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Moderate to Vigorous Physical Activity and Sedentary Time and Cardiometabolic Risk Factors in Children and Adolescents

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Context Sparse data exist on the combined associations between physical activity and sedentary time with cardiometabolic risk factors in healthy children.

Objective To examine the independent and combined associations between objectively measured time in moderate- to vigorous-intensity physical activity (MVPA) and sedentary time with cardiometabolic risk factors.

Design, Setting, and Participants Pooled data from 14 studies between 1998 and 2009 comprising 20 871 children (aged 4-18 years) from the International Children's Accelerometry Database. Time spent in MVPA and sedentary time were measured using accelerometry after reanalyzing raw data. The independent associations between time in MVPA and sedentary time, with outcomes, were examined using meta-analysis. Participants were stratified by tertiles of MVPA and sedentary time.

Main Outcome Measures Waist circumference, systolic blood pressure, fasting triglycerides, high-density lipoprotein cholesterol, and insulin.

Results Times (mean [SD] min/d) accumulated by children in MVPA and being sedentary were 30 (21) and 354 (96), respectively. Time in MVPA was significantly associated with all cardiometabolic outcomes independent of sex, age, monitor wear time, time spent sedentary, and waist circumference (when not the outcome). Sedentary time was not associated with any outcome independent of time in MVPA. In the combined analyses, higher levels of MVPA were associated with better cardiometabolic risk factors across tertiles of sedentary time. The differences in outcomes between higher and lower MVPA were greater with lower sedentary time. Mean differences in waist circumference between the bottom and top tertiles of MVPA were 5.6 cm (95% CI, 4.8-6.4 cm) for high sedentary time and 3.6 cm (95% CI, 2.8-4.3 cm) for low sedentary time. Mean differences in systolic blood pressure for high and low sedentary time were 0.7 mm Hg (95% CI, −0.07 to 1.6) and 2.5 mm Hg (95% CI, 1.7-3.3), and for high-density lipoprotein cholesterol, differences were −2.6 mg/dL (95% CI, −1.4 to −3.9) and −4.5 mg/dL (95% CI, −3.3 to −5.6), respectively. Geometric mean differences for insulin and triglycerides showed similar variation. Those in the top tertile of MVPA accumulated more than 35 minutes per day in this intensity level compared with fewer than 18 minutes per day for those in the bottom tertile. In prospective analyses (N=6413 at 2.1 years' follow-up), MVPA and sedentary time were not associated with waist circumference at follow-up, but a higher waist circumference at baseline was associated with higher amounts of sedentary time at follow-up.

Conclusion Higher MVPA time by children and adolescents was associated with better cardiometabolic risk factors regardless of the amount of sedentary time.

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NATIONAL AND INTERNATIONAL public health authorities agree that children and adolescents should accumulate at least 60 minutes of moderate- to vigorous-intensity physical activity (MVPA) daily.[1-6] Although the exact amount of physical activity needed for optimal health is unknown, recent research has established inverse cross-sectional associations between objectively measured physical activity with adiposity and cardiometabolic risk factors in youth.[7-10]

Many health authorities and organizations have also recognized the potentially detrimental effects of prolonged time spent sedentary and consequently compiled guidelines for reducing the amount of sedentary time, especially TV viewing.[3-6,11] Some recent reports appear to confirm the importance of reducing sedentary time in youth as they suggest that higher levels of objectively measured time spent sedentary is associated with adiposity[8] and an adverse cardiometabolic risk profile.[12]

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Time spent in MVPA is weakly to moderately associated with time spent sedentary in youth,[8,13] suggesting both variables may be independently associated with cardiometabolic risk factors. However, the independent and combined associations between objectively measured time spent in MVPA and time spent sedentary in relation to cardiometabolic risk factors in youth remain unclear.

A better understanding of the relations between physical activity and sedentary time in relation to cardiometabolic risk factors will aid the development of physical activity interventions, counseling, and public health policy.

Therefore, we examined the cross-sectional and prospective associations between MVPA and time spent sedentary with established cardiometabolic risk factors in as many as 20 871 children and adolescents (aged 4-18 years) using a meta-analytical approach combining data from multiple cohorts in which physical activity and sedentary time have been measured objectively by accelerometry.

METHODS

Study Design

The International Children's Accelerometry Database (ICAD, http://www.mrc-epid.cam.ac.uk/Research/Studies/) was established to pool data on objectively measured physical activity from studies in youth worldwide. The aims, design, study selection, inclusion criteria, and methods of the ICAD project have been described in detail previously.[14] Briefly, in 2008 a PubMed search for potential contributors was undertaken. From this search 19 studies using the same type of accelerometer (Actigraph) and including at least 400 participants aged 3 to 18 years were identified. Additional studies were identified by personal communication. In total, 25 studies were identified and approached, of which 21 studies contributed data to the ICAD.[14] Formal data-sharing agreements were established and all partners consulted with their individual research board to confirm sufficient ethical approval had been attained for contributing data.

Participants

For the present analyses we used data on children and adolescents (aged 4-18 years) from 14 studies from Australia, Brazil, Europe, and the United States,[15-25] in which data on objectively measured physical activity and at least 1 of the cardiometabolic outcomes were available at 1 time point (N = 20 871). These studies were performed between 1998 and 2009. Information on cardiometabolic outcomes was not available from 7 studies and individuals from these studies were therefore excluded from the present analyses. Baseline and follow-up data for at least 1 of the outcome variables in combination with baseline physical activity data were available in 6413 participants.

Measurements

Assessment of Physical Activity and Sedentary Time. A detailed description of the assessment of physical activity is available elsewhere.[14] All available accelerometer data from the ICAD project were reanalyzed to provide physical activity outcome variables across studies that could be directly compared using specifically developed and commercially available software (KineSoft, version 3.3.20). Data files were reintegrated to a 60-second epoch and nonwear time was defined as 60 minutes of consecutive zeros, allowing for 2 minutes of nonzero interruptions.[26] All children with at least 1 day with at least 500 minutes of measured monitor wear time between 7 AM and midnight were included. Total physical activity was expressed as total counts, including sedentary minutes, divided by measured time per day (counts/min, cpm). Time spent sedentary was defined as all minutes showing less than 100 cpm[27] and MVPA time as minutes showing more than 3000 cpm,[27-29] which corresponds to about 4.6 metabolic equivalents.[27]

Assessment of Anthropometry and Cardiometabolic Outcomes. Outcome variables were 5 established cardiometabolic measures reflecting abdominal adiposity (waist circumference), glucose metabolism (fasting insulin), lipid metabolism (fasting triglycerides and HDL cholesterol), and resting systolic blood pressure. Skewed variables (fasting insulin and triglycerides) were log transformed before analyses.

Height and weight were measured using standardized clinical procedures across studies. Body mass index (BMI) was calculated as weight in kilograms divided by height in meters squared and participants were categorized into normal weight, overweight, and obese groups according to age and sex-specific cut points.[30] In all studies except for the NHANES (National Health and Nutrition Examination Survey), waist circumference was measured with a metal anthropometric tape midway between the lower rib margin and the iliac crest, at the end of gentle expiration.[15-22,25] In NHANES waist circumference was measured with a metal tape just above the iliac crest at the midaxillary line.[31]

Systolic blood pressure (SBP) was measured in 10 studies[16,17,20,21,23,24,26] out of the 14. Details of the measurements have been reported previously.[17,18,32,33] In the Avon Longitudinal Study of Parents and Children (ALSPAC)[25] blood pressure was measured with a Dinamap 9301 vital signs monitor. In the Copenhagen School Child Intervention Study (CSCIS)[16] and European Youth Heart Study (EYHS [Denmark, Estonia, Norway, and Portugal]),[17] blood pressure was measured using a Dinamap XL vital signs monitor every second minute during a 10-minute period following a 10-minute rest in a seated position and using the average of the last 3 readings. In the Movement and Activity Glasgow Intervention in Children (MAGIC)[20] and the Pelotas[21] studies, blood pressure was measured twice after 5 to 10 minutes of seated rest using a digital Omron sphygmomanometer.

Of the 14 studies, at baseline, fasting insulin was measured in 7 studies,[16-18,23,24] and fasting triglycerides and HDL cholesterol in 8 studies[10,16-18,23,24] according to standard clinical procedures as previously described.[10,16,18,23,24]

Statistical Analysis. Descriptive results are expressed as mean for continuous variables and percentages for categorical variables. Differences between sexes were tested by analysis of variance. Associations between total physical activity (cpm), MVPA, and sedentary time were analyzed by Pearson correlation coefficients.

Linear regression models were run separately for each study to estimate the cross-sectional associations between total physical activity (cpm), MVPA (min/d), and sedentary time (min/d) with each of the outcome variables. We thereafter mutually adjusted exposures (MVPA and sedentary time) for each other (ie, when MVPA was modeled as the main exposure, the analysis was adjusted for sedentary time and when sedentary time was modeled as the main exposure, the analysis was adjusted for MVPA) and examined the independent associations between MVPA and sedentary time with each of the outcomes. Results were expressed as regression coefficients representing the change in the outcome per 100 change in cpm, 10-minute change in MVPA, and 60-minute change in sedentary time. Regression coefficients were thereafter combined across studies using random effects meta-analysis adjusted for sex, age, monitor wear time, and waist circumference (when waist circumference was not modeled as the outcome).

Heterogeneity across studies was examined by the I^2 statistic. To explore possible reasons for heterogeneity between studies in the exposure effects, the following study-level covariates were included in meta-regression models[34]: mean age, median monitor wear time, proportion of girls, and proportion of normal-weight, overweight, and obese individuals.

Due to sex and age differences in MVPA and sedentary time, in combined associations analyses we first stratified each outcome by sex and age group (<7 years, 7 to 9 years, 10 to 13 years, and >13 years) for MVPA and sedentary time. These groups were then recombined into 9 new tertile groups with a similar mean age (range, 11.2-11.4 years). Sex- and age-adjusted means and 95% CI for each outcome and tertile group were calculated and a linear trend in the outcome across levels of MVPA within tertiles of sedentary time was tested by analysis of variance. Mean difference and its 95% CI between the bottom and top tertiles of MVPA across sedentary categories were calculated for waist circumference, systolic blood pressure, and HDL cholesterol. Geometric ratio and its 95% CI from bottom to top tertiles of MVPA across sedentary categories were calculated for fasting insulin and triglycerides because they are log-normal distributed.

Baseline and follow-up data on waist circumference were available in a subsample of 6413 participants. To estimate the prospective association between baseline MVPA and sedentary time with follow-up measures of waist circumference, a similar approach to that described previously was used, with additional adjustment in the models for follow-up time and the baseline value of the outcome variable.

There were no significant MVPA by sedentary time interactions for any of the analyses.

Because this study was an exploratory analysis of observational data rather than a confirmatory analysis of a clinical trial, formal correction for multiple testing was not done. All the analyses were conducted using Stata/SE version 11.2. All significance testing was 2-sided with a *P* value of less than .05 denoting statistical significance.

RESULTS

The baseline characteristics of the studies and sample are summarized in TABLE 1, TABLE 2, TABLE 3, and TABLE 4. Overall, 74.9% of children were categorized as normal weight, 17.7% as overweight, and 7.4% as obese. Children's physical activity was monitored for an average of 5.2 days (median, 835-min/d; 25th and 75th percentiles, 777 and 924 min/d) and 92.3% of children provided 3 or more days of valid recordings (>500-min/d).

Boys were significantly more active than girls and spent about 55% more of average daytime in MVPA. Conversely, girls spent approximately 5% more of the daytime sedentary. Time spent sedentary was moderately inversely correlated with time spent in MVPA ($r=-0.34$; $P<.001$) and strongly inversely correlated with total physical activity (cpm; $r=-0.70$; $P<.001$). MVPA was strongly correlated with overall physical activity ($r=0.83$; $P<.001$), explaining 68.9% of the variance in total physical activity.

Total physical activity (cpm) was significantly and inversely associated with waist circumference, fasting insulin, and triglycerides after adjustment for sex, age, and waist circumference when fasting insulin and triglycerides were the outcomes. MVPA was significantly and inversely associated with all cardiometabolic outcomes after adjustment for the same confounding variables as shown previously. Time spent sedentary was significantly and positively associated with fasting insulin after adjustment for confounders, but not with any of the other cardiometabolic outcomes (TABLE 5).

We thereafter modeled the associations between MVPA with the cardiometabolic outcomes after additional adjustment for time sedentary and the covariates mentioned previously (Table 5 and eFigure 1A-E, available at http://www.jama.com). The associations between MVPA and all cardiometabolic outcomes remained statistically significant independent of time spent sedentary. Conversely, time spent sedentary was not associated with any of the outcomes after additional adjustment for MVPA (Table 5 and eFigure 2A-E).

Meta-regression analysis was used to examine the sources of heterogeneity when modeling the association between time in MVPA and outcome variables (eFigure 1A-E). When modeling associations between MVPA and waist circumference, heterogeneity (I^2=93%) was partly explained by different associations between MVPA and waist circumference across BMI groups (*P* for interaction<.001).

The combined association analyses between time spent in MVPA and sedentary time with the cardiometabolic outcomes are shown in FIGURE 1. Higher levels of MVPA were associated with significantly lower values of waist circumference, systolic blood pressure, fasting insulin and fasting triglycerides, and higher values of HDL cholesterol across tertiles for sedentary time. The differences in outcomes between higher and lower MVPA were greater the lower the sedentary time. The mean differences (95% CI) between the bottom and top tertiles of MVPA across sedentary categories varied between 3.6 cm (95% CI, 2.8-4.3 cm) and 5.6 cm (95% CI, 4.8-6.4 cm) for waist circumference; 0.7 mm Hg (95% CI, −0.07 to 1.6 mm Hg) and 2.5 mm Hg (95% CI, 1.7 to 3.3 mm Hg) for SBP; and −2.6 mg/dL (95% CI, −1.4 to −3.9 mg/dL) and −4.5 mg/dL (95% CI, −3.3 to −5.6 mg/dL) for HDL cholesterol. The ratio between bottom and top tertiles of MVPA across sedentary categories varied between 1.39 (1.27: 1.53) and 1.71 (1.53:1.91) for insulin, and 1.15 (1.09:1.21) and 1.27 (1.20: 1.35) for triglycerides, suggesting a 71% and 27% difference between extreme MVPA groups for fasting insulin and triglycerides, respectively.

Youth in the top tertile of MVPA accumulated more than 35 minutes per day in this intensity level compared with fewer than 18 minutes per day for those in the low tertile.

Data on waist circumference were available from 7 studies (N=6413) at 2 different time points with a median follow-up time of 2.1 years (range, 0.3-8.0 years). Neither time in MVPA ($\beta = 0.00024$; 95% CI, −0.0057 to 0.0062) nor sedentary time ($\beta = -0.0024$; 95% CI, −0.0057 to 0.0010) was associated with waist circumference at follow-up after adjustment for sex, age, monitor wear time (min/d), follow-up time, and baseline waist circumference.

We then examined whether baseline waist circumference was associated with time spent in MVPA and

Table 1. Cohort Characteristics and Measurements

Study	Country, Measurement Year	No. of Participants: Boys	No. of Participants: Girls	Age Range, y	Mean (SD): Height, cm	Weight, kg	BMI[a]	Waist, cm	Birth Weight, g
ALSPAC,[25] 2001	United Kingdom, 2003/2004; 2005/2006	3158	3436	10-15	151.9 (8.2)	44.7 (10.7)	19.2 (3.4)	68.6 (9.5)	3409 (551)
Ballabeina,[15] 2009	Switzerland, 2008 and 2009	299	300	4-8	113.4 (6.3)	20.3 (3.4)	15.7 (1.6)	53.2 (4.4)	NA
CSCIS,[16] 2005	Denmark, 2001/2002; 2004/2005	356	311	6-11	124.5 (7.1)	25.2 (5.3)	16.1 (2.0)	56.4 (6.1)	NA
Riddoch et al,[17] 2005[b]	Denmark, 1997/1998; 2003/2004	607	751	9-16	148.8 (15.5)	42.1 (14.5)	18.5 (3.1)	63.4 (8.3)	3396 (587)
Riddoch et al,[17] 2005[b]	Estonia, 1998/1999	294	366	9-16	152.7 (17.5)	44.6 (15.8)	18.4 (3.1)	62.4 (8.1)	3540 (598)
KISS,[18] 2006	Switzerland, 2005; 2006	235	260	6-14	136.6 (13.2)	33.0 (10.2)	17.3 (2.8)	58.6 (7.1)	3357 (568)
MAGIC,[20] 2006	Scotland, 2002	205	213	4-5	102.7 (4.3)	17.3 (2.4)	16.3 (1.5)	51.3 (3.6)	NA
NHANES,[23] 2005	United States, 2003/2004	1193	1154	6-18	153.9 (17.7)	53.9 (22.1)	21.9 (5.9)	75.3 (15.8)	NA
NHANES,[24] 2010	United States, 2005/2006	1225	1229	6-18	152.7 (18.0)	52.8 (22.4)	21.7 (6.0)	74.9 (16.1)	NA
Riddoch et al,[17] 2005[b]	Norway, 1999/2000	194	190	9-10	139.2 (6.4)	33.2 (5.9)	17.0 (2.2)	60.3 (5.7)	3459 (587)
PEACH,[22] 2009	United Kingdom, 2006/2007; 2008/2009	605	635	10-13	145.7 (7.3)	39.8 (9.5)	18.6 (3.4)	66.9 (9.1)	NA
Pelotas,[21] 2008	Brazil, 2006/2007	238	217	13-14	158.0 (8.4)	51.1 (12.0)	20.3 (3.8)	68.6 (8.4)	3218 (533)
Riddoch et al,[17] 2005[b]	Portugal, 1999/2000; 2008	610	613	9-16	141.5 (13.7)	38.8 (13.2)	18.9 (3.5)	63.3 (8.3)	3385 (526)
SPEEDY,[19] 2008	United Kingdom, 2007	878	1098	9-11	141.0 (6.6)	36.5 (8.3)	18.2 (3.2)	64.1 (8.4)	3349 (582)

Abbreviations: ALSPAC, Avon Longitudinal Study of Parents and Children; CSCIS, Copenhagen School Child Intervention Study; EYHS, European Youth Heart Study; KISS, Kinder Sportstudie; MAGIC, Movement and Activity Glasgow Intervention in Children; NA, not available; NHANES, National Health and Nutrition Examination Survey; PEACH, Personal and Environmental Associations with Children's Health; SPEEDY, Sport, Physical Activity and Eating Behavior: Environmental Determinants in Young People.
[a] Body mass index (BMI) is calculated as weight in kilograms divided by height in meters squared.
[b] Part of the European Youth Heart Study.

sedentary time at follow-up. Baseline waist circumference was not associated with time in MVPA at follow-up (β=−0.0037; 95% CI, −0.60 to 0.052).

In contrast, a higher baseline waist circumference was associated with increased time spent sedentary (β=0.40; 95% CI, 0.19–0.61) adjusted for sex, baseline age, baseline sedentary time, monitor wear time, and follow-up time (FIGURE 2).

Table 2. Cohort Characteristics of Sexual Maturity[a]

Source	Sexual Maturity Stage 1	2	3	4	5
ALSPAC,[25] 2001	1510 (22.9)	2334 (35.4)	1820 (27.6)	804 (12.2)	125 (1.9)
CSCIS,[16] 2005	454 (75.8)	126 (21.0)	19 (3.2)	0	0
Riddoch et al (Denmark),[17] 2005[b]	807 (59.4)	129 (9.5)	27 (2.0)	187 (13.8)	208 (15.3)
Riddoch et al (Estonia),[17] 2005[b]	281 (42.6)	60 (9.1)	57 (8.6)	132 (20.0)	130 (19.7)
KISS,[18] 2006	345 (69.7)	102 (20.7)	33 (6.7)	12 (2.4)	2 (0.4)
Riddoch et al (Norway),[17] 2005[b]	315 (82.1)	64 (16.7)	5 (1.2)	0	0
Riddoch et al (Portugal),[17] 2005[b]	422 (34.5)	471 (38.5)	29 (2.4)	75 (6.1)	226 (18.5)

[a] Participant numbers by sexual maturity level were provided only for the 7 studies shown. Sexual maturity according to secondary sex staging based on pubic hair in boys and breast development in girls; data are number and frequencies in each group.
[b] Part of the European Youth Heart Study.

COMMENT

Time spent in MVPA is associated with multiple cardiometabolic risk factors independent of time spent sedentary and other confounding factors. Belonging to the top tertile for MVPA is associated with favorable metabolic health regardless of the amount of time spent sedentary. In contrast, time spent sedentary is unrelated to these risk factors after adjusting for time spent in MVPA. Neither time spent in MVPA nor time spent sedentary predicted a higher waist circumference in prospective analyses. However, baseline waist circumference predicted increased time spent sedentary at follow-up.

Strengths of our study include the large sample size, which allowed us to stratify our sample into 9 different

Table 3. Cohort Diagnostic Values[a]

Study	DBP, mm Hg	SBP, mm Hg	Insulin, Median (IQR), pmol/L	Triglycerides, Median (IQR), mg/dL	HDL Cholesterol, mg/dL	Total Physical Activity, cpm	Sedentary, min/d	MVPA, min/d
ALSPAC,[25] 2001	58.7 (6.5)	105.5 (9.9)	NA	NA	NA	597 (189)	356 (75)	35 (21)
Ballabeina,[15] 2009	NA	NA	NA	NA	NA	702 (182)	236 (65)	22 (13)
CSCIS,[16] 2005	58.1 (6.0)	98.7 (8.5)	21.1 (19.7-22.6)	20.1 (16.6-25.9)	57.5 (10.8)	738 (198)	268 (62)	36 (20)
Riddoch et al (Denmark),[17] 2005[b]	61.3 (6.2)	104.9 (10.0)	49.1 (47.6-50.7)	29.3 (21.6-39.4)	58.3 (13.1)	581 (248)	356 (107)	30 (23)
Riddoch et al (Estonia),[17] 2005[b]	61.2 (7.1)	105.9 (11.3)	47.1 (45.1-49.3)	26.6 (21.2-35.1)	54.4 (11.2)	625 (243)	343 (106)	38 (26)
KISS,[18] 2006	NA	NA	50.2 (47.3-53.1)	23.6 (16.6-27.8)	63.3 (13.5)	647 (210)	278 (99)	44 (23)
MAGIC,[20] 2006	60.8 (6.6)	97.0 (7.8)	NA	NA	NA	756 (187)	192 (57)	26 (16)
NHANES,[23] 2005	57.7 (11.6)	106.8 (10.3)	58.3 (55.2-61.5)	31.7 (23.2-44.0)	54.4 (12.7)	541 (226)	375 (106)	27 (21)
NHANES,[24] 2010	58.0 (10.9)	108.0 (10.6)	63.5 (60.3-66.8)	30.9 (22.8-41.7)	54.4 (13.1)	526 (228)	378 (105)	24 (20)
Riddoch et al (Norway),[17] 2005[b]	62.6 (5.8)	102.9 (7.6)	NA	30.5 (24.7-35.9)	59.5 (12.0)	711 (293)	325 (102)	45 (27)
PEACH,[22] 2009	NA	NA	NA	NA	NA	570 (170)	362 (72)	29 (17)
Pelotas,[21] 2008	68.2 (11.2)	110.7 (14.1)	NA	NA	NA	388 (144)	491 (93)	20 (16)
Riddoch et al (Portugal),[17] 2005[b]	55.0 (6.4)	96.9 (9.8)	28.2 (27.1-(29.3)	23.6 (18.9-33.6)	60.2 (12.7)	562 (215)	367 (94)	29 (21)
SPEEDY,[19] 2008	NA	NA	NA	NA	NA	602 (180)	352 (63)	28 (17)

Abbreviations: BMI, body mass index; cpm, counts per minute; DBP, diastolic blood pressure; HDL, high-density lipoprotein; IQR, interquartile range; MVPA, moderate- to vigorous-intesity physical activity; NA, not available; PA, physical activity; SBP, systolic blood pressure.
SI Conversion Factors: to convert insulin to μIU/mL, divide by 6.945; triglycerides to mmol/L, multiply by 0.0113; HDL cholesterol to mmol/L, multiply by 0.0259.
[a] Data are shown as mean (SD) unless otherwise stated.
[b] Part of the European Youth Heart Study.

groups with reasonably large samples in each stratum when examining the combined associations between time in MVPA, sedentary time, and cardiometabolic outcomes. Another strength includes the meta-analyses of 14 individual studies, providing more robust estimates of the observed associations. Time in MVPA and sedentary time were measured objectively, reducing the possibility of misclassification, and raw individual data files were cleaned, processed, and reanalyzed in a standardized manner in all participants.[14]

The observational study design limits inferences of causality. However, the cross-sectional associations between time in MVPA and the cardiometabolic risk factors, independent of sedentary time, were consistent in our meta-analyses and in the combined association analyses. It is unlikely that the metabolic risk factors lead to lower levels of physical activity, whereas it is biologically plausible that physical activity affects multiple cardiometabolic outcomes, possibly with the exception of adiposity. Indeed, results from exercise interventions suggest that both moderate- and vigorous-intensity exercise reduce the postprandial triacylglycerol concentrations in normal-weight[35] and overweight children,[36] improve insulin sensitivity in overweight children,[37,38] and improve systolic blood pressure in normotensive adolescents.[39]

Table 4. Baseline Descriptive Characteristics of Participants Stratified by Sex (n = 20 871)[a]

	No. (%)		
	Boys (n = 10 098)	Girls (n = 10 773)	*P* Value[b]
Age, y	11.3 (2.9)	11.3 (2.8)	.48
Weight, kg	43.1 (17.7)	42.7 (15.6)	.04
Height, cm	147.4 (17.5)	145.6 (15.1)	<.001
Waist circumference, cm	67.5 (12.4)	66.8 (12.1)	<.001
BMI[c]	19.1 (4.2)	19.4 (4.5)	<.001
Race, % white[d]	74.1	76.1	
Normal weight, %	76.2	73.7	
Overweight, %	16.7	18.6	
Obese, %	7.1	7.7	
Sexual maturity[d]			
Stage1	1983 (48.3)	1551 (40.0)	
Stage 2	1186 (28.9)	791 (20.4)	
Stage 3	386 (9.4)	582 (15.0)	
Stage 4	271 (6.6)	531 (13.7)	
Stage 5	279 (6.8)	423 (10.9)	
Birth weight, g[d]	3457 (588)	3342 (536)	<.001
Diastolic BP, mm Hg[d]	58.5 (8.7)	59.4 (8.3)	<.001
Systolic BP, mm Hg	105.5 (10.9)	104.2 (10.4)	<.001
Fasting insulin, geometric mean (95% CI), pmol/L[d]	35.0 (33.8-36.1)	39.3 (38.1-40.7)	<.001
Fasting triglycerides, geometric mean (95% CI), mg/dL[d]	27.0 (26.6-27.4)	28.6 (28.2-29.0)	<.001
HDL cholesterol, mg/dL[d]	56.0 (13.1)	56.8 (12.7)	.0011
Physical activity			
Total activity, cpm	642 (226)	540 (193)	<.001
Sedentary, min/d	345 (96)	363 (96)	<.001
MVPA, min/d	37 (23)	24 (17)	<.001

Abbreviations: BMI, body mass index; BP, blood pressure; HDL, high-density lipoprotein; MVPA, moderate- to vigorous-intensity physical activity.

SI Conversion Factors: to convert insulin to μIU/mL, divide by 6.945; triglycerides to mmol/L, multiply by 0.0113; HDL cholesterol to mmol/L, multiply by 0.0259.

[a] Data are shown as mean (SD) unless otherwise stated.

[b] *P* value denotes statistical differences between sex (analysis of variance).

[c] BMI is calculated as weight in kilograms divided by height in meters squared.

[d] White/other race descriptions from 10 studies,[17,19,21-24,26] (boys, n=8585; girls; n=9248); pubic hair in boys (n=3878) and breast development in girls (n=4105) from 7 studies,[16-18,26]; birth weight from 8 studies,[17-19,21,26] (boys, n=5511; girls, n=6132); diastolic and systolic BP from 10 studies,[16,17,20,21,23,24,26] (boys, n=7348; girls, n=7754); fasting insulin from 7 studies,[16-18,23,24] (boys, n=2590; girls, n=2671); excludes Riddoch et al (Norway); fasting triglycerides from 8 studies,[16-18,23,24] (boys, n=2785; girls, n=2896); excludes Riddoch et al (Norway); HDL cholesterol from 8 studies,[16-18,23,24] (boys, n=4104; girls, n=4256); excludes Riddoch et al (Norway).

Table 5. Associations Between Total Physical Activity, Time Spent in MVPA, and Sedentary Time With Cardiometabolic Risk Factors in 20 871 Children

	β Coefficients (95% CI)[a]				
	Waist Circumference, cm (n = 20 871)	SBP, mm Hg[b] (n = 15 062)	Insulin, pmol/L[b] (n = 5261)	Triglycerides, mg/dL[b] (n = 5689)	HDL Cholesterol, mg/dL (n = 8360)
Total PA, cmp	−0.35 (−0.50 to −0.16)	−0.10 (−0.26 to 0.05)	−0.026 (−0.033 to −0.020)	−0.021 (−0.026 to −0.016)	0.19 (−0.11 to 0.48)
MVPA, min/d	−0.52 (−0.76 to −0.28)	−0.15 (−0.30 to −0.06)	−0.028 (−0.038 to −0.017)	−0.017 (−0.025 to −0.009)	0.25 (−0.034 to 0.53)
Sedentary, min/d	0.13 (−0.094 to 0.358)	−0.043 (−0.21 to 0.20)	0.012 (0.0029 to 0.022)	0.014 (−0.0031 to 0.030)	−0.064 (−0.24 to 0.12)
MVPA, min/d[c]	−0.54 (−0.79 to −0.30)	−0.17 (−0.30 to −0.04)	−0.030 (−0.043 to −0.017)	−0.014 (−0.023 to −0.0046)	0.31 (0.036 to 0.59)
Sedentary, min/d[c]	−0.12 (−0.32 to 0.09)	−0.10 (−0.21 to 0.02)	−0.009 (−0.026,0.008)	0.006 (−0.010 to 0.023)	0.096 (−0.098 to 0.29)

Abbreviations: HDL, high-density lipoprotein; MVPA, moderate- to vigorous-intensity physical activity; SBP, systolic blood pressure.

See Table 3 for SI conversion factors.

[a] Coefficients represent the change in the outcome for a 100-cpm change in total physical activity and a 10-minute change in time spent in MVPA and a 60-minute change in time spent sedentary. Data are adjusted for age, sex, monitor wear minutes, and waist circumference (when it is not the outcome).

[b] SBP is additionally adjusted for height; and fasting insulin and triglycerides were log transformed.

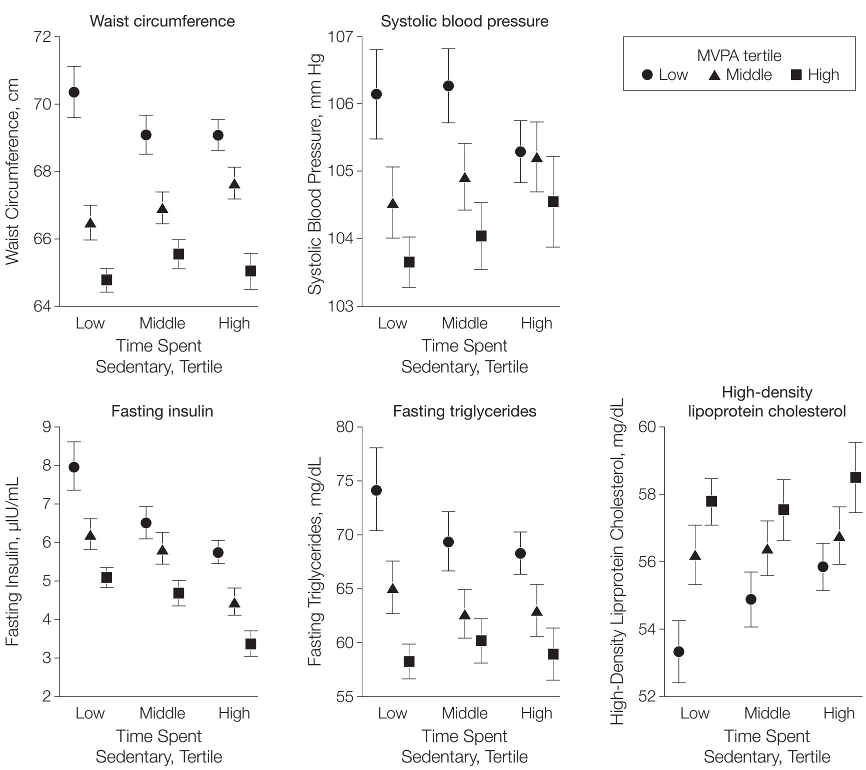
[c] MVPA is additionally adjusted for sedentary time and sedentary time is mutually adjusted for MVPA.

Although we controlled for confounding factors, we cannot exclude the possibility that unmeasured (eg, genotype and dietary intake) or poorly measured confounders explain our observations. Our intensity threshold for MVPA (3000 cpm) was higher compared with some other previous studies in children.[10] However, when reanalyzing our data using a lower intensity threshold of 2000 cpm, the observations were materially unchanged (data not shown).

Previous observations suggest that overall physical activity and time spent in MVPA is associated with a more healthy cardiometabolic profile in young individuals.[9,10,40,41] It has also been suggested that objectively measured time spent sedentary is associated with adiposity[8] and insulin resistance[12] in children. Further, overall physical activity measured by accelerometry appears associated with a favorable cardiometabolic profile independent of self-reported time spent viewing TV.[42] The present results extend previous observations by meta-analyzing data from as many as 14 different studies and by mutually adjusting time in MVPA and sedentary time for each other. Further, the combined associations analyses consistently confirmed that time in MVPA appears more important than time spent sedentary in relation to cardiometabolic outcomes in children.

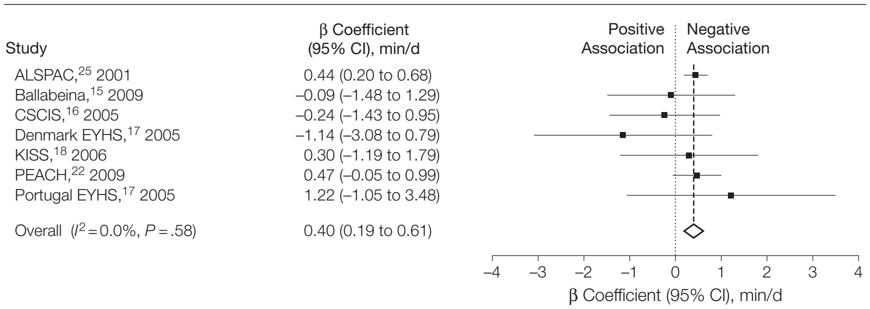
The magnitude of associations between time in MVPA and the cardiometabolic outcomes were small and could be considered by some as not clinically meaningful. A 10-minute difference in MVPA was associated with approximately 0.5-cm difference in waist circumference and approximately a 1-pmol/L difference in fasting insulin. However, the magnitude of associations may be underestimated. This is because physical activity is highly variable in children, and our measure of physical activity comprising 5 days on average may not fully reflect the true activity levels of the participants. The intraclass correlation coefficient (ICC) for within-individual differences in accelerometer-measured physical activity is approximately 0.5.[28] Assuming all measurement error stems from within-individual variability, the ICC can be used for measurement error correction by dividing the regression coefficients by the ICC.[43] This suggests that the true magni-

Figure 1. Combined Associations of Time Spent Sedentary and in MVPA With 5 Metabolic Risk Factors



Mean time spent sedentary in the low, middle, and high tertile groups were 268.0 (range, 28.0-399), 351.6 (range, 203.0-479.8), and 433.3 (range, 262.3-755.8) minutes per day, respectively. Mean time spent in moderate- to vigorous-intensity physical activity (MVPA) was 12.0 (range, 0-27.2), 27.0 (range, 8.4-45.7), and 52.5 (range, 20.6-185.0) minutes per day in the low, middle, and high MVPA groups. Mean age was 11.2 to 11.4 years across tertile groups. Data for each group are sex- and age-adjusted means (geometric means for fasting insulin and triglycerides) and 95% CI (*P* for trend $<$.001 for all outcomes across all sedentary tertiles except systolic blood pressure in the high sedentary group; *P* for trend=.11).

Figure 2. Associations Between Baseline Waist Circumference and Time Spent Sedentary at Follow-up



β coefficients show difference in time spent sedentary (min/d) for 1-cm difference in baseline waist circumference. Model adjusted for sex, age, monitor wear time, baseline time spent sedentary, and follow-up time.

tudes of the associations may be at least twice as strong as those observed.

Results from the combined analyses were more substantial. Waist circumference differed by as much as 5.6 cm (95% CI, 4.8-6.4) between those in the top tertiles for MVPA compared with those in the bottom tertiles. If this difference in waist circumference persists into adulthood, it may confer considerable health risks because waist circumference is linearly associated with all-cause mortality.[44,45] For example, every 5-cm increase in waist circumference is associated with an increased relative risk of 17% and 13% for all-cause mortality in men and women, respectively.[44]

Further, the differences in cardiometabolic risk factors between the top and bottom tertiles of MVPA were remarkable similar to the effects observed from a 12-month high-intensity exercise intervention in sedentary individuals with type 2 diabetes.[46] Taken together, this suggests that the magnitude of differences in cardiometabolic risk factors observed between high- and low-active healthy youth is clinically significant irrespective of the amount of time spent sedentary.

Moving from the bottom to the top tertile for MVPA requires an increase in MVPA of at least 20 minutes per day. Increasing daily activity at this intensity level can be achieved by participating in activities such as brisk walking, jogging, cycling, playing soccer, and other team sports.

Our results contradict some previous observations in adults suggesting that objectively measured sedentary time is associated with metabolic outcomes independent of time in MVPA.[47] When interpreting the differences in results between studies in children and adults, the following should be considered: (1) total physical activity (cpm) is significantly higher in children compared with adults; (2) differences in the definition of MVPA and differences in the relative amount of time spent sedentary between studies may also contribute to the conflicting results; and (3) the between-individual variability in time in MVPA and time spent sedentary may vary between children and adults.

In contrast to studies in adults,[48-50] we were not able to confirm that baseline time in MVPA or sedentary time predicted any of the cardiometabolic outcomes at follow-up. This may be explained by the generally more healthy metabolic risk profile in children compared with middle-aged adults. Other differences include higher overall levels of activity, more time accumulated in MVPA, and less time spent sedentary in children compared with adults.[26]

The observation that baseline waist circumference predicted time spent sedentary at follow-up corroborates studies in children and adults,[51,52] supporting the hypothesis that the association between physical activity, sedentary time, and weight gain may be bidirectional.

Our results have implications for public health policy and physical activity counselling. Children should be encouraged to increase their participation in physical activity of at least moderate intensity rather than reducing their overall sedentary time as this appears more important in relation to cardiometabolic health. However, our measure of sedentary time takes into account the accumulated time spent sedentary rather than a specific behavior (eg, TV viewing). Therefore, decreasing TV time in youth may still be an important public health goal as TV viewing may be associated with other unhealthy behaviors such as snacking and soft drink consumption.[53,54] Further TV viewing is also associated with exposure to advertisements that often promote unhealthy dietary habits.[55]

In conclusion, higher levels of time in MVPA appear to be associated with better cardiometabolic risk factors regardless of the amount of time spent sedentary in youth.

Author Contributions: Drs Ekelund and Luan had full access to all of the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.
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Acquisition of data: Ekelund, Sherar, Griew.
Analysis and interpretation of data: Ekelund, Luan, Esliger, Cooper.
Drafting of the manuscript: Ekelund, Cooper.
Critical revision of the manuscript for important intellectual content: Ekelund, Luan, Sherar, Esliger, Griew, Cooper.
Statistical analysis: Ekelund, Luan.
Obtained funding: Ekelund, Cooper.
Administrative, technical, or material support: Sherar, Esliger, Griew.
Study supervision: Ekelund.
Dr Esliger developed the program for accelerometer data reduction and analyses, assisted with data cleaning and reduction, and contributed to interpretation of the data; and Ms Griew organized the phenotypic information.

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