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ORIGINAL RESEARCH

Associations of Physical Activity and Sedentary Time From Childhood to Adolescence With Cognition in Adolescence: The PANIC Study

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Purpose: Investigate the associations of cumulative exposure to physical activity (PA), sedentary time (ST), and screen time from childhood to adolescence over an 8-year follow-up with cognition in adolescence. ***Methods:*** All together, 260 adolescents (136 boys) who were 15–17 y at 8-y follow-up were analyzed. PA and ST were assessed using an Actiheart device, and different types of PA, nonscreen-based ST, and screen time were assessed by a questionnaire at baseline, 2-y and 8-y examinations. Cognition was assessed using CogState tests at 8-year examinations. ***Results:*** Self-reported cumulative unsupervised PA from childhood to adolescence was inversely associated with accuracy in working memory task (standardized regression coefficient, $\beta = -0.127$; 95% confidence interval [CI], −0.247 to −0.008) in adolescence. Self-reported nonscreen-based ST was inversely associated with reaction time ($\beta = -0.176$; 95% CI, −0.299 to −0.053) and accuracy ($\beta = -0.149$; 95% CI, −0.274 to −0.024) in working memory tasks. Self-reported screen time was inversely associated with reaction time ($\beta = -0.194$; 95% CI, −0.316 to −0.071) and accuracy ($\beta = -0.233$; 95% CI, −0.355 to −0.112) in both working memory tasks and directly associated with overall cognition ($\beta = 0.187$; 95% CI, 0.070 to 0.305). ***Conclusion:*** Accumulating less unsupervised PA and more screen time from childhood to adolescence was associated with better cognition in adolescence.

Keywords: accelerometer, questionnaire, CogState, screen time

Key Points

- Higher levels of self-reported cumulative unsupervised physical activity and lower levels of self-reported cumulative screen time from childhood to adolescence were associated with poorer cognition in adolescence.
- Device-assessed cumulative physical activity or sedentary time from childhood to adolescence was not related to cognition in adolescence.
- The associations of physical activity and sedentary time from childhood to adolescence with cognition in adolescence depend on the type and assessment method of physical activity and sedentary time.

Insufficient levels of physical activity (PA) have been associated with poorer cognition in children[1,2] and adults.[3] Cognition comprises high-order mental processes, such as executive functions, attention, working memory, and associative learning, which are typically assessed through standardized cognitive tests or academic performance.[4] Childhood and adolescence are critical periods for cognitive and brain development,[5] yet PA, particularly moderate to vigorous PA (MVPA), tends to decrease during this period, whereas sedentary time (ST) and screen time tend to increase.[6–8] The effects of PA, along with prolonged ST and screen time, on cognition may require prolonged cumulative exposure to low levels of PA and high levels of ST and screen time, often beginning in childhood.[9] Despite this, no evidence exists on the associations of cumulative exposure to PA, ST, and screen time from childhood to adolescence with cognition in adolescence.[10] Moreover, little is known about the potential modifying role of sex in the association between PA and cognition and the associations of

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PA from childhood to adolescence at different intensities with cognition in adolescents.[10,11]

PA, ST, and screen time may influence cognition in adolescents by releasing neurotrophic factors, altering brain structure and function, and affecting sleep, stress, and anxiety.[12] Nonetheless, the available cross-sectional evidence regarding the relationship between PA and cognition in adolescents remains mixed. Some cross-sectional studies suggest that device-assessed[11,13] and self-reported PA[14,15] are directly associated with cognition in adolescents, whereas a previous study[16] suggests a weak, if any, association between self-reported PA and cognition in children and adolescents. Furthermore, the respective evidence from longitudinal studies of adolescents is limited and inconsistent.[17,18] The variability in findings may be partly due to differences in PA intensity and context, as well as in the methods used to measure PA.[16,18] Consequently, further research that incorporates both self-reported and device-assessed PA is essential for a clearer understanding of how the intensity and context of PA influence the relationship between PA and cognitive function in adolescence.

The current evidence on the relationship between ST and cognition is also mixed, lacking device-assessed ST measurements and contextualization of sedentary activities. Longitudinal studies indicate that more ST is associated with poorer working memory in childhood and adolescence among boys[17] and girls.[19] Conversely, Wickel[18] reported that more ST in childhood and adolescence was associated with better inhibition, working memory, and overall cognition in adolescence. However, cross-sectional studies found no associations between self-reported ST and cognition in adolescents.[14,15]

The potential moderating role of sex may result from the differing levels of physical, psychological, and brain development observed in boys and girls.[20,21] However, evidence for the modifying role of sex on the association of PA, ST, and screen time with cognition, as well as the associations of PA at different intensities with cognition in adolescents, remains unclear and limited.[11,13–16,18] The associations of PA at different intensities with cognition in adolescents may differ, as MVPA and vigorous physical activity (VPA) potentially activate mechanisms that improve cognitive functions—such as greater increases in brain-derived neurotrophic factor (BDNF), lactate, and neurovascular responses—more than light physical activity (LPA).[22–24] Identifying the potential moderating role of sex on the associations between PA and cognition, along with the associations of PA at varying intensities with cognition in adolescents, may assist in individualizing PA guidelines.

Most significantly, no studies have investigated the associations of cumulative exposure to PA, ST, and screen time from childhood to adolescence with cognition in adolescence.[17–19] Therefore, we investigated the associations of cumulative PA, ST, and screen time from ages 8 to 16 years with cognition at age 16 using device-assessed and self-report measures. We also examined whether sex modifies these associations and investigated how different intensities of PA from childhood to adolescence are associated with cognition in adolescence.

Methods

Study Design and Participants

The present analyses are based on data from the Physical Activity and Nutrition in Children (PANIC) study, which is an 8-year PA and dietary intervention study in a general population of children followed up until adolescence. For the present analysis, we treated the participants as a prospective cohort as the CogState cognitive test battery was administered only during the 8-year follow-up. The Research Ethics Committee approved the study protocol in 2006 (Statement 69/2006) and 2015 (Statement 422/2015). Written informed consent was acquired from the parent or caregiver of each child, and every child provided assent to participation. The PANIC study was carried out following the principles of the Declaration of Helsinki, revised in 2008. The funding sources had no role in collecting, analyzing, or interpreting the data or approving publications.

We invited 736 children aged 6–9 years who started the first grade in 16 primary schools of Kuopio (Figure 1). All together, 512 children (264 boys, 248 girls), who accounted for 70% of those invited, participated in the baseline examinations. The participants did not differ in age, sex, or body mass index (BMI) standard deviation score from all children who started the first grade in the city of Kuopio. We excluded 6 children from the study at baseline because of physical disabilities that could hamper intervention participation or lack of time or motivation to attend the study. As a result, data from 506 participants were used in the baseline statistical analyses. All together, 437 children (223 boys, 214 girls) who participated in the baseline examinations attended the 2-year follow-up examinations and represented 85% of those attending the baseline examinations.

Finally, 277 adolescents (151 boys, 126 girls) participated in the 8-year follow-up examinations and represented 54% of those attending the baseline examinations. Those who participated in the 8-year follow-up examinations did not differ in age, BMI-standard deviation score, the distribution of sex, or study groups at baseline compared with those who dropped out. However, at baseline, those who participated in the 8-year follow-up examinations had higher levels of device-assessed MVPA (mean difference [MD] = 15.6 min; 95% confidence interval [CI], 3.9 to 27.3) and VPA (MD = 5.6 min; 95% CI, 1.5 to 9.7) and self-reported organized exercise (MD = 3.4 min; 95% CI, 0.4 to 6.3) and had less self-reported nonscreen-based ST (MD = −17.1 min; 95% CI, −31.2 to −2.8) compared with those who dropped out. A total of 17 adolescents (15 boys; 2 girls) were excluded from the statistical analyses because they had no valid data on cumulative self-reported PA (n = 1), ST (n = 1), screen time (n = 2), or cognition (n = 13) at the 8-year follow-up examinations. Therefore, 260 adolescents (136 boys; 124 girls) aged 15.8 (0.4) years from the 8-year follow-up examinations were used for the statistical analyses to explore the associations of self-reported cumulative PA, ST, and screen time with cognition. The included 136 boys had more advanced pubertal status ($P = .040$) and lower levels of total PA ($P = .043$) and self-reported unsupervised PA (ie, all bouts of PA that do not take place during organized sessions; $P = .013$) than the 15 excluded boys. The 124 included girls had less self-reported screen time ($P = .044$) than the 2 excluded girls. All together, 23 participants (13 boys; 10 girls) had no data on pubertal status. We included these participants in the statistical analyses because pubertal status was used only as a covariate. We replaced the missing data on pubertal status by multiple imputation using 10 imputed data sets. A total of 161 participants (88 boys; 73 girls) were included in the intervention group, and 99 were in the control group (48 boys; 51 girls). Of the 260 participants, 171 (88 boys; 83 girls) had data on device-assessed PA and ST. These 171 participants were included in the statistical analyses to explore the associations of device-assessed cumulative PA and ST with cognition. Of the 171 participants, a total of 105 participants (56 boys; 49 girls) were included in the intervention group, and 66 were in the control group (32 boys; 34 girls).

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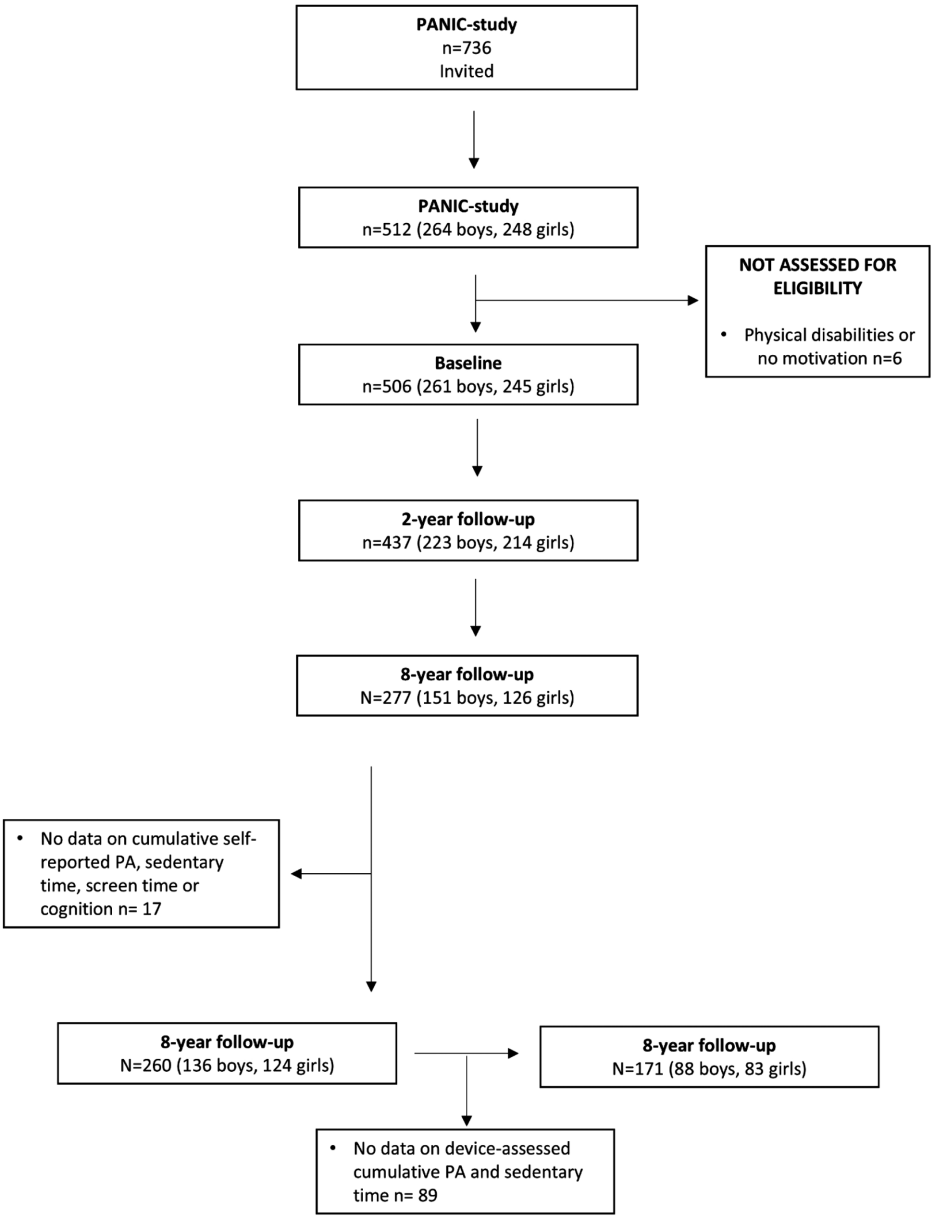


Figure 1 — Study flow diagram. PA indicates physical activity; PANIC, Physical Activity and Nutrition in Children.

Assessment of Body Size and Composition and Pubertal Status at 8-Year Follow-Up

Two repeated measurements of body mass were carried out by the InBody 720 bioelectrical impedance device (Biospace) to an accuracy of 0.1 kg (Table 1). The mean of these 2 values was used in the statistical analyses. Body stature was measured 3 times with the adolescents standing in the Frankfurt plane without shoes using a wall-mounted stadiometer to an accuracy of 0.1 cm. The mean of the nearest 2 values was used in the statistical analyses. BMI was calculated by dividing body mass (in kilograms) by stature squared (in meter square), and BMI-standard deviation score was calculated using the Finnish references.[25] Body fat percentage was measured using the Lunar dual-energy X-ray absorptiometry device (GE Medical Systems). A research physician assessed pubertal status using the 5-stage scale described by Tanner.[26]

Assessment of Self-Reported Physical Activity, Nonscreen-Based Sedentary Time and Screen Time at Baseline, 2-Year Follow-Up, and 8-Year Follow-Up

Self-reported PA, nonscreen-based ST, and screen time were assessed using the PANIC Physical Activity Questionnaire, administered by parents at baseline and at the 2-year follow-up. At the 8-year follow-up, the adolescents completed the questionnaire themselves (Table 1). The types of self-reported PA included unsupervised PA (ie, all bouts of PA that do not take place during organized sessions), organized sports (ie, participation in organized sports training), and all organized exercise (eg, sports, afterschool exercise clubs, and other supervised/coached exercise hobbies).

The frequency of each type of self-reported PA, expressed in sessions per week, and the duration of a single session of each type

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Table 1 Measures in Different PANIC Study Stages

	PANIC study stages		
	Baseline	2-y follow-up	8-y follow-up
Measures			
Body size and composition and pubertal status			X
Self-reported PA, ST, and screen time	X	X	X
Device-assessed PA and ST	X	X	X
Self-reported cumulative PA, ST, and screen time			X
Device-assessed cumulative PA and ST			X
Cognitive functions			
RCPM	X		
CogState			X

Abbreviations: PA, physical activity; PANIC, Physical Activity and Nutrition in Children; RCPM, Raven's Colored Progressive Matrices; ST, sedentary time.

of PA, expressed in hours per session to an accuracy of half an hour, were asked. The amount of each type of self-reported PA was calculated by multiplying the frequency of each PA per week and the duration of a single session of PA, weighted by the number of weekdays and weekend days and reported in minutes per day. The amount of total self-reported PA was calculated by summing the amounts of each PA type and was also reported in minutes per day. All children at baseline, 2-year follow-up, and 8-year follow-up had 90 minutes of physical education per week, which was included in the total self-reported PA.

The average daily duration for each sedentary behavior activity was asked. Nonscreen-based ST was calculated by summing up the time spent listening to music, playing a musical instrument, reading, writing, drawing, doing arts and crafts, playing board games, and resting and was reported in minutes per day. Screen time was calculated by summing the time spent watching television and videos, using a computer, playing video games, using a mobile phone, and playing mobile games, also reported in minutes per day.

Sedentary behavior and PA questionnaires with a similar structure to the PANIC Physical Activity Questionnaire, such as the Youth Physical Activity questionnaire, have shown good short-term repeatability over 4 days with an intraclass correlation of .86 to .92.[27]

Assessment of Device-Assessed Physical Activity and Sedentary Time at Baseline, 2-Year Follow-Up, and 8-Year Follow-Up

PA and ST were assessed using a combined heart rate and body movement sensor Actiheart (CamNtech Ltd) for a minimum of 4 consecutive days and analyzed in 60-second epochs at baseline, 2-year follow-up, and 8-year follow-up[28] (Table 1). The combined heart rate and movement sensor was attached to the child's chest with 2 standard electrocardiographic electrodes (Bio Protech Inc). The children were asked to wear the monitor continuously, including sleep and water-based activities. VPA was defined as PAs at ≥7 standard metabolic equivalents (MET), MVPA at ≥ 4 METs, LPA at >1.5 and ≤4.0 METs, and ST at ≤1.5 METs, sleep excluded.[29] These cut-off values are frequently used in studies examining PA among children and adolescents.[30] Total physical activity (TPA) was calculated by summing LPA and MVPA (LPA + MVPA). PA data were defined to be valid if there was a minimum of 48 hours of activity recording in weekday and weekend day hours that included at least 12 hours from morning (3–9 AM), midday (9 AM–3 PM), afternoon (3–9 PM), and night (9 PM–3 AM) to avoid potential bias from overrepresenting specific times and activities of the days.

Computation of the Measures of Device-Assessed and Self-Reported Cumulative PA, Sedentary Time, and Screen Time

We used the area under the curve approach for device-assessed and self-reported PA, ST, and screen time at baseline, 2-year follow-up, and 8-year follow-up to utilize all of the data collected over the 8-year period and describe the long-term exposure to PA, ST, and screen time from childhood to adolescence (Table 1). The area under the curve method offers advantages over other longitudinal analysis models by measuring the long-term cumulative exposure, rather than solely analyzing changes in PA, ST, and screen time, which can lead to biased causal-effect estimates.[31] We estimated participant-specific curves for PA, ST, and screen time using an additive linear mixed model with cubic splines, which models nonlinear effect as a random effect (see Supplementary Material S1 [available online] for details).[32,33]

Assessment of Cognition at Baseline and 8-Year Follow-Up

Nonverbal reasoning was assessed using the Raven's Colored Progressive Matrices (RCPM)[34] at baseline and was used only as a covariate in the statistical analyses (Table 1). The RCPM represents high-order executive functioning involving inhibition, working memory, and mental flexibility (see Supplementary Material S1 [available online] for details).[34]

The CogState test battery (CogState Ltd) was utilized to assess cognitive function during the 8-year follow-up examinations (Table 1). Psychomotor function (reaction time) was assessed using the Detection Test, attention (reaction time and accuracy) was measured with the Identification Test, working memory was evaluated through the 1-back task and the 2-back task (reaction time and accuracy), and paired-associate learning (errors) was examined using the continuous paired associate learning task on a desktop personal computer (see Supplementary Material S3 [available online] for details).[35] Overall cognition was calculated by summing standardized scores across all CogState tests and dividing it by the number of CogState

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test variables. Lower scores on reaction time outcomes and the number of errors indicated better performance, and higher scores on accuracy outcomes and overall cognition also reflected better performance. The construct validity of the CogState test battery has been demonstrated in a large group of healthy adults and children,[36] and the test has been found to be applicable in different cultures as there are only minimal language requirements to undertake the tests.[37]

Statistical Analyses

All statistical analyses were carried out using the SPSS statistical analysis software (version 27.0). The normality of the distributions of the variables was tested with the Kolmogorov–Smirnov test and visually from histograms. Differences in descriptive characteristics, PA, ST, and screen time between sexes were analyzed by the Student *t* test, the Mann–Whitney *U* test, or the chi-square test. The associations of cumulative PA, ST, and screen time with cognition were investigated using linear regression analyses adjusted for age, sex, and parental education at 8-year follow-up and the RCPM score at baseline. The data were adjusted for parental education as it has been associated directly with cognition[38] and PA.[39] Age, sex, parental education, and the RCPM score were entered into the linear regression models in the first step, and the measures of cumulative PA, ST, and screen time were entered separately into the models in the second step. The standardized regression coefficients β and their 95% CIs were reported for each factor. We considered standardized regression coefficients between 0.10 and 0.29 as small, between 0.30 and 0.49 as medium, and ≥ 0.50 as large effect sizes.[40] Differences and associations with P values ≤ .05 were considered statistically significant. The data were corrected for multiple comparisons using the Benjamini–Hochberg false discovery rate (FDR) with an FDR value of 0.2 ($FDR_{0.2}$). If the associations of cumulative PA, ST, and screen time with cognition were statistically significant after adjustment for sex, age, and parental education at 8-year follow-up and the RCPM score at baseline, the data were additionally adjusted for body fat percentage and pubertal status at 8-year follow-up and study group. Body fat percentage, pubertal status, and study group were entered into the models separately to evaluate their independent influence on the associations. Analyses by sex were conducted similarly, except for not using sex as a covariate. Finally, we investigated whether sex modified the associations of cumulative PA, ST, and screen time with cognition using general linear models.

Results

Characteristics of Participants

Boys were heavier and taller and had a lower body fat percentage and their parents had a higher level of education than girls' parents at the 8-year follow-up. However, girls had more advanced pubertal status than boys (Table 2). Boys accumulated more self-reported total PA, unsupervised PA, organized sports, and screen time and less self-reported nonscreen-based ST than girls. In addition, boys accumulated more device-assessed MVPA and VPA than girls. Boys had shorter reaction times on the Detection Test, 1-back task, and 2-back task, suggesting better psychomotor function and working memory than girls. However, boys demonstrated lower accuracy in the Identification Test and made more errors in the continuous paired associate learning task, indicating poorer attention and paired-associate learning compared with girls.

Associations of Cumulative Physical Activity and Sedentary Time With Cognition

Higher levels of self-reported cumulative unsupervised PA were associated with poorer accuracy in the 2-back task after adjustment for sex, age, and parental education at 8-year follow-up and the RCPM score at baseline (Table 3), but the association was not statistically significant after $FDR_{0.2}$ correction. Higher levels of self-reported cumulative nonscreen-based ST were associated with better reaction time in the 2-back task and poorer accuracy in the 1-back task (Table 3). Higher levels of self-reported cumulative screen time were associated with better reaction time in the 1-back task and 2-back task and better overall cognition (Table 3). These associations remained statistically significant after $FDR_{0.2}$ correction. Further adjustment for body fat percentage and pubertal status at 8-year follow-up or study group did not materially change associations. Other self-reported measures of PA and device-assessed cumulative PA and ST were not associated with cognition (Table 4).

Associations of Cumulative Physical Activity and Sedentary Time With Cognition in Boys

Higher levels of self-reported cumulative unsupervised PA were associated with poorer accuracy in the 2-back task in boys after adjustment for age and parental education at 8-year follow-up and the RCPM score at baseline (Table 5). Higher levels of self-reported cumulative organized sports were associated with better reaction time in the 1-back task. Higher levels of self-reported cumulative nonscreen-based ST were associated with better reaction time in the 2-back task. Higher levels of self-reported cumulative screen time were associated with better reaction time in the 2-back task. Device-assessed cumulative PA and ST were not associated with cognition in boys (Table 6). All of these associations remained after $FDR_{0.2}$ correction, except the association between higher levels of cumulative organized sports participation and better reaction time in the 1-back task. All of these associations also remained materially unchanged after further adjustment for body fat percentage, pubertal status, or study group.

Associations of Cumulative Physical Activity and Sedentary Time With Cognition in Girls

Higher levels of self-reported cumulative screen time were associated with better reaction times in the 1-back task in girls (Table 7). Higher levels of self-reported cumulative screen time were associated with better reaction times in the 2-back task and better overall cognition. Higher levels of device-assessed cumulative LPA were associated with better accuracy in the 1-back task (Table 8). All of these associations remained after $FDR_{0.2}$ correction and after further adjustment for body fat percentage, pubertal status, or study group.

Sex Differences in the Associations of Cumulative Physical Activity and Sedentary Time With Cognition

Higher levels of device-assessed cumulative LPA were associated with better accuracy in the 1-back task test in girls but not in boys ($P = .025$ for interaction). The associations between device-assessed cumulative LPA and reaction time in the 2-back task in

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Table 2 Descriptive Characteristics of All 260 Participants at 8-Year Follow-Up

	All adolescents (N = 260)	Boys (n = 136)	Girls (n = 124)	*P*
Background characteristics				
Age, y	15.8 (0.4)	15.8 (0.4)	15.8 (0.4)	.349
Body mass, kg	62.0 (12.5)	65.7 (13.9)	57.9 (9.2)	**<.001**
Body stature, cm	171.3 (8.6)	176.4 (7.4)	165.7 (5.8)	**<.001**
Body mass index—SD score	0.0 (1.0)	–0.1 (1.1)	0.1 (0.9)	.262
Body fat percentage, %	22.7 (10.2)	17.1 (9.4)	28.9 (7.1)	**<.001**
Pubertal status, n (%)[†]				**.004**
Stage 3	19 (8.0)	15 (12.2)	4 (3.5)	
Stage 4	137 (57.8)	76 (61.8)	61 (53.5)	
Stage 5	81 (34.2)	32 (26.0)	49 (43.0)	
Parental education, %				**.026**
Vocational school or less	13.4	13.2	13.7	
Polytechnic	40.4	33.1	48.4	
University degree	46.2	53.7	37.9	
Self-reported PA and sedentary behavior				
TPA, min/d	147.9 (106.3)	172.6 (126.5)	120.9 (69.5)	**<.001**
Organized sports, min/d	26.8 (35.0)	32.6 (39.9)	20.5 (28.9)	**.033**
All organized exercise, min/d	33.9 (42.6)	40.8 (49.5)	26.3 (31.9)	.221
Unsupervised PA, min/d	86.1 (85.2)	101.1 (97.4)	69.7 (66.0)	**.004**
Nonscreen-based ST, min/d	192.1 (162.5)	154.9 (130.4)	232 (183.8)	**<.001**
Screen time, min/d	345.1 (191.6)	375.9 (208.6)	311.3 (165.4)	**.002**
Device-assessed PA and ST				
TPA,[§] min/d	367.0 (133)	376.6 (133.8)	352.4 (132.1)	.368
LPA,[§] min/d	319.9 (113.3)	323.1 (111.9)	315.1 (116.6)	.727
MVPA,[§] min/d	47.1 (36.6)	53.6 (39.8)	37.4 (28.8)	**.044**
VPA,[§] min/d	11.4 (14.4)	14.7 (16.1)	6.5 (9.6)	**.013**
ST,[§] min/d	607 (134.7)	603.3 (137.1)	613.5 (132.4)	.709
Cognition				
Overall cognition (standardized score)	0.00 (0.51)	0.02 (0.49)	–0.01 (0.52)	.447
Detection test (log10 ms)[#]	2.50 (0.06)	2.49 (0.05)	2.51 (0.06)	**.031**
Identification task (log10 ms)[#]	2.68 (0.06)	2.68 (0.06)	2.68 (0.05)	.840
1-back task (log10 ms)[#]	2.87 (0.10)	2.85 (0.09)	2.89 (0.10)	**.004**
2-back task (log10 ms)[#]	2.96 (0.11)	2.93 (0.10)	2.99 (0.10)	**<.001**
Identification task (arcsine proportion correct)[¤]	1.41 (0.15)	1.38 (0.16)	1.43 (0.13)	**.007**
1-back task (arcsine proportion correct)[¤]	1.39 (0.15)	1.38 (0.14)	1.39 (0.17)	.217
2-back task (arcsine proportion correct)[¤]	1.27 (0.18)	1.28 (0.17)	1.25 (0.18)	.208
Continuous paired associate learning task (errors)	31 (33)	38 (38)	23 (24)	**<.001**

Abbreviations: LPA, light physical activity; MVPA, moderate to vigorous physical activity; PA, physical activity; ST, sedentary time; TPA total physical activity; VPA, vigorous physical activity. Note: The data are mean (SD) and corresponding *P* values from the Student *t* test for independent samples for continuous variables with normal distributions, from the Mann–Whitney *U* test for continuous variables with skewed distributions, and from the chi-square test for categorical variables. *P* values refer to statistical significance for differences between boys and girls, with significant values bolded.

[†]237 adolescents (123 boys, 114 girls). [§]103 adolescents (62 boys; 41 girls). [#]Mean of the log10 transformed reaction times for correct responses, lower score = faster responses, better performance. [¤]Arcsine transformation of the square root of the proportion of correct responses, higher score = higher accuracy, better performance.

boys and girls ($P = .048$ for interaction) and between MVPA and accuracy in the Identification Test in boys and girls ($P = .047$ for interaction) were different (see Table S1 in Supplementary Material S2 [available online]). However, these associations between PA and cognition were statistically nonsignificant. Higher levels of self-reported cumulative screen time were associated with better reaction times in the 1-back task in girls but not in boys ($P = .008$ for interaction; see Table S2 in Supplementary Material S2 [available online]). No other sex differences in the associations of cumulative PA or ST with cognition were observed (see Tables S1 and S2 in Supplementary Material S2 [available online]).

Discussion

To the best of the authors' knowledge, this study is the first to investigate the associations of cumulative exposure to PA, ST, and screen time from childhood to adolescence with cognition in

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Table 3 Associations of Self-Reported Cumulative PA, ST, and Screen Time With Measures of Cognition in All 260 Participants

	Psychomotor function	Attention		Working memory				Paired-associate learning	Overall cognition
	Detection test (reaction time, lower = better)	Identification test (reaction time, lower = better)	Identification test (accuracy, higher = better)	1-back task (reaction time, lower = better)	1-back task (accuracy, higher = better)	2-back task (reaction time, lower = better)	2-back task (accuracy, higher = better)	Continuous paired associate learning test (errors, lower = better)	Composite score (higher = better)
	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)
Total PA	–0.075 (–0.198 to 0.048)	–0.069 (–0.197 to 0.059)	–0.001 (–0.129 to 0.127)	–0.036 (–0.162 to 0.090)	0.089 (–0.037 to 0.215)	0.019 (–0.107 to 0.145)	–0.079 (–0.200 to 0.042)	0.045 (–0.077 to 0.166)	–0.007 (–0.128 to 0.114)
All organized exercise	–0.076 (–0.195 to 0.043)	–0.120 (–0.243 to 0.003)	0.005 (–0.119 to 0.129)	–0.071 (–0.192 to 0.050)	0.043 (–0.080 to 0.165)	–0.027 (–0.148 to 0.095)	0.002 (–0.115 to 0.119)	0.031 (–0.087 to 0.148)	0.048 (–0.069 to 0.164)
Unsupervised PA	–0.038 (–0.160 to 0.085)	–0.002 (–0.129 to 0.126)	–0.005 (–0.132 to 0.123)	0.002 (–0.123 to 0.127	0.078 (–0.048 to 0.204	0.040 (–0.085 to 0.165)	**–0.127 (–0.247 to –0.008)**	0.043 (–0.078 to 0.164)	–0.054 (–0.174 to 0.067)
Organized sports	–0.071 (–0.190 to 0.048)	–0.121 (–0.244 to 0.002)	–0.018 (–0.142 to 0.106)	–0.081 (–0.202 to 0.040)	0.037 (–0.086 to 0.159)	–0.031 (–0.153 to 0.091)	0.027 (–0.090 to 0.144)	0.035 (–0.083 to 0.152)	0.047 (–0.070 to 0.164)
Nonscreen-based ST	–0.030 (–0.153 to 0.092)	–0.121 (–0.248 to 0.006)	0.022 (–0.106 to 0.149)	–0.114 (–0.239 to 0.010)	**–0.149 (–0.274 to –0.024)**	**–0.176 (–0.299 to –0.053)**	–0.059 (–0.179 to –0.061)	0.035 (–0.086 to 0.156)	0.053 (–0.067 to 0.173)
Screen time	–0.043 (–0.165 to 0.079)	–0.094 (–0.221 to 0.032)	0.036 (–0.091 to 0.163)	**–0.194 (–0.316 to –0.071)**	0.037 (–0.088 to 0.163)	**–0.233 (–0.355 to –0.112)**	0.029 (–0.091 to 0.149)	–0.028 (–0.148 to 0.092)	**0.187 (0.070 to 0.305)**

Abbreviations: CI, confidence interval; PA, physical activity; ST, sedentary time. Note: The data are standardized regression coefficients β with their 95% CIs from linear regression analyses adjusted for sex, age, and parental education at 8-year follow-up and the Raven's Colored Progressive Matrices score at baseline. Overall cognition was calculated by summing standardized scores across all CogState tests and dividing it by the number of CogState test variables. For reaction time outcomes, more negative β values indicate better performance (faster responses) with higher levels of the exposure. For accuracy and overall cognition, more positive β values indicate better performance. Statistically significant results have been bolded.

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Table 4 Associations of Device-Assessed Cumulative PA and ST With Measures of Cognition in 171 Participants

	Psychomotor function	Attention		Working memory				Paired-associate learning	Overall cognition
	Detection test (reaction time, lower = better)	Identification test (reaction time, lower = better)	Identification test (accuracy, higher = better)	1-back task (reaction time, lower = better)	1-back task (accuracy, higher = better)	2-back task (reaction time, lower = better)	2-back task (accuracy, higher = better)	Continuous paired associate learning test (errors, lower = better)	Composite score (higher = better)
	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)
TPA	–0.092 (–0.267 to 0.083)	–0.086 (–0.271 to 0.098)	0.005 (–0.180 to 0.190	–0.035 (–0.215 to 0.146)	0.035 (–0.146 to 0.216)	0.057 (–0.125 to 0.240)	–0.140 (–0.312 to 0.033)	–0.026 (–0.201 to 0.150)	–0.017 (–0.193 to 0.158)
LPA	–0.027 (–0.186 to 0.131)	0.059 (–0.108 to 0.227)	–0.047 (–0.214 to 0.121)	0.046 (–0.117 to 0.209)	0.077 (–0.086 to 0.241)	0.038 (–0.127 to 0.203)	0.000 (–0.158 to 0.157)	0.098 (–0.060 to 0.257	–0.061 (–0.220 to 0.098
MVPA	–0.067 (–0.268 to 0.133)	–0.066 (–0.278 to 0.145)	–0.017 (–0.228 to 0.195)	–0.176 (–0.381 to 0.029	0.084 (–0.123 to 0.291	–0.091 (–0.299 to 0.118)	0.144 (–0.054 to 0.342	–0.075 (–0.276 to 0.126	0.157 (–0.043 to 0.356)
VPA	–0.049 (–0.251 to 0.153)	–0.132 (–0.344 to 0.081)	0.023 (–0.190 to 0.236)	–0.073 (–0.281 to 0.135	0.079 (–0.129 to 0.287)	–0.020 (–0.230 to 0.190)	0.109 (–0.090 to 0.309)	0.052 (–0.150 to 0.255)	0.074 (–0.128 to 0.276)
ST	0.043 (–0.104 to 0.191)	–0.028 (–0.184 to 0.127)	0.016 (–0.139 to 0.171)	–0.027 (–0.179 to 0.124)	–0.032 (–0.184 to 0.120)	–0.049 (–0.202 to 0.104)	–0.064 (–0.209 to 0.082)	–0.047 (–0.195 to 0.100)	0.021 (–0.127 to 0.168)

Abbreviations: CI, confidence interval; LPA, light physical activity; MVPA, moderate to vigorous physical activity; ST, sedentary time; TPA total physical activity; VPA, vigorous physical activity. Note: The data are standardized regression coefficients β and their 95% CIs from linear regression analyses adjusted for sex, age, and parental education at 8-year follow-up and the Raven's Colored Progressive Matrices score at baseline. Overall cognition was calculated by summing standardized scores across all CogState tests and dividing it by the number of CogState test variables. For reaction time outcomes, more negative β values indicate better performance (faster responses) with higher levels of the exposure. For accuracy and overall cognition, more positive β values indicate better performance.

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Table 5 Associations of Self-Reported Cumulative PA, Nonscreen-Based ST, and Screen Time With Measures of Cognition in 136 Boys

	Psychomotor function	Attention		Working memory				Paired-associate learning	Overall cognition
	Detection test (reaction time, lower = better)	Identification test (reaction time, lower = better)	Identification test (accuracy, higher = better)	1-back task (reaction time, lower = better)	1-back task (accuracy, higher = better)	2-back task (reaction time, lower = better)	2-back task (accuracy, higher = better)	Continuous paired associate learning test (errors, lower = better)	Composite score (higher = better)
	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)
Total PA	–0.125 (–0.295 to 0.045)	–0.044 (–0.217 to 0.129)	–0.042 (–0.217 to 0.133)	–0.068 (–0.239 to 0.104)	0.149 (–0.018 to 0.315)	0.011 (–0.161 to 0.185)	–0.115 (–0.281 to 0.050)	0.080 (–0.083 to 0.244)	–0.026 (–0.189 to 0.137)
All organized exercise	–0.130 (–0.298 to 0.038)	–0.111 (–0.281 to 0.059)	–0.057 (–0.229 to 0.115)	–0.150 (–0.317 to 0.018)	0.074 (–0.092 to 0.239)	–0.047 (–0.217 to 0.124)	–0.026 (–0.190 to 0.139)	0.073 (–0.089 to 0.235)	0.038 (–0.123 to 0.199)
Unsupervised PA	–0.061 (–0.233 to 0.111)	0.035 (–0.140 to 0.209)	–0.012 (–0.188 to 0.163)	0.029 (–0.144 to 0.202	0.147 (–0.020 to 0.315)	0.061 (–0.112 to 0.235)	**–0.182 (–0.346 to –0.017)**	0.067 (–0.098 to 0.232)	–0.087 (–0.251 to 0.077)
Organized sports	–0.130 (–0.298 to 0.039)	–0.122 (–0.293 to 0.048)	–0.075 (–0.248 to 0.098)	**–0.175 (–0.343 to –0.008)**	0.049 (–0.118 to 0.216)	–0.067 (–0.238 to 0.104)	–0.008 (–0.173 to 0.158)	0.083 (–0.079 to 0.245)	0.040 (–0.122 to 0.202)
Nonscreen-based ST	0.031 (–0.138 to 0.200)	–0.085 (–0.255 to 0.085)	0.016 (–0.156 to 0.188)	–0.049 (–0.218 to 0.120)	–0.127 (–0.292 to 0.037)	**–0.181 (–0.349 to –0.014)**	–0.049 (–0.213 to 0.115)	0.027 (–0.135 to 0.189)	0.029 (–0.132 to 0.190)
Screen time	0.055 (–0.120 to 0.230)	–0.089 (–0.266 to 0.087)	0.073 (–0.105 to 0.251)	–0.069 (–0.244 to 0.106)	0.041 (–0.131 to 0.213)	**–0.193 (–0.367 to –0.020)**	–0.018 (–0.188 to 0.153)	–0.056 (–0.223 to 0.112)	0.136 (–0.029 to 0.302)

Abbreviations: CI, confidence interval; PA, physical activity; ST, sedentary time. Note: The data are standardized regression coefficients with corresponding 95% CI from linear regression analyses adjusted for age, parental education, and Raven's Colored Progressive Matrices baseline score. Overall cognition was calculated by summing standardized scores across all CogState tests and dividing it by the number of CogState test variables. For reaction time outcomes, more negative β values indicate better performance (faster responses) with higher levels of the exposure. For accuracy and overall cognition, more positive β values indicate better performance. Statistically significant results have been bolded.

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Table 6 Associations of Device-Assessed Cumulative PA and ST With Measures of Cognition in 88 Boys

	Psychomotor function	Attention		Working memory				Paired-associate learning	Overall cognition
	Detection test (reaction time, lower = better)	Identification test (reaction time, lower = better)	Identification test (accuracy, higher = better)	1-back task (reaction time, lower = better)	1-back task (accuracy, higher = better)	2-back task (reaction time, lower = better)	2-back task (accuracy, higher = better)	Continuous paired associate learning test (errors, lower = better)	Composite score (higher = better)
	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)
TPA	–0.146 (–0.360 to 0.069)	–0.025 (–0.245 to 0.196)	0.056 (–0.276 to 0.164)	–0.066 (–0.282 to 0.151)	0.095 (–0.115 to 0.304)	0.051 (–0.169 to 0.272)	–0.165 (–0.372 to 0.041)	0.006 (–0.203 to 0.215)	–0.038 (–0.249 to 0.174)
LPA	0.001 (–0.219 to 0.221)	0.012 (–0.212 to 0.236)	–0.026 (–0.249 to 0.197)	–0.075 (–0.295 to 0.144)	–0.119 (–0.331 to 0.093)	–0.141 (–0.363 to 0.081)	0.061 (–0.151 to 0.273)	0.150 (–0.059 to 0.359	–0.034 (–0.249 to 0.181)
MVPA	–0.073 (–0.305 to 0.159)	–0.046 (–0.282 to 0.191)	–0.096 (–0.331 to 0.138)	–0.145 (–0.375 to 0.086	0.082 (–0.144 to 0.307)	–0.015 (–0.251 to 0.221)	0.177 (–0.044 to 0.398)	–0.109 (–0.331 to 0.114)	0.288 (–0.104 to 0.347)
VPA	–0.020 (–0.241 to 0.202)	–0.137 (–0.361 to 0.087)	–0.024 (–0.249 to 0.200)	–0.066 (–0.287 to 0.156)	0.048 (–0.167 to 0.264)	–0.006 (–0.231 to 0.219)	0.116 (–0.096 to 0.329)	0.021 (–0.193 to 0.234)	0.052 (–0.164 to 0.269)
ST	0.078 (–0.157 to 0.312)	0.017 (–0.222 to 0.256)	0.024 (–0.214 to 0.262)	0.089 (–0.145 to 0.323)	0.056 (–0.172 to 0.283)	0.039 (–0.200 to 0.277)	–0.169 (–0.392 to 0.054)	–0.039 (–0.265 to 0.186)	–0.044 (–0.273 to 0.185)

Abbreviations: CI, confidence interval; LPA, light physical activity (>1.5 and ≤4.0 standard METs); METs, metabolic equivalents; MVPA, moderate to vigorous physical activity (>4.0 standard METs); PA, physical activity; ST, sedentary time (≤1.5 standard METs, sleep excluded); TPA, total physical activity; VPA, vigorous physical activity (>7.0 standard METs). Note: The data are standardized regression coefficients with corresponding 95% CI from linear regression analyses adjusted for age, parental education, and Raven's Colored Progressive Matrices baseline score. Overall cognition was calculated by summing standardized scores across all CogState tests and dividing it by the number of CogState test variables. For reaction time outcomes, more negative β values indicate better performance (faster responses) with higher levels of the exposure. For accuracy and overall cognition, more positive β values indicate better performance.

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Table 7 Associations of Self-Reported Cumulative PA, Nonscreen-Based ST, and Screen Time With Measures of Cognition in 124 Girls

	Psychomotor function	Attention		Working memory				Paired-associate learning	Overall cognition
	Detection test (reaction time, lower = better)	Identification test (reaction time, lower = better)	Identification test (accuracy, higher = better)	1-back task (reaction time, lower = better)	1-back task (accuracy, higher = better)	2-back task (reaction time, lower = better)	2-back task (accuracy, higher = better)	Continuous paired associate learning test (errors, lower = better)	Composite score (higher = better)
	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)
Total PA	0.004 (–0.166 to 0.173	–0.118 (–0.296 to 0.060)	0.105 (–0.076 to 0.285)	0.005 (–0.177 to 0.186)	0.005 (–0.172 to 0.181)	0.023 (–0.162 to 0.209)	–0.021 (–0.185 to 0.142)	–0.059 (–0.239 to 0.120)	0.030 (–0.140 to 0.200)
All organized exercise	–0.004 (–0.172 to 0.163)	–0.133 (–0.309 to 0.042)	0.143 (–0.034 to 0.321)	0.028 (–0.151 to 0.207)	0.004 (–0.171 to 0.178)	–0.006 (–0.190 to 0.177)	0.039 (–0.123 0.201)	–0.080 (–0.257 to 0.098)	0.064 (–0.103 to 0.232)
Unsupervised PA	0.001 (–0.168 to 0.170)	–0.068 (–0.246 to 0.110)	0.020 (–0.161 to 0.200)	–0.036 (–0.217 to 0.145)	–0.007 (–0.183 to 0.169)	0.001 (–0.184 to 0.186)	–0.049 (–0.212 to 0.114)	–0.015(–0.194 to 0.165)	0.002 (–0.167 to 0.172)
Organized sports	–0.002 (–0.169 to 0.165)	–0.120 (–0.296 to 0.055)	0.099 (–0.079 to 0.278)	0.027 (–0.153 to 0.206)	0.015 (–0.160 to 0.189)	0.002 (–0.182 to 0.185)	0.058 (–0.104 to 0.219)	–0.082 (–0.260 to 0.095)	0.059 (–0.109 to 0.226)
Nonscreen-based ST	–0.078 (–0.245 to 0.088)	–0.148 (–0.322 to 0.026)	0.010 (–0.168 to 0.189)	–0.148 (–0.324 to 0.029)	–0.149 (–0.321 to 0.023)	–0.157 (–0.337 to 0.024)	–0.048 (–0.209 to 0.114)	0.056 (–0.121 to 0.233)	0.066 (–0.101 to 0.233)
Screen time	–0.131 (–0.296 to 0.034)	–0.086 (–0.262 to 0.089)	–0.023(–0.202 to 0.155)	**–0.335 (–0.503 to –0.167)**	0.039 (–0.135 to 0.213)	**–0.306 (–0.480 to –0.132)**	0.080 (–0.080 to 0.241)	0.013 (–0.164 to 0.190)	**0.246 (0.085 to 0.407)**

Abbreviations: CI, confidence interval; PA, physical activity; ST, sedentary time. Note: The data are standardized regression coefficients with corresponding 95% CI from linear regression analyses adjusted for age, parental education, and Raven's Colored Progressive Matrices baseline score. Overall cognition was calculated by summing standardized scores across all CogState tests and dividing it by the number of CogState test variables. For reaction time outcomes, more negative β values indicate better performance (faster responses) with higher levels of the exposure. For accuracy and overall cognition, more positive β values indicate better performance. Statistically significant results have been bolded.

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Table 8 Associations of Device-Assessed Cumulative PA and ST With Measures of Cognition in 83 Girls

	Psychomotor function	Attention		Working memory				Paired-associate learning	Overall cognition
	Detection test (reaction time, lower = better)	Identification test (reaction time, lower = better)	Identification test (accuracy, higher = better)	1-back task (reaction time, lower = better)	1-back task (accuracy, higher = better)	2-back task (reaction time, lower = better)	2-back task (accuracy, higher = better)	Continuous paired associate learning test (errors, lower = better)	Composite score (higher = better)
	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)
TPA	–0.018 (–0.224 to 0.187)	–0.181 (–0.397 to 0.035)	0.177 (–0.046 to 0.401)	0.038 (–0.183 to 0.260)	–0.109 (–0.327 to 0.109)	0.045 (–0.181 to 0.272)	–0.055 (–0.261 to 0.150)	–0.149 (–0.370 to 0.071)	0.035 (–0.171 to 0.241)
LPA	0.008 (–0.199 to 0.214)	0.127 (–0.091 to 0.345)	–0.063 (–0.290 to 0.164)	0.118 (–0.102 to 0.339)	**0.269 (0.057 to 0.480)**	0.182 (–0.042 to 0.405)	–0.056 (–0.262 to 0.150)	0.076 (–0.147 to 0.299	–0.106 (–0.311 to 0.099)
MVPA	0.026 (–0.182 to 0.234)	–0.015 (–0.237 to 0.206)	0.215 (–0.009 to 0.439)	–0.098 (–0.321 to 0.124)	0.038 (–0.184 to 0.259)	–0.143 (–0.370 to 0.083)	–0.021 (–0.229 to 0.187)	–0.008 (–0.233 to 0.217)	0.087 (–0.120 to 0.294)
VPA	–0.002 (–0.207 to 0.203)	0.026 (–0.193 to 0.246)	0.210 (–0.012 to 0.431)	–0.025 (–0.246 to 0.196)	0.071 (–0.148 to 0.289)	–0.046 (–0.272 to 0.180)	–0.022 (–0.227 to 0.184)	0.077 (–0.144 to 0.299)	0.034 (–0.171 to 0.239)
ST	–0.067 (–0.278 to 0.144)	–0.135 (–0.359 0.088)	–0.022 (–0.255 to 0.212)	–0.123 (–0.349 to 0.103)	–0.159 (–0.381 to 0.064)	–0.141 (–0.372 to 0.090)	0.045 (–0.167 to 0.256)	–0.130 (–0.357 to 0.097)	0.142 (–0.067 to 0.351)

Abbreviations: CI, confidence interval; LPA, light physical activity (>1.5 and ≤4.0 standard METs); METs, metabolic equivalents; MVPA, moderate to vigorous physical activity (>4.0 standard METs); ST, sedentary time (≤1.5 standard METs, sleep excluded); TPA; total physical activity; VPA, vigorous physical activity (>7.0 standard METs). Note: The data are standardized regression coefficients with corresponding 95% CI from linear regression analyses adjusted for age, parental education, and Raven's Colored Progressive Matrices baseline score. Overall cognition was calculated by summing standardized scores across all CogState tests and dividing it by the number of CogState test variables. For reaction time outcomes, more negative β values indicate better performance (faster responses) with higher levels of the exposure. For accuracy and overall cognition, more positive β values indicate better performance. Statistically significant results have been bolded.

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adolescence using both device-assessed and self-reported measures. We found that higher levels of self-reported cumulative unsupervised PA from childhood to adolescence were associated with poorer working memory in adolescence. Higher levels of self-reported cumulative nonscreen-based ST from childhood to adolescence were associated with shorter reaction times but poorer accuracy in the working memory task in adolescence. Moreover, higher levels of self-reported cumulative screen time from childhood to adolescence were associated with better working memory and overall cognition in adolescence. Device-assessed cumulative PA or ST was not associated with cognition in the whole study population. Higher levels of self-reported cumulative organized sports and nonscreen-based ST from childhood to adolescence were associated with better working memory among boys but not among girls. In addition, higher levels of self-reported cumulative unsupervised PA from childhood to adolescence were related to poorer working memory in adolescence among boys but not among girls. Higher levels of device-assessed cumulative LPA from childhood to adolescence were associated with better working memory in adolescence among girls but not among boys. Finally, higher levels of self-reported cumulative screen time from childhood to adolescence were associated with better overall cognition in adolescence among girls but not among boys.

The inverse association between self-reported cumulative unsupervised PA from childhood to adolescence and working memory in adolescence contradicts the results of previous studies showing direct cross-sectional[14,15] and longitudinal[17] associations of self-reported organized sports,[14] active commuting to school,[15] and extracurricular PA[17] with cognition in adolescents. However, whereas Wickel[18] reported an inverse association between a change in device-assessed MVPA from the age of 9 years to the age of 15 years and working memory at the age of 15 years, we found that cumulative device-assessed MVPA was not associated with cognition in adolescents. Therefore, these inconsistent findings suggest that higher levels of PA in some circumstances may be related to poorer cognition, but that the associations may depend on several other factors, such as population characteristics, the context of PA, or the method used to assess PA. One explanation for our observations may be that unsupervised PA replaces certain activities that may enhance cognition, such as reading and doing homework. Inconsistencies between self-reported and device-assessed PA and ST and their associations with cognition may be due to inaccurate reporting of PA and ST. The reasons for the reporting inaccuracy may be social desirability bias or parents' unawareness of their children's PA and ST when they are not with them.[41] In addition, the lack of significant associations between device-assessed PA and cognition might result from limited variability in MVPA in adolescents, which can mask small effects. Furthermore, device-assessed measurements of PA may overlook important qualitative and contextual aspects of PA.[14,16,17] The true association between PA and cognition in children and adolescents might be small, and during childhood and adolescence, neurobiological maturation, pubertal processes, and social and educational influences could overshadow the contribution of PA.[5] Because this association is probably small, studies with limited sample sizes might lack the statistical power needed to detect it, possibly explaining the inconsistent findings in earlier research. Although the exact reasons for the inverse association between self-reported cumulative unsupervised PA and working memory are unknown, it is important to note that this association needs to be interpreted cautiously as the inverse association did not remain after FDR correction and other measures of cumulative PA were not associated with cognition.

We found direct associations of self-reported cumulative nonscreen-based ST and screen time from childhood to adolescence with cognition in adolescence. Nevertheless, we did not observe an association between device-assessed cumulative ST from childhood to adolescence and cognition in adolescence, contradicting the results of Wickel,[18] who reported that increased device-assessed ST from the age of 9 to 15 years was associated with better cognition at the age of 15 years. However, the evidence on the association between device-assessed ST and cognition in youth is mixed and from cross-sectional studies.[42,43] One explanation for our finding may be that nonscreen-based ST and screen time include activities that may improve cognition, such as reading, writing, doing homework, and playing video and board games.[44,45] The lack of significant associations between device-assessed ST and cognition in our study aligns with previous systematic review and may result from context-dependence not captured by device-assessed measurements.[43] In addition, using a combined accelerometer and heart rate monitor placed on the chest, rather than on the thigh, may lead to an underestimation of the time spent in sedentary activities as the thigh placement would provide a more accurate estimate of ST.[46]

Self-reported cumulative time spent in organized sports from childhood to adolescence was directly associated with working memory in adolescence among boys but not among girls. This contradicts the results of a previous study that found no sex difference in the associations of self-reported participation in organized sports with cognition.[14] Earlier research has indicated that engaging in sports can improve cognition.[47] This may be attributed to the greater opportunities for motor learning and cognitively stimulating activities, resulting in beneficial neural adaptations[48] and increased possibilities for social interaction and goal-oriented behavior.[49] The observed direct association between organized sports and working memory in boys, but not in girls, may be attributed to boys experiencing a more significant acute increase in BDNF following organized sports, including VPA, which is thought to mediate PA-induced cognitive improvements.[22] The results of our study suggest that participating in organized sports in childhood and adolescence may have beneficial effects on working memory in adolescence among boys. However, the direct association between organized sports and working memory must be interpreted cautiously as the results did not remain after FDR correction.

Higher levels of device-assessed cumulative LPA from childhood to adolescence were associated with better working memory in adolescence among girls but not among boys. Our findings are consistent with those of Pindus and coworkers,[11] who observed that spending relatively more time in device-assessed activities at higher intensities was associated with better attentional control in adolescence among girls but not among boys. Our results suggest that even lighter PA could improve cognition in girls. One explanation for our finding might be that device-assessed LPA, particularly in girls, includes talking and socializing with friends, which could enhance cognition.[49] Activities including socializing may be less important for boys who, in our study, tended to engage more in device-assessed VPA and self-reported organized sports than girls.

The strengths of the present study include a relatively large general population of children followed for 8 years until adolescence; valid and reproducible measures of PA, ST, screen time, and cognition; and the possibility to control for a variety of potential confounders. Moreover, device-assessed and self-reported PA and ST offered us both contextual information on health behavior and valid information on movement behaviors and gave us a complete picture of PA and ST in childhood and adolescence.[50] However, our study also includes limitations that need to be considered. The

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participants' cognitive performance was only assessed in adolescence, preventing detailed longitudinal analyses. Therefore, it is impossible to determine causality and exclude the possibility of reverse causation, that is, that individuals with better cognition have less cumulative unsupervised PA and more nonscreen-based ST. However, we used the RCPM score at baseline as a covariate in the statistical analyses, which decreases the possibility of reverse causation. In addition, the measures of cumulative PA and ST taken from baseline to the 8-year follow-up may not reflect the possible changes in PA and ST during the period between baseline, 2-year follow-up, and 8-year follow-up. Therefore, it is possible that these measures may either overestimate or underestimate the overall exposure to PA and sedentary behavior in some participants. Finally, although the sample size is relatively large, it may have limited power to detect small associations between PA and cognition, especially after adjusting for multiple potential confounders.

Conclusion

We found that higher levels of self-reported cumulative unsupervised PA and lower levels of self-reported cumulative screen time from childhood to adolescence were associated with poorer cognition in adolescence. We observed no associations of device-assessed cumulative PA or ST from childhood to adolescence with cognition in adolescence. However, higher levels of device-assessed cumulative light PA from childhood to adolescence were associated with better working memory in adolescence among girls but not among boys, suggesting that the associations of PA and ST with cognition partly depend on sex as well as measurement methods and context of PA and ST. Future studies should repeatedly assess not only PA and ST but also cognition to allow for complete statistical analyses on longitudinal associations of PA and sedentary behaviors with cognition and provide evidence on these associations from childhood to adolescence and even adulthood.

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