Changes in Physical Activity and Sedentary Patterns on Cardiometabolic Outcomes in the Transition to Adolescence: International Children's Accelerometry Database 2.0

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Objective To examine the associations of changes in physical activity and sedentary patterns with changes in cardiometabolic outcomes from childhood to adolescence.

Study design Youth from the International Children's Accelerometry Database (n = 1088; 55% girls), aged 8-13 years and followed for ~4 years, were used in this analysis. Hip-mounted accelerometers were used and all physical activity intensities were expressed as the % of total wear-time. Sedentary time was separated into time spent in bouts <10 minutes and ≥10 minutes. A composite z score for cardiometabolic risk (CMR score) was computed by summing the standardized values for systolic and diastolic blood pressure, triglycerides (TG), low-density lipoprotein cholesterol (LDL-c), and the inverse high-density lipoprotein cholesterol. Multivariate analyses were performed using adjusted linear regression models.

Results Increase in sedentary time was unfavorably associated with changes in CMR score (β = 0.021; CI 0.004-0.037), TG (β = 0.003; CI 0.001-0.005), and diastolic blood pressure (β = 0.068; CI 0.009-0.128). Decrease in moderate-to-vigorous physical activity was unfavorably associated with changes in LDL-c (β = −0.009; CI −0.017 to −0.001) and TG (β = −0.007; CI −0.013 to −0.001). Increase in ≥10 minutes sedentary time was unfavorably associated with changes in CMR score (β = 0.017; CI 0.004-0.030), LDL-c (β = 0.003; CI 0.000-0.005), and TG (β = 0.003; CI 0.000-0.004). Decrease in light-intensity physical activity was unfavorably associated with changes in CMR score (β = −0.020; CI = −0.040 to 0.000).

Conclusions More physical activity and less prolonged sedentary time are beneficial for cardiometabolic health in youth transitioning to adolescence. *(J Pediatr 2020;225:166-73)*.

The role of physical activity in overall health is well established,[1] with sensor-based physical activity being inversely associated with cardiometabolic risk in youth.[2] However, evidence assessing the relationship between physical activity and cardiometabolic outcomes in youth has mostly focused on moderate-to-vigorous physical activity, an important factor contributing to cardiometabolic health of youth.[3] Despite the benefits of moderate-to-vigorous physical activity, other intensities of physical activity also may contribute to cardiometabolic health. For instance, sedentary time has been unfavorably associated with health outcomes such as body-fat percentage and insulin levels.[4,5]

Moreover, cross-sectional investigations suggest that the manner in which sedentary time is accumulated may play an important role in the associations with health outcomes, with shorter bouts of sedentary time and more frequent breaks potentially favoring healthier cardiometabolic profiles.[6,7] Despite several experimental findings suggesting that prolonged sedentary bouts may have a

ALSPAC	Avon Longitudinal Study of Parents and Children
CMR score	Cardiometabolic risk score
DBP	Diastolic blood pressure
EYHS	European Youth Heart Study
HDL-c	High-density lipoprotein cholesterol
ICAD	International Children's Accelerometry Database
LDL-c	Low-density lipoprotein cholesterol
SBP	Systolic blood pressure
TG	Triglycerides
WC	Waist circumference

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P.J. is supported by a postdoctoral scholarship from the Portuguese Foundation for Science and Technology (SFRH/BPD/115977/2016). This work was partly supported by Fundação para a Ciência e Tecnologia, under Grant UIDB/00447/2020 to CIPER – Centro Interdisciplinar para o Estudo da Performance Humana (unit 447). Pooling of the data was funded through a grant from the National Prevention Research Initiative (grant number G0701877). The funding sources had no involvement in study design; in the collection, analysis and interpretation of data; in the writing of the report; and in the decision to submit the article for publication. http://www.mrc.ac.uk/research/initiatives/nationalprevention-research-initiative-npri/. The funding partners relevant to this award are the British Heart Foundation, Cancer Research UK, Department of Health, Diabetes UK, Economic and Social Research Council, Medical Research Council, Research and Development Office for the Northern Ireland Health and Social Services, Chief Scientist Office, Scottish Executive Health Department, The Stroke Association, Welsh Assembly Government, and World Cancer Research Fund. The other authors declare no conflicts of interest.

https://doi.org/10.1016/j.jpeds.2020.06.018

negative impact on cardiometabolic pathways,[8] evidence from observational investigations on this topic in youth is sparse, inconclusive, and does not allow for the establishment of causality.[9,10] Longitudinal investigations are a step forward to establishing causality.[11] The public health recommendation to "sit less, move more" is widespread, but understanding how distinct physical activity intensities and patterns influence cardiometabolic outcomes in youth as they progress from childhood to adolescence is important for more effective strategies and recommendations to be made.

Our goal was to longitudinally investigate the relationship of changes in light-intensity physical activity and moderate-to-vigorous physical activity, as well as changes in total sedentary time and time spent in prolonged sedentary time with changes in composite and individual cardiometabolic outcomes in a large, multicenter sample of youth transitioning to adolescence.

Methods

The International Children's Accelerometry Database (ICAD; http://www.mrc-epid.cam.ac.uk/research/studies/icad/) is a pooled database covering accelerometer and sociodemographic data from more than 20 studies of 3- to 18-year-old youths worldwide. More details about ICAD aims, study selection, inclusion criteria, and methods have been previously described.[12]

The European Youth Heart Study (EYHS) assessed 1604 youth aged 8-10 years old from Odense, Denmark, and the island of Madeira, Portugal, between September 1997 and July 2000. Those youth were then invited to participate in the study after approximately 6 years. For the current analyses, we considered the participants who had at least 3 valid days of accelerometer data (including 1 weekend day) and all cardiometabolic outcomes of interest on both time of first data collection (T1) and follow-up, which yielded a total sample of 272 participants from the EYHS. The EYHS was approved by the local scientific ethics committee (case no. 96/272) and performed in accordance with the Helsinki Declaration.

The Avon Longitudinal Study of Parents and Children (ALSPAC) performed in England included 13 978 youth who were born between April 1991 and December 31, 1992. Details on all the cohorts can be found in a previous publication.[13] Although the assessment moments in the EYHS were approximately 6 years apart, the ALSPAC collected data every 1-3 years; therefore, we excluded wave 2 from ALSPAC and considered waves 1 and 3, so that similar T1 age and follow-up period would be considered. For the current analyses, 816 participants from ALSPAC were included.

In all studies, participant/parental written informed consent was obtained and consulted with their respective research boards to ensure appropriate ethical approval of data-sharing. Because the ICAD dataset is an anonymous data source, the Human Subject Committee did not review this pooled analysis (ie, 2019).

A description of the ICAD demographic variables has been previously described.[12] We used the ICAD 2nd classification system for ethnicity, which differentiates between white, black, Asian, mixed, and other. For the parents' education level, the ICAD 2nd classification system also was used: (1) up to and including completion of compulsory education; (2) some post-compulsory education or vocational training; (3) completed undergraduate or postgraduate education.

Body height and weight were measured with a stadiometer and a calibrated scale, respectively.[12] Waist circumference (WC) was measured with a metal tape according to the protocol previously described.[12]

Cardiometabolic risk factors included systolic blood pressure (SBP), diastolic blood pressure (DBP), fasting high- and low-density lipoprotein cholesterol (HDL-c and LDL-c), and triglycerides (TG). A full description of blood collection procedures for studies in the ICAD database is available elsewhere.[12] A composite z score for cardiometabolic risk (CMR score) was derived by standardizing and then summing the following continuously distributed markers: SBP, DBP, LDL-c, TG, and inverted fasting HDL-c. The standardizing of these factors was achieved by subtracting the sample mean from the individual mean and then dividing by the SD (of the sample mean). The CMR score was calculated at T1 and follow-up. A greater score implied greater risk.

All accelerometer data were reprocessed by the ICAD group to ensure consistency across studies and waves according to a standardized harmonization protocol.[12] Accelerometer data were collected using the hip-mounted ActiGraph 7164, also known as the CSA and MTI. All individual participant data were re-analyzed using KineSoft, version 3.3.20 (KineSoft, Saskatchewan, Canada; http://www.kinesoft.org/) and reintegrated to 60-second epochs. Periods of 60 minutes of consecutive zeros were considered as non-wear time, allowing for 2 minutes of non-zero interruptions. The inclusion criteria for accelerometry data for this report were a valid wear-time of ≥10 hours per day for ≥3 days, including 1 weekend day at both T1 and follow-up time points. A data dictionary, which provides a definition of all accelerometer variables in the ICAD database, can be found at http://www.mrc-epid.cam.ac.uk/Research/Studies/.

ICAD provides several cut points to differentiate physical activity intensities. The following cut points were considered: sedentary time <100 counts/min; light-intensity physical activity ≥100 to <2000 counts/min; and moderate-to-vigorous physical activity ≥2000 counts/min. The time in bouts of distinct length spent in different physical activity intensities (ie, 1-3, 3-5, 5-10, 10+ minutes) were provided by the ICAD database. The time in these bouts was summed to obtain the total time spent in each activity intensity. In addition, a period of uninterrupted sedentary time was considered a bout, and bouts of <10 minutes and bouts of ≥10 minutes represented non-prolonged and prolonged sedentary time, respectively.

All statistical analyses were performed using IBM SPSS Statistics (version 25.0, 2012; IBM Corp, Armonk, New York). Descriptive statistics included means ± SD for all measured variables at both moments. Differences between T1 and follow-up were analyzed using paired-sample *t* tests.

For all exposures, the % of total wear time was calculated (ie, [exposure in minutes/total wear-time in minutes] * 100). The change (Δ) in % of total wear time in a specific behavior was then calculated (follow-up % exposure minus T1 % exposure) and used as the independent variable in the regression models in order to account for significant differences in total wear time between time points. For all cardiometabolic outcomes and the CMR scores, the change variable (Δ) was calculated (follow-up value minus the T1 value) and used in the regression models. Multiple linear regression models were used to assess the relationship between changes in the exposures (ie, % of sedentary time, light-intensity physical activity, moderate-to-vigorous physical activity, <10 minutes sedentary time, and ≥10 minutes sedentary time) and changes in the outcomes (ie, CMR score, SBP, DBP, HDL-c, LDL-c, and TG), adjusting for T1 age, sex, ethnicity, mother's education level, father's education level, accelerometer valid days, study, follow-up duration, and the outcome and exposure at T1, to control for the variation in their initial levels. A separate regression model was performed for each exposure/outcome pair.

Interactions for sex or study with exposures and the cardiometabolic outcomes were tested by including in each model the respective variable of interaction (eg, sex*Δ sedentary time%) and examining the *P* value for the association of this variable with the specific outcome (eg, Δ TG) among all the other exposures. Interaction was checked for each independent model and if $P \geq .05$, then no interaction existed. In regression models with SBP or DBP, further adjustment for changes in height was performed. All regression models were checked for linearity, normality, and homoscedasticity and all linear regression assumptions were met. In addition, the variance inflation factor was used to check collinearity. All models had a variance inflation factor <2. Additional regression analyses with similar models were performed in 4 groups (inactive, moderately inactive, moderately active, and active), stratified based on the quartiles of moderate-to-vigorous physical activity to examine the associations within each of these groups. Statistical significance was set at $P < .05$.

Results

No significant interactions for sex or study with exposures and the cardiometabolic outcomes were observed. Thus, girls and boys from all the 3 studies were combined in the analyses with sex and study added as covariates in the models. A total of 1088 youth (601 girls), who were primarily of white ethnicity (92%), were included. Participants were from the ALSPAC-England (N = 816; 75%), the EYHS-Denmark (N = 196; 18%), and the EYHS-Portugal (N = 76; 7%). Table I shows the participants' demographics, cardiometabolic outcomes, and accelerometer-derived exposures at T1 and follow-up, and the results for the paired *t* tests.

As presented in Table I, T1 and follow-up were separated by an average of 4.37 years. All exposures significantly

Table I. Participant characteristics, cardiometabolic outcomes, and accelerometer-derived exposures at T1 and follow-up

(N = 1088)	T1	Follow-up	Δ (Follow-up T1)	*P* value
Demographics	Mean ± SD	Mean ± SD	Mean ± SD	
Age, y	11.3 ± 1.0	15.6 ± 0.5	4.4 ± 1.2	**<.001**
Body height, cm	148.1 ± 8.7	169.5 ± 8.6	21.4 ± 8.8	**<.001**
Body weight, kg	40.7 ± 9.5	61.2 ± 10.8	20.5 ± 8.1	**<.001**
Waist circumference, cm*	65.3 ± 8.8	75.4 ± 7.9	10. 1 ± 6.6	**<.001**
Cardiometabolic outcomes				
LDL-c, mmol/L	2.4 ± 0.6	2.1 ± 0.6	−0.3 ± 0.5	**<.001**
HDL-c, mmol/L	1.4 ± 0.3	1.3 ± 0.3	−0.1 ± 0.3	**<.001**
TG, mmol/L	1.0 ± 0.5	0.8 ± 0.3	−0.2 ± 0.6	**<.001**
SBP, mm Hg/min	104.7 ± 9.6	119.3 ± 12.3	14.6 ± 12.8	**<.001**
DBP, mm Hg/min	59.2 ± 6.5	65.3 ± 8.7	6.2 ± 9.9	**<.001**
Accelerometer-derived exposures				
Sedentary time, min/d	352.5 ± 76.4	470.5 ± 81.7	118.1 ± 92.9	**<.001**
Sedentary time, %	44.5 ± 8.9	58.0 ± 8.7	13.5 ± 10.3	**<.001**
Light-intensity physical activity, min/d	360.4 ± 60.8	275.5 ± 65.6	−84.9 ± 75.4	**<.001**
Light-intensity physical activity, %	45.6 ± 7.3	33.9 ± 7.2	−11.7 ± 8.4	**<.001**
Moderate-to-vigorous physical activity, min/d	65.1 ± 32.1	52.3 ± 32.1	−12.8 ± 38.4	**<.001**
Moderate-to-vigorous physical activity, %	8.2 ± 4.0	6.4 ± 3.6	−1.8 ± 4.4	**<.001**
<10 min sedentary time, min/d	141.3 ± 22.5	126.4 ± 28.7	−15.0 ± 33.9	**<.001**
<10 min sedentary time, %	17.9 ± 2.7	15.6 ± 3.2	−2.3 ± 3.8	**<.001**
≥10 min sedentary time, min/d	211.1 ± 79.9	344.2 ± 92.8	133.0 ± 100.6	**<.001**
≥10 min sedentary time, %	26.7 ± 9.8	42.5 ± 10.9	15.8 ± 12.1	**<.001**
Total wear time, min/d	790.8 ± 60.5	812.2 ± 79.6	21.4 ± 89.2	**<.001**

<10 min sedentary time, total sedentary time in bouts of less than 10 minutes; *≥10 min sedentary time*, total sedentary time in bouts equal or longer than 10 minutes; *T1*, time of first data collection. Δ, change; %, percentage of total wear time spent in that specific behavior; *P* value for the paired-sample *t* test between time points with 5% significance.
The bold means that there are statistically significant results.
*The sample size for T1 waist circumference is N = 1088, but the follow-up sample size considering this variable is only N = 946.

changed over time ($P < .001$), with youth increasing sedentary time by 118.1 min/d, especially the prolonged sedentary time (>10 min sedentary time), with an increase of 133.0 min/d. On the contrary, light-intensity physical activity was reduced by 84.9 min/d, moderate-to-vigorous physical activity by 12.8 min/d, and the non-prolonged sedentary time (<10 minutes sedentary time) decreased 15.0 min/d from childhood to adolescence. At T1, 73%, and on follow-up, 64%, of the participants had 6 or more accelerometer valid days.

Table II displays the results of linear regression examining the associations between changes in physical activity and sedentary patterns with changes in CMR score and individual cardiometabolic outcomes, adjusting for the previously mentioned confounders. An increase in total sedentary time over time was associated with unfavorable changes in CMR score, TG, and DBP, and an increase in >10 minutes sedentary time from T1 to follow-up was related with unfavorable changes in CMR score, LDL-c, and TG ($P < .05$). A decrease in moderate-to-vigorous physical activity over time was related with unfavorable changes in LDL-c and TG, and a reduction in light-intensity physical activity from T1 to follow-up was associated with unfavorable changes in CMR score ($P < .05$).

Table III presents the results for the regression analyses performed for the 4 categories (inactive, moderately inactive, moderately active, and active) based on moderate-to-vigorous physical activity quartiles. An increase in total sedentary time over time was associated with unfavorable changes in CMR score, TG, and DBP for the moderately active group at T1. An increase in >10 minutes sedentary time from T1 to follow-up was related with unfavorable changes in TG and DBP for the moderately active group at T1, and with unfavorable changes in CMR score and LDL-c for the active group at T1 ($P < .05$). A decrease in moderate-to-vigorous physical activity over time was related with unfavorable changes in LDL-c in the inactive group only ($P < .05$). A reduction in light-intensity physical activity from T1 to follow-up was associated with unfavorable changes in CMR score for the moderately inactive ($P < .05$), and with unfavorable changes in TG and DBP for the moderately active group ($P < .05$). Finally, a decrease in <10 minutes sedentary time from T1 to follow-up was related with unfavorable changes in TG for the moderately active group and with unfavorable changes in LDL-c for the active group ($P < .05$).

Table II. Associations for changes in physical activity and sedentary patterns with changes in cardiometabolic outcomes

(N = 1088)	Δ CMR score*	Δ LDL-c	Δ HDL-c	Δ TG	Δ SBP*	Δ DBP*
	Standardized β (95% CI)					
Δ % sedentary time	**0.021 (0.004-0.037)**	0.003 (0.000-0.006)	0.001 (−0.001, 0.003)	**0.003 (0.001-0.005)**	0.010 (−0.061, 0.081)	**0.068 (0.009- 0.128)**
Δ % light-intensity physical activity	**−0.021 (−0.041, −0.001)**	−0.003 (−0.007, 0.001)	−0.001 (−0.003, 0.002)	−0.003 (−0.006, 0.000)	−0.021 (−0.106, 0.065)	−0.071 (−0.143, 0.001)
Δ % moderate-to-vigorous physical activity	−0.035 (−0.075, 0.005)	**−0.009 (−0.017, −0.001)**	−0.002 (−0.006, 0.002)	**−0.006 (−0.012, −0.000)**	0.029 (−0.142, 0.200)	−0.090 (−0.233, 0.054)
Δ % <10 min sedentary time	−0.039 (−0.082, 0.004)	−0.005 (−0.013, 0.004)	0.001 (−0.004, 0.005)	−0.006 (−0.012, 0.001)	−0.065 (−0.250, 0.119)	−0.020 (−0.175, 0.135)
Δ % ≥10 min sedentary time	**0.018 (0.004-0.031)**	**0.003 (0.000-0.005)**	0.001 (−0.001, 0.002)	**0.003 (0.001-0.004)**	0.013 (−0.044, 0.070)	0.045 (−0.003, 0.093)

Δ, change (Follow-up-T1); β = standardized β adjusted for T1 age, sex, ethnicity, father's education, mother's education, study, accelerometer valid days, follow-up duration, T1 metabolic parameter, and T1 % of exposure.
*Additionally adjusted for Δ height.

Discussion

Few investigations have assessed the longitudinal associations of sensor-based physical activity and sedentary time with cardiometabolic outcomes in youth,[11,14-16] and most of these investigations had a follow-up of less than 2 years.[17] One investigation longitudinally considered the issue of distinct sedentary time accumulation patterns, but with a follow-up time of 10 months.[11] Thus, our findings extend the ones

Table III. Associations for changes in physical activity and sedentary patterns with changes in CMR score stratified according to T1 moderate-to-vigorous physical activity quartiles

(N = 1088)	Δ CMR-score*	Δ LDL-c	Δ HDL-c	Δ TG	Δ SBP*	Δ DBP*
	Standardized β (95% CI)					
Inactive						
Δ % sedentary time	0.019 (−0.014, 0.053)	0.003 (−0.004, 0.009)	−0.001 (−0.005, 0.003)	0.004 (−0.001, 0.009)	−0.071 (−0.214, 0.071)	0.054 (−0.052, 0.161)
Δ % light-intensity physical activity	−0.018 (−0.057, 0.020)	0.000 (−0.008, 0.007)	0.002 (−0.002, 0.007)	−0.003 (−0.009, 0.003)	0.051 (−0.114, 0.216)	−0.032 (−0.156, 0.092)
Δ % moderate-to-vigorous physical activity	−0.057 (−0.158, 0.043)	**−0.020 (−0.040, 0.000)**	−0.003 (−0.014, 0.008)	−0.009 (−0.025, 0.006)	0.257 (−0.163, 0.676)	−0.299 (−0.613, 0.015)
Δ % <10 min sedentary time	−0.018 (−0.112, 0.076)	−0.002 (−0.021, 0.017)	--0.004 (−0.006, 0.015)	−0.003 (−0.018, 0.011)	0.104 (−0.289, 0.498)	0.052 (−0.244, 0.347)
Δ % ≥10 min sedentary time	0.014 (−0.013, 0.040)	0.002 (−0.003, 0.007)	−0.001 (−0.004, 0.002)	0.003 (−0.001, 0.007)	−0.052 (−0.164, 0.059)	0.030 (−0.054, 0.113)
Moderately inactive						
Δ % sedentary time	0.038 (−0.004, 0.079)	0.003 (−0.004 0.011)	−0.002 (−0.004, 0.004)	0.003 (−0.003, 0.009)	−0.007 (−0.184, 0.169)	**0.201 (0.048, 0.354)**
Δ % light-intensity physical activity	**−0.048 (−0.097, 0.000)**	−0.002 (−0.010, 0.007)	0.001 (−0.004, 0.005)	−0.002 (−0.010, 0.005)	−0.099 (−0.304, 0.107)	**−0.262 (−0.441, −0.084)**
Δ % moderate-to-vigorous physical activity	−0.016 (−0.116, 0.084)	−0.015 (−0.032, 0.003)	−0.001 (−0.011, 0.009)	−0.004 (−0.019, 0.011)	0.254 (−0.160, 0.667)	−0.076 (−0.449, 0.297)
Δ % <10 min sedentary time	−0.071 (−0.159, 0.018)	−0.004 (−0.020, 0.012)	0.005 (−0.004, 0.014)	−0.001 (−0.015, 0.012)	−0.126 (−0.502, 0.251)	−0.253 (−0.582, 0.076)
Δ % ≥10 min sedentary time	0.028 (−0.003, 0.060)	0.002 (−0.003, 0.008)	−0.001 (−0.004, 0.003)	0.001 (−0.003, 0.006)	0.013 (−0.121, 0.147)	**0.140 (0.023-0.256)**
Moderately active						
Δ % sedentary time	**0.029 (0.000-0.060)**	0.000 (−0.007, 0.006)	0.000 (−0.003, 0.003)	**0.005 (0.000-0.010)**	0.128 (−0.010, 0.266)	0.061 (−0.059, 0.180)
Δ % light-intensity physical activity	−0.028 (−0.066, 0.010)	0.000 (−0.008, 0.009)	−0.001 (−0.005, 0.003)	**−0.006 (−0.012, 0.000)**	−0.107 (−0.281, 0.067)	−0.032 (−0.182, 0.119)
Δ % moderate-to-vigorous physical activity	−0.046 (−0.114, 0.022)	0.000 (−0.015, 0.015)	0.003 (−0.005, 0.010)	−0.005 (−0.015, 0.005)	−0.265 (−0.571, 0.041)	−0.104 (−0.367, 0.158)
Δ % <10 min sedentary time	−0.052 (−0.132, 0.029)	0.001 (−0.017, 0.018)	−0.003 (−0.012, 0.006)	**−0.013 (−0.024, −0.001)**	−0.301 (−0.671, 0.068)	0.064 (−0.254, 0.382)
Δ % ≥10 min sedentary time	**0.026 (0.001-0.051)**	0.000 (−0.006, 0.005)	0.000 (−0.002, 0.003)	**0.005 (0.001-0.008)**	0.122 (0.007- 0.237)	0.036 (−0.064, 0.135)
Active						
Δ % sedentary time	0.027 (−0.006, 0.059)	0.005 (−0.001, 0.011)	0.000 (−0.004, 0.003)	−0.001 (−0.005, 0.003)	0.081 (−0.048, 0.209)	0.058 (−0.059, 0.176)
Δ % light-intensity physical activity	−0.025 (−0.065, 0.014)	−0.007 (−0.014, 0.000)	−0.001 (−0.005, 0.003)	0.002 (−0.003, 0.007)	−0.060 (−0.217, 0.098)	−0.038 (−0.184, 0.108)
Δ % moderate-to-vigorous physical activity	−0.046 (−0.121, 0.029)	−0.001 (−0.015, 0.013)	0.006 (−0.002, 0.013)	−0.002 (−0.012, 0.008)	−0.243 (−0.534, 0.049)	−0.117 (−0.384, 0.149)
Δ % <10 min sedentary time	−0.070 (−0.158, 0.017)	**−0.018 (−0.034, −0.002)**	0.002 (−0.006, 0.011)	−0.004 (−0.016, 0.007)	0.005 (−0.340, 0.349)	0.009 (−0.305, 0.322)
Δ % ≥10 min sedentary time	**0.026 (0.001- 0.052)**	**0.005 (0.000- 0.010)**	−0.001 (−0.003, 0.002)	0.000 (−0.003, 0.004)	0.059 (−0.047, 0.165)	0.036 (−0.062, 0.133)

Δ, change (follow-up-T1); β = standardized β adjusted for T1 age, sex, ethnicity, father's education, mother's education, study, accelerometer valid days, follow-up duration, T1 metabolic parameter, and T1 % of exposure.
*Additionally adjusted for Δ height.

from this publication, by encompassing a 4-year follow-up in youth transitioning to adolescence.

Similar to our results, Chinapaw et al found that a decrease in moderate-to-vigorous physical activity was unfavorably associated with changes in TG; however, in opposition to their findings,[11] moderate-to-vigorous physical activity was not related with a CMR score in our investigation. These differences may be explained by the greater heterogeneity in our sample due to the fact that we used data from 3 countries, whereas Chinapaw et al used data from 1 country. Most likely, however, discrepancies in the results were due to the fact that they included insulin resistance in their CMR score. Thus, the components of CMR score in our investigation may not fully represent the cardiometabolic health risk. Ideally, we would have also considered WC as one of the main outcomes in the analyses; however, due to the low number of participants with data on WC at T1, we did not include this marker in the analyses to maximize our sample size.

During adolescence, moderate-to-vigorous physical activity declines[18] with prolonged sedentary time.[19] Moderate-to-vigorous physical activity starts to decline from around the age of primary school entry.[20] Our data confirm this trend with a reduction of 20% (ie, 12.8 min/day) in moderate-to-vigorous physical activity from T1 to follow-up. Previous investigations have observed that moderate-to-vigorous physical activity attenuated or eliminated the association between sedentary time and cardiometabolic outcomes in youth.[10,21,22] Consistent with most of the existing evidence,[14,16,17] we also found that a decrease in moderate-to-vigorous physical activity was unfavorably associated with changes in LDL-c and TG, which further demonstrates the importance of increasing or at least maintaining moderate-to-vigorous physical activity levels when transitioning from childhood into adolescence. Interestingly, when the regression analyses were stratified by the initial level of moderate-to-vigorous physical activity (ie, inactive, moderately inactive, moderately active, and active), the associations for the decrease in moderate-to-vigorous physical activity with unfavorable changes in TG disappeared, which can be explained by the lower sample size in each group, and the unfavorable relationship with changes in LDL-c was only significant for the inactive group at T1. This finding suggests that reductions in moderate-to-vigorous physical activity over time can possibly be deleterious exclusively for the ones already presenting lower moderate-to-vigorous physical activity levels.

Cross-sectional data[7,9,23] suggest that the pattern of sedentary time accumulation may be differently associated with cardiometabolic outcomes. Extending these cross-sectional findings, we observed that an increase in ≥10 minutes' sedentary time was unfavorably associated with changes in CMR score, LDL-c, and TG, whereas no relationship was found for the bouts <10 minutes' sedentary time in the overall sample. Chinapaw et al found an increase in prolonged sedentary time (ie, ≥10 minutes) to be favorably associated with changes in CMR score,[11] thus contradicting our results. However, the study by Chinapaw et al included different cardiometabolic risk factors into their CMR score (ie, TG, total cholesterol/HDL cholesterol ratio, homoeostatic model assessment of insulin resistance, systolic blood pressure, and WC), which may explain the differences between our findings and the ones from this investigation.[11]

Other longitudinal investigations have reported that total sedentary time is unrelated with cardiometabolic outcomes,[15,17,24] but these investigations have considered shorter follow-up periods compared with the 4-year follow-up in our investigation. A review of longitudinal investigations on this topic considered a follow-up of <2 years as an exclusion criteria.[25] If the magnitude of increase in sedentary time (ie, 28.2 min/d) observed in a previous investigation with 1-year follow-up[15,17,24] is extrapolated to reflect a 4-year follow-up period, the increase in sedentary time (ie, 112.8 min/d) would be similar to the increase in sedentary time observed in our study (118.1 min/d). Thus, the differences in the findings for the longitudinal associations of sedentary time patterns with cardiometabolic outcomes between our and prior investigations may simply be due to the follow-up period.

With one exception,[11] previous investigations did not account for specific sedentary time accumulation patterns, such as differentiating between shorter and longer bouts of sedentary time, which are important features considering that the manner in which sedentary time is accumulated may influence the association with health outcomes.[6,7] Väistö et al found unfavorable longitudinal associations of total sedentary time with individual cardiometabolic outcomes,[14] whereas our results suggest that mostly prolonged bouts of sedentary time are detrimentally associated with cardiometabolic outcomes in youth. This may be explained by non-prolonged sedentary time bouts being likely associated with greater levels of physical activity. There is evidence showing that breaks in sedentary time are as much a metric of frequency of physical activity as that of sedentary time,[26] and a greater time spent in non-prolonged sedentary time bouts suggests a greater frequency of sedentary time breaks, and, therefore, potentially greater physical activity, especially light-intensity physical activity. There are other metrics that better represent the extent to which sedentary time is prolonged or interrupted (ie, fragmentation index),[27] but due to the ICAD data, we were not able to use this kind of approach.

We found an unfavorable association between a decrease in light-intensity physical activity and change in CMR score. Investigations using linear regression models showed that light-intensity physical activity may be associated with favorable cardiometabolic outcomes, suggesting that light-intensity physical activity may be an effective substitute for sedentary time when aiming to improve cardiometabolic health.[7,28] However, these linear regression models may not work with "intermediate intensities" due to collinearity issues, and different statistical approaches have shown no relationship for light-intensity physical activity with cardiometabolic outcomes.[29,30] In fact, no associations for the change in light-intensity physical activity with changes in individual cardiometabolic outcomes were found in our

investigation for the overall sample ($P \geq .05$); thus, the impact of possibly displacing sedentary time with light-intensity physical activity may not be as effective on improving cardiometabolic outcomes compared with displacing sedentary time with moderate-to-vigorous physical activity in the long term.[14]

The small effect-sizes and the lack of a clear explanatory mechanism to explain the different findings observed for overall sedentary time and prolonged sedentary time when considering the distinct cardiometabolic risk factors justify future research to better understand whether these results can be replicated in other samples or if they are a result of statistical chance. Future longitudinal investigations should take into account that different activity levels at the beginning of the follow-up period can modify the relationship between changes in some of these sensor-based features with the individual cardiometabolic risk factors over time.

Even though our sample consisted of multicenter data, the majority of participants were white (92%) and from the ALSPAC, which limits the generalizability to other populations. Another factor that must be presented as a limitation is the age of the data. There is evidence suggesting that the inverse associations for moderate-to-vigorous physical activity with overall cardiometabolic risk and dyslipidemia, and the positive association for sedentary time with overall cardiometabolic risk are explained by alterations in body fat content.[31] We did not include a measure of body fat, as WC was only available for a reduced number of participants, and thus this must be recognized as a limitation.

The use of relatively long epochs (60 seconds) may have limited our ability to detect the relatively common intermittent bouts of physical activity among youth, thus possibly underestimating youth's moderate-to-vigorous physical activity. Youth, especially the ones from younger ages, perform quick and spontaneous changes in the intensity of their movement when they are playing. This means that if we choose a 60-second epoch, we will have an average count value for the entire minute (eg, light-intensity physical activity), that can either reflect a situation in which the 60 seconds were actually spent in light-intensity physical activity or erroneously another possible scenario in which 10 seconds were spent in moderate-to-vigorous physical activity followed by 40 seconds of sedentary time, and 10 seconds more of moderate-to-vigorous physical activity (eg, playing soccer). In our investigation, by using a 60-second epoch, we might have underestimated moderate-to-vigorous physical activity while overestimating light-intensity physical activity to a greater extent in T1 than at the 4-year follow-up when the children were adolescents and potentially had a less spontaneous physical activity profile. Consequently, the real differences in moderate-to-vigorous physical activity over time could have been greater than the ones found, which could have further strengthened the associations between the decrease in moderate-to-vigorous physical activity and the unfavorable changes in cardiometabolic risk factors.

In opposition, the allowance of 2 minutes of non-zero interruptions in the non-wear time criteria could potentially underestimate total sedentary time. When using accelerometer-based data, it is important to account for the type of activities performed during the non-wear time periods. However, we are not dealing with original data but instead data that came from a large repository in which some criteria (ie, specified in the methods) were used to standardize the data. We were not provided with the information on what the participants were doing in the non-wear time Finally, with the 60 minutes of zeros to define non-wear time, we should acknowledge that it makes a difference whether youth took off the accelerometer 1 hour before bedtime or 1 hour during a swimming class. However, all these limitations are constraints of using ICAD data. Beyond the limitations associated with accelerometry, a measure of maturational status was not available to control for the potential confounding effect of maturation changes on cardiometabolic outcomes. Thus, although we controlled for age, it is well known that during the pubertal years there is large heterogeneity in youth of the same age in terms of biological maturation.[32]

Lastly, the ICAD database does not include sleep data. Thus, we were unable to assess all the domains of the 24-hour activity model (ie, sleep, sedentary time, light-intensity physical activity, and moderate-to-vigorous physical activity) using compositional analysis, which would have allowed us to understand the impact of changing one behavior while taking into account all the other behaviors.

Our results highlight the importance of encouraging moderate-to-vigorous physical activity and reducing prolonged sedentary time as a means of improving cardiometabolic outcomes in youth during the transition into adolescence. Also, our data highlight the importance of the initial activity level of youth, suggesting that distinct activity profiles may alter the potential for some behavioral domains to change the cardiometabolic risk over time. ■

We thank all participants and funders of the original studies that contributed data to ICAD. We gratefully acknowledge the past contributions of Prof Chris Riddoch, Prof Ken Judge, Prof Ashley Cooper, and Dr Pippa Griew to the development of ICAD. The list of ICAD Collaborators is available in the ***Appendix*** *(available at www.jpeds.com).*

Submitted for publication Jan 9, 2020; last revision received Jun 2, 2020; accepted Jun 5, 2020.

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Data Statement

Data sharing statement available at www.jpeds.com.

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Appendix

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