity physical activity; MPA, moderate-intensity physical activity; VPA, vigorous-intensity physical activity; MVPA, moderate-plus-vigorous-intensity physical activity.

² Basic adjustment: age and sex; *n* = 1862.

³ Full adjustment: age, sex, socioeconomic status, birth weight, maternal BMI, sleep duration; model with waist circumference as outcome also adjusted for height; *n* = 1440.

⁴ Full adjustment plus MVPA; *n* = 1440.

⁵ Full adjustment plus objectively measured sedentary time; *n* = 1440.

the only statistically significant association was observed with BMI. MPA was inversely associated with WC and FMI even after adjustment for covariates. After adjustment for sedentary time, the association between MPA and WC was attenuated (*P* = 0.05), and the association with FMI was no longer statistically significant. VPA, combined MVPA, and total activity (count/min) were all inversely associated with each of the adiposity indexes, independent of covariates, and remained significant after further adjustment for objectively measured sedentary time. Adiposity measures of FMI and WC stratified by quartiles of VPA adjusted for age, sex, socioeconomic status, birth weight, maternal BMI, and sleep duration (and height where WC is the outcome) are shown in **Figure 1**. A significant trend was observed (*P* for trend < 0.001), with those in the least active quartile for VPA showing the highest levels of FMI and WC.

We also reran the series of regression models analysis using volunteers with 3 valid days, including at least one weekend day (*n* = 1679); again we found no differences in the reported direction and magnitude of the regression coefficients (data not shown).

Standardized regression coefficients for the associations between subcomponents of PA with the adiposity indexes are shown in **Table 3**. As determined by the standardized regression co-

efficients, the magnitude of the association between activity subcomponents and adiposity indexes increased with higher intensity levels; and was greatest for VPA. There was limited evidence of an association between MPA and WC (*P* = 0.05), but none for an association with FMI or BMI. After MVPA was adjusted for, there was no association between objectively measured sedentary time and adiposity.

Adjusted odds ratios for associations between meeting PA recommendations (model 1), meeting screen-time recommendations (model 2), and meeting both PA and screen-time recommendations (model 3) and weight category are shown in **Table 4**. Children who accumulated ≥ 60 min/d of MPA were 34% less likely to be overweight/obese than were those not meeting recommendations. In contrast, there was no difference in the likelihood of being categorized as overweight or obese between those who met the recommendation of ≤ 2 h/d of screen time and those who did not meet this recommendation. We thereafter compared children categorized as not meeting either recommendation with those who met both PA and screen time recommendations. Children who met both screen-time and PA recommendations were 31% less likely to be overweight or obese than were children meeting neither recommendation (*P* = 0.028), although after adjustment for covariates this association was attenuated (*P* = 0.059) (data not shown). Odds ratios for being categorized as overweight

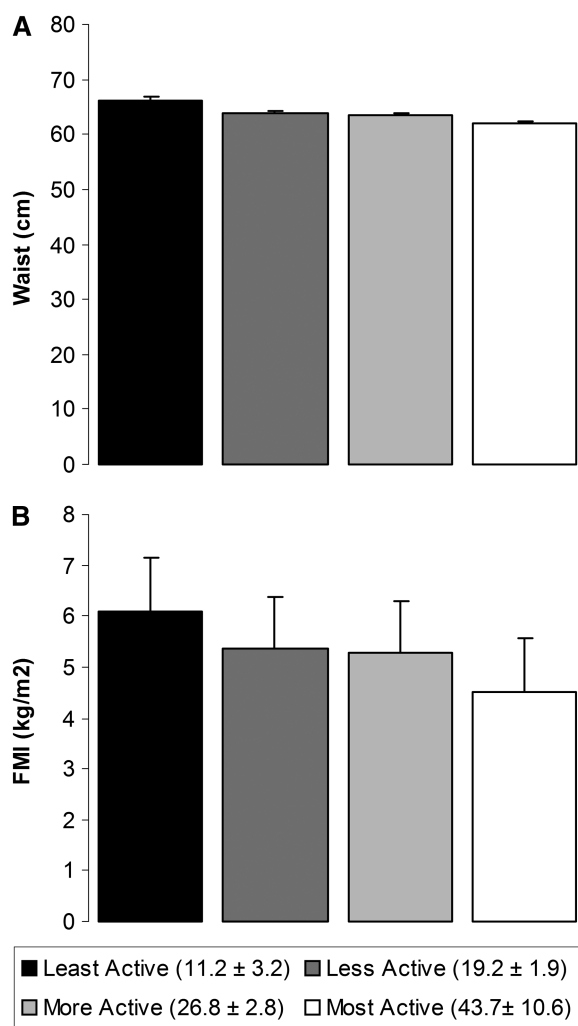


FIGURE 1. Adjusted mean (\pm SE) waist circumference (A) and fat mass index (FMI; B) across quartiles of vigorous-intensity physical activity (VPA) (P for trend <0.01). Data were analyzed by multilevel linear regression adjusted for age, sex, socioeconomic status, birth weight, maternal BMI, sleep duration, and height, where waist circumference was the outcome ($n = 1440$). Mean (\pm SD) values are shown in parentheses for each quartile of VPA (min/d) from least active to most active.

or obese by quartiles of MVPA for overweight and obesity are shown in **Figure 2**.

DISCUSSION

In this cross-sectional study we found inverse associations between time spent in PA (MPA, VPA, and total PA) and measures of adiposity (WC, FMI, and BMI) in children, independent of objectively measured sedentary time, with a stronger association observed for participation in VPA. These associations were also independent of other potentially important covariates (ie, energy intake, sleep duration, birth weight, socioeconomic status, and maternal BMI). The positive associations between sedentary time with WC and FMI diminished after MVPA was controlled for, which suggests that higher VPA may be more influential than lower sedentary time in relation to childhood obesity. Furthermore, when examining the public health recommendations concerning screen time and PA and risk

of overweight and obesity, more active children were less likely to be overweight or obese, but greater screen-time use alone did not significantly increase the odds of being overweight/obese.

Despite the plethora of literature on the associations between PA and adiposity, it remains debatable whether the intensity of activity influences body composition. Using dual-energy X-ray absorptiometry to more precisely measure adiposity, Gutin et al (7) reported that a lower percentage body fat was associated with larger volumes of VPA but not with MPA in 425 children aged 9–10 y. In 780 children aged 9–10 y from Sweden, Ruiz et al (8) also reported that VPA but not MPA was associated with adiposity, whereas another study in 1292 European children aged 9–10 y also showed VPA to be significantly associated with adiposity, as measured by the sum of skinfold thickness (11). Our data extend these previous findings, which suggest that higher-intensity PA is more strongly associated with lower adiposity, irrespective of time spent sedentary (Table 3). For example, 6.5 min of vigorous intensity activity daily (1 SD) was associated with a difference in WC of ≈ 1.32 cm, whereas 13.6 min of time spent in MPA was associated with a more modest 0.49-cm difference in WC.

Displacement theory suggests that time spent watching TV and playing electronic games reduces the time allocated to PA. However, the degree to which sedentary behavior prohibits time spent active remains unknown. Some studies report negative associations between PA and TV viewing (28, 29), whereas others, including longitudinal studies, have reported that TV viewing is largely unrelated to time spent in PA (30, 31). Marshall et al (31) reported that, despite finding a positive relation between TV viewing and body fatness, the association was too small to be clinically meaningful. Furthermore, a recent review suggests that electronic game and computer use have a limited effect on obesity (32). Others have also reported no cross-sectional associations between objectively measured sedentary time (11, 33) and screen time (34, 35) with adiposity. In accordance, our data suggest that focusing on leisure-based screen time irrespective of activity may not be sufficient to curb childhood obesity. First, we found no correlation between self-reported screen time and adiposity. Second, although less-active children were more likely to be overweight, increased screen time did not significantly increase these odds in this study if children were already meeting the MVPA recommendation of 60 min/d. Third, once we controlled for energy intake and MVPA in our multilevel linear regression analyses, we found that objectively measured sedentary time was not significantly associated with any indicator of adiposity.

Nevertheless, although our observations were independent of sedentary time, evidence of the co-occurrence of low levels of activity and high levels of screen time (eg, reference 36), suggests that strategies targeting both may be necessary. Only 40% of the children in this study met the combined recommendation for MVPA and screen time. Given other emerging negative sequelae of excessive screen time, such as violence and aggressive behavior, poor academic performance and poor body image (17), it seems sensible that intervention studies also look to target reducing screen-based leisure time, even though this may not necessarily directly affect PA or adiposity (eg, 37).

Unlike previous studies (33, 38), we found no interaction by sex in these analyses. Our data suggest that the differences in the magnitude of the associations observed across boys and girls may not be present in this age group. Therefore, any public health

TABLE 3

Independent standardized regression coefficients for the associations between total physical activity (PA) and PA intensity with adiposity indicators in 10-y-old children¹

	Waist circumference			Log-transformed fat mass index			BMI		
	β	95% CI	<i>P</i>	β	95% CI	<i>P</i>	β	95% CI	<i>P</i>
Sedentary (min/d) ²	0.32	0.07, 0.11	0.11	0.024	0.003, 0.044	0.02	0.036	-0.022, 0.09	0.23
Sedentary (min/d) ³	-0.05	-0.49, 0.38	0.81	0.0001	-0.02, 0.02	0.944	-0.001	-0.07, 0.06	0.69
LPA (min/d) ⁴	-0.007	-0.43, 0.42	0.97	0.01	-0.012, 0.032	0.37	0.06	0.04, 0.12	0.03
MPA (min/d) ⁴	-0.49	-0.99, 0.009	0.05	-0.022	-0.05, 0.005	0.12	-0.006	-0.08, 0.07	0.86
VPA (min/d) ⁴	-1.32	-1.7, -0.95	<0.0001	-0.075	-0.1, -0.053	<0.0001	-0.15	-0.21, -0.08	<0.0001
MVPA (min/d) ⁴	-1.09	-1.84, -0.85	<0.0001	-0.059	-0.09, -0.032	<0.0001	-0.094	-0.16, -0.02	0.009
Total PA (counts/min) ⁴	-0.93	-1.39, -0.48	<0.0001	-0.055	-0.08, -0.03	<0.0001	-0.095	-0.15, -0.04	0.001

¹ *n* = 1440. LPA, light-intensity physical activity; MPA, moderate-intensity physical activity; VPA, vigorous-intensity physical activity; MVPA, moderate-plus-vigorous-intensity physical activity. Standardized *z* scores were calculated for each physical activity measure, and multilevel linear regression analyses were used to examine the associations between these standardized measures of physical activity and each of the adiposity indexes.

² Full-model adjustment: age, sex, socioeconomic status, birth weight, maternal BMI, sleep duration, and MVPA; model with waist circumference as outcome was also adjusted for height.

³ Full-model adjustment: age, sex, socioeconomic status, birth weight, maternal BMI, sleep duration, height, and objectively measured sedentary time; model with waist circumference as outcome was also adjusted for height.

⁴ Full-model adjustment: age, sex, socioeconomic status, birth weight, maternal BMI, sleep duration, height, and objectively measured MVPA; model with waist circumference as outcome was also adjusted for height.

strategies are likely to be equally applicable to boys and girls of this age group.

The present study had several limitations. Because of the cross-sectional design of the study, it was not possible to infer causality or specify the direction of the effect. Although we controlled for several covariates, there may be residual confounding by other variables, such as genetic variation, dietary composition (ie, fat intake), and sociocultural factors, which may explain our findings, at least in part. However, reanalyzing our data using dietary fat intake (as a percentage of total energy) as a covariate did not yield differences in the magnitude of the effect relative to controlling for total energy intake (data not shown).

Leisure-based screen time was measured with a self-reported questionnaire; participants were asked about their average duration and frequency of use. The Youth Physical Activity Questionnaire was previously shown reasonable validity and reliability for time spent in MVPA and PA energy expenditure (25); however, it is difficult to assess the validity of these self-reports, and we found that self-reported screen time was unrelated to adiposity and only very weakly associated with objectively measured sedentary time. The limitations of accelerometry should also be considered. For example, accelerometers do not accurately reflect activity associated with bicycling, contact sports (accelerometers are usually not worn in this situation), and

TABLE 4

Adjusted odds ratios (ORs) for being overweight or obese compared with normal weight according to whether current physical activity (PA) and screen-time recommendations for children were met¹

	Adjusted ORs for being overweight or obese compared with normal-weight children			
	Sample	Adjusted OR	95% CI	<i>P</i>
	%			
Model 1				
Met PA recommendation				
No (reference)	31	1		
Yes	69	0.66	0.52, 0.83	<0.001
Model 2				
Met TV/screen-time recommendation				
No (reference)	41.4	1		
Yes	58.6	0.9	0.78, 1.2	0.9
Model 3				
Met PA and TV/screen-time recommendation				
No (reference)	14	1		
Did not meet PA recommendation but met TV/screen-time recommendation	17.6	1.10	0.73, 1.5	0.76
Met PA recommendation but did not meet TV/screen-time recommendation	28.4	0.7	0.49, 1.0	0.054
Yes	40	0.69	0.49, 0.96	0.028

¹ *n* = 1856. Screen-time recommendations: ≥ 60 min/d moderate-plus-vigorous-intensity PA and ≤ 2 h television (TV) and other screen time. ORs adjusted for age and sex.

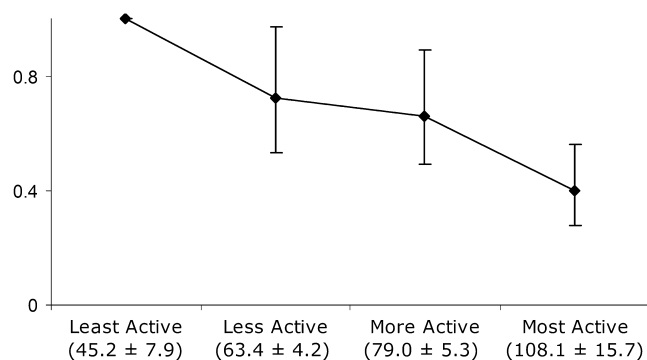


FIGURE 2. Adjusted odds ratios (and 95% CIs) for overweight or obesity compared with normal-weight children by quartiles of objectively measured moderate-plus-vigorous-intensity physical activity (MVPA) (P for trend <0.01). Data were analyzed by logistic regression analyses adjusted for age and sex ($n = 1856$). Mean (\pm SD) values shown in parentheses for each quartile of MVPA (min/d) from least active to most active. $n = 1856$.

swimming, or the intensity of activities such as walking up a hill and upper body movement. However, objective measurement of PA reduces the error and bias commonly associated with self-reported measures. This measure has been extensively validated, both in the laboratory and during free-living conditions (39). The use of leg-to-leg bioimpedance analysis (BIA) has been tested in various populations in the laboratory showing good reliability and validity (40–42) and has also been identified as a suitable alternative to skinfold-thickness measurements in the field setting (43). However, it should be noted that, because of the logistics of testing a large sample size of children, our BIA measurements were conducted throughout the whole school day (ie, not at a uniform time) and the children had not fasted. Therefore, limitations related to BIA, such as hydration status, recent exercise, and meal intake should be considered when interpreting the results of this study (44).

Some strengths of the study should be noted. For instance, we were able to measure body composition using BIA. This measure is more feasible for the assessment of body fat in larger sample sizes than are other more accurate but more costly measures of adiposity, such as dual-energy X-ray absorptiometry, and is more precise than the use of BMI alone. Unlike other studies, we examined associations between PA and adiposity independently of time spent sedentary with various indexes of obesity and the overall effect of PA and screen-time recommendations using odds ratios. We were also able to additionally control for many potentially important covariates, such as sleep duration, birth weight, maternal obesity, and energy intake in a relatively large population-based sample of British children aged 9–10 y.

In summary, more vigorous intensities of activity are associated with adiposity, independent of time spent sedentary and other important covariates, and appear to influence adiposity to a greater degree than sedentary time in children aged 9–10 y. Advice from health professionals, individual-level interventions, and population-based strategies may need to incorporate higher intensity-based activities to help curb the growing obesity epidemic. Future work may focus on studying what behaviors contribute most to the amount of VPA performed by children and what demographic and modifiable variables are associated with VPA.

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REFERENCES

- Ebbeling CB, Pawlak DB, Ludwig DS. Childhood obesity: public-health crisis, common sense cure. *Lancet* 2002;360:473–82.
- Wang Y, Lobstein T. Worldwide trends in childhood overweight and obesity. *Int J Pediatr Obes* 2006;1:11–25.
- Reilly JJ, Methven E, McDowell ZC, et al. Health consequences of obesity. *Arch Dis Child* 2003;88:748–52.
- Salad JM. Update on the metabolic syndrome in children. *Curr Opin Pediatr* 2007;19:183–91.
- Ekelund U, Brage S, Froberg K, et al. TV viewing and physical activity are independently associated with metabolic risk in children: the European Youth Heart Study. *PLoS Med* 2006;3:e488.
- Ness AR, Leary SD, Mattocks C, et al. Objectively measured physical activity and fat mass in a large cohort of children. *PLoS Med* 2007;4:e97.
- Gutin B, Yin Z, Humphries MC, Barbeau P. Relations of moderate and vigorous physical activity to fitness and fatness in adolescents. *Am J Clin Nutr* 2005;81:746–50.
- Ruiz JR, Rizzo NS, Hurtig-Wennlof A, Ortega FB, Warnberg J, Sjostrom M. Relations of total physical activity and intensity to fitness and fatness in children: the European Youth Heart Study. *Am J Clin Nutr* 2006;84:299–303.
- Ortega FB, Ruiz JR, Sjostrom M. Physical activity, overweight and central adiposity in Swedish children and adolescents: the European Youth Heart Study. *Int J Behav Nutr Phys Act* 2007;4:61.
- Wittmeier KD, Mollard RC, Kriellaars DJ. Physical activity intensity and risk of overweight and adiposity in children. *Obesity (Silver Spring)* 2008;16:415–20.
- Ekelund U, Sardinha LB, Anderssen SA, et al. Associations between objectively assessed physical activity and indicators of body fatness in 9- to 10-y-old European children: a population-based study from 4 distinct regions in Europe (the European Youth Heart Study). *Am J Clin Nutr* 2004;80:584–90.
- Chen X, Beydoun MA, Wang Y. Is sleep duration associated with childhood obesity? A systematic review and meta-analysis. *Obesity (Silver Spring)* 2008;16:265–74.
- Frisancho AR. Prenatal compared with parental origins of adolescent fatness. *Am J Clin Nutr* 2000;72:1186–90.
- Reilly JJ, Armstrong J, Dorosty AR, et al. Early life risk factors for obesity in childhood: cohort study. *BMJ* 2005;330:1357.
- Singhal A, Wells J, Cole TJ, Fewtrell M, Lucas A. Programming of lean body mass: a link between birth weight, obesity, and cardiovascular disease? *Am J Clin Nutr* 2003;77:726–30.
- Strong WB, Malina RM, Blimkie CJ, et al. Evidence based physical activity for school-age youth. *J Pediatr* 2005;146:732–7.
- American Academy of Pediatrics, Committee on Public Education. Children, adolescents, and television. *Pediatrics* 2001;107:423–6.
- Hamilton MT, Hamilton DG, Zderic TW. Role of low energy expenditure and sitting in obesity, metabolic syndrome, type 2 diabetes, and cardiovascular disease. *Diabetes* 2007;56:2655–67.
- van Sluijs EM, Skidmore PM, Mwanza K, et al. Physical activity and dietary behaviour in a population-based sample of British 10-year old children: the SPEEDY study (Sport, Physical activity and Eating behaviour: environmental Determinants in Young people). *BMC Public Health* 2008;8:388.
- Trost SG, Ward DS, Moorehead SM, Watson PD, Riner W, Burke JR. Validity of the computer science and applications (CSA) activity monitor in children. *Med Sci Sports Exerc* 1998;30:629–33.
- McCarthy HD, Ellis SM, Cole TJ. Central overweight and obesity in British youth aged 11–16 years: cross sectional surveys of waist circumference. *BMJ* 2003;326:624.
- Tyrrell VJ, Richards G, Hofman P, Gillies GF, Robinson E, Cutfield WS. Foot-to-foot bioelectrical impedance analysis: a valuable tool for the

- measurement of body composition in children. *Int J Obes Relat Metab Disord* 2001;25:273–8.
23. VanItallie TB, Yang M, Heymsfield S, Funk R, Boileau R. Height-normalised indices of body's fat-free and fat mass: potentially useful indicators of nutritional status. *Am J Clin Nutr* 1990;52:953–9.
 24. Cole TJ, Bellizzi MC, Flegal KM, Dietz WH. Establishing a standard definition for child overweight and obesity worldwide: international survey. *BMJ* 2000;320:1240–3.
 25. Corder K, van Sluijs EM, Wright A, Whincup P, Wareham NJ, Ekelund U. Is it possible to assess free-living physical activity and energy expenditure in young people by self-report? *Am J Clin Nutr* 2009;89:862–70.
 26. Telford A, Salmon J, Jolley D, Crawford D. Reliability and validity of physical activity questionnaires for children: the children's leisure activities study survey. *Pediatr Exerc Sci* 2004;16:64–78.
 27. Crawley H. Food portion sizes. London, United Kingdom: Stationary Office, 2002.
 28. Eisenmann JC, Bartee RT, Wang MQ. Physical activity, TV viewing, and weight in U.S. youth: 1999 Youth Risk Behavior Survey. *Obes Res* 2002;10:379–85.
 29. Tammelin T, Ekelund U, Remes J, Nayha S. Physical activity and sedentary behaviors among Finnish youth. *Med Sci Sports Exerc* 2007;39:1067–74.
 30. Taveras EM, Field AE, Berkey CS, et al. Longitudinal relationship between television viewing and leisure-time physical activity during adolescence. *Pediatrics* 2007;119:e314–9.
 31. Marshall SJ, Biddle SJ, Gorely T, Cameron N, Murdey I. Relationships between media use, body fatness and physical activity in children and youth: a meta-analysis. *Int J Obes Relat Metab Disord* 2004;28:1238–46.
 32. Rey-Lopez JP, Vicente-Rodriguez G, Biosca M, Moreno LA. Sedentary behaviour and obesity development in children and adolescents. *Nutr Metab Cardiovasc Dis* 2008;18:242–51.
 33. Purslow LR, Hill C, Saxton J, Corder K, Wardle J. Differences in physical activity and sedentary time in relation to weight in 8-9 year old children. *Int J Behav Nutr Phys Act* 2008;5:67.
 34. Danielzik S, Czerwinski-Mast M, Langnase K, Dilba B, Muller MJ. Parental overweight, socioeconomic status and high birth weight are the major determinants of overweight and obesity in 5-7 y-old children: baseline data of the Kiel Obesity Prevention Study (KOPS). *Int J Obes Relat Metab Disord* 2004;28:1494–502.
 35. Davison KK, Marshall S, Birch L. Cross-sectional and longitudinal associations between TV viewing and girls' body mass index, overweight status, and percentage of body fat. *J Pediatr* 2006;149:32–7.
 36. Anderson SE, Economos CD, Must A. Active play and screen time in US children aged 4 to 11 years in relation to sociodemographic and weight status characteristics: a nationally representative cross-sectional analysis. *BMC Public Health* 2008;8:366.
 37. Dennison BA, Russo TJ, Burdick PA, Jenkins PL. An intervention to reduce television viewing by preschool children. *Arch Pediatr Adolesc Med* 2004;158:170–6.
 38. Eisenmann JC, Bartee RT, Smith DT, Welk GJ, Fu Q. Combined influence of physical activity and television viewing on the risk of overweight in US youth. *Int J Obes (Lond)* 2008;32:613–8.
 39. Ekelund U, Yngve A, Westerterp K, Sjöström M. Energy expenditure assessed by heart rate and doubly labeled water in young athletes. *Med Sci Sports Exerc* 2002;34:1360–6.
 40. Nunez C, Gallagher D, Visser M, Pi-Sunyer FX, Wang Z, Heymsfield SB. Bioimpedance analysis: evaluation of leg-to-leg system based on pressure contact footpad electrodes. *Med Sci Sports Exerc* 1997;29:524–31.
 41. Sung RY, Lau P, Yu CW, Lam PK, Nelson EA. Measurement of body fat using leg to leg bioimpedance. *Arch Dis Child* 2001;85:263–7.
 42. Unick JL, Utter AC, Schumm S, McInnis T. Evaluation of leg-to-leg BIA in assessing body composition in high-school-aged males and females. *Res Sports Med* 2006;14:301–13.
 43. Goss F, Robertson R, Williams A, et al. A comparison of skinfolds and leg-to-leg bioelectrical impedance for the assessment of body composition in children. *Dyn Med* 2003;2:5.
 44. Kushner RF, Gudivaka R, Schoeller DA. Clinical characteristics influencing bioelectrical impedance analysis measurements. *Am J Clin Nutr* 1996;64:423S–7S.