HOSTED BY

ELSEVIER

Available online at www.sciencedirect.com

ScienceDirect

Journal of Sport and Health Science 9 (2020) 265–273

www.jshs.org.cn

Original article

Longitudinal associations of physical activity and pubertal development with academic achievement in adolescents

Eero A. Haapala [a,b,*], Henna L. Haapala [a], Heidi Syväoja [c], Tuija H. Tammelin [c], Taija Finni [a], Noona Kiuru [d]

[a] *Faculty of Sport and Health Sciences, University of Jyväskylä, Jyväskylä, FI-40014, Finland*
[b] *Department of Physiology, Institute of Biomedicine, School of Medicine, University of Eastern Finland, Kuopio Campus, FI-70211, Finland*
[c] *LIKES Research Centre for Physical Activity and Health, Jyväskylä, FI-40700, Finland*
[d] *Department of Psychology, Faculty of Education and Psychology, University of Jyväskylä, Jyväskylä, FI-40014, Finland*

Received 9 January 2019; revised 25 April 2019; accepted 22 May 2019
Available online 12 July 2019

Abstract

Objective: We sought to investigate the longitudinal associations of moderate-to-vigorous physical activity (MVPA) and pubertal development with academic achievement in adolescents.
Methods: A total of 635 adolescents (283 boys, 352 girls) aged 11–13 years participated in the study. MVPA was assessed by the Health Behaviour in School-aged Children study questionnaire, and pubertal development was assessed by the Pubertal Development Scale at beginning of the 6th grade (baseline) and end of the 7th grade (follow-up). Grade point average (GPA) at the end of Grades 5 and 7 was computed from data acquired from the school registers. The data were analyzed using linear regression and analyses of covariance.
Results: In boys, MVPA was positively associated with GPA at baseline after adjustment for age ($\beta = 0.144$, 95% confidence interval (CI): 0.028–0.260, $p = 0.028$). In girls, the Pubertal Development Scale was positively associated with GPA at baseline ($\beta = 0.104$, 95%CI: −0.004 to 0.211, $p = 0.058$) and follow-up ($\beta = 0.104$, 95%CI: −0.002 to 0.211, $p = 0.055$) after adjustment for age, and these associations strengthened after further adjustment for MVPA ($p < 0.05$). Adolescents who were inactive at baseline or at baseline and follow-up had lower GPA during follow-up than their continuously highly active peers (mean difference = −0.301, 95%CI: −0.543 to −0.058, $p = 0.009$) and all other adolescents (mean difference = −0.247, 95%CI: −0.475 to −0.019, $p = 0.029$). These differences were greater in girls than in boys.
Conclusion: Lower levels of MVPA were associated with lower GPA in boys at baseline. Girls who were continuously inactive had lower GPA over the follow-up period than those who were continuously active. Finally, earlier pubertal development was associated with better academic achievement in girls.

Keywords: Adolescents; Brain; Children; Cognition; Exercise; Maturity; Physical activity

1. Introduction

Higher levels of physical activity (PA) have been associated with decreased body fat content and more favorable cardiometabolic risk factor levels and better bone health in children and adolescents.[1,2] Evidence on the positive associations between PA and academic achievement is also emerging.[3,4] However, the direction of these associations is still largely unknown because most studies on the association of PA with academic achievement have been cross-sectional.[3–5] Pubertal development during adolescence may influence PA and academic achievement, but few studies among adolescents have investigated independent associations of PA and pubertal development with academic achievement.[5] Furthermore, the transition from primary school to lower secondary school is a critical transition among adolescents, but there are no previous longitudinal studies on the associations of PA or pubertal development with academic achievement during this period.

The results of cross-sectional studies suggest a positive association between self-reported PA and academic achievement in youth.[3,4] However, the evidences from studies utilizing

Peer review under responsibility of Shanghai University of Sport.
* Corresponding author.
E-mail address: eero.a.haapala@jyu.fi (E.A. Haapala).

https://doi.org/10.1016/j.jshs.2019.07.003
Cite this article: Haapala EA, Haapala HL, Syväoja H, Tammelin TH, Finni T, Kiuru N. Longitudinal associations of physical activity and pubertal development with academic achievement in adolescents. *J Sport Health Sci* 2020;9:265–73.

device-based measures of PA show weak, if any, associations with academic achievement.[4–6] Although some longitudinal studies have found a positive association between PA assessed at the baseline of the study with subsequent academic achievement,[7–9] not all studies have confirmed these observations.[10] Furthermore, in a longitudinal study among adolescents, better academic achievement predicted higher levels of PA but not *vice versa*.[11]

Pubertal development is a discrete physiological phase of maturation resulting in sexually dimorphic changes in body size and composition, social behavior, and brain development.[12] Puberty results from the activation of hypothalamus-pituitary-gonadal axis and, therefore, secretion of gonadotropin-releasing hormone.[13] Pubertal development is commonly evaluated using breast development in girls and testicular enlargement in boys, using stages described by Tanner.[14,15] On average, girls enter puberty at 8–13 years of age whereas the first signs of testicular enlargement in boys appear at 9.5–13.5 years of age.[14,15] Because breast development and testicular enlargement provide only a rough estimate of the stage and rate of maturation, differences between calendar age and measured or estimated age at peak height velocity in boys and girls and age at menarche in girls have also been used to measure maturity status in youth.[16] Furthermore, girls experience their first menses 2.0–2.5 years after entering the pubertal phase.[12] Girls have their adolescent growth spurt at the age of 11–13 years, approximately 2 years earlier than boys. During the adolescent growth spurt, stature increases on average 20–25 cm in girls and 25–30 cm in boys. Moreover, during puberty, body fat percentage increases in girls while it decreases in boys.[17]

Brain maturation is characterized by rapid growth in size and slow functional maturation until adulthood.[18,19] Brain imaging studies have shown that girls achieve their peak grey matter volume earlier than boys[12] and that grey matter volume decreases from the age of 10 years in girls and 12–14 years in boys, whereas the white matter volume increases in both girls and boys until early adulthood.[18,19] Furthermore, maturation results in improvements in functional connectivity between brain areas,[20] and improved connectivity has been related to better literacy skills[19] and academic performance in youth.[21]

Early pubertal development has been linked to social and behavioral problems and early sexual behavior in girls, while early pubertal development in boys has been associated with popularity and assertiveness.[12] These maturation-related changes may increase physical and mental stress and change social networks, which can have negative effects on academic achievement.[12] However, early or average pubertal development has been related to higher educational attainment in boys in some studies,[22] although some studies show that early-maturing adolescents have poorer academic achievement and a lower education attainment than their later-maturing peers.[23,24]

PA has been found to decrease, and cognitive functions, such as working memory and inhibitory control, improve with increasing age in children and adolescents.[25–28] However, higher levels of PA have been found to improve brain structures, brain functions, and cognitive functions in children to a greater extent than can be explained by maturation alone.[3] Furthermore, the hypothalamus-pituitary-gonadal axis mediates the release of gonadotropins, which, in addition to having effects on pubertal development and the central nervous system, affects body size and composition, which may in turn directly or indirectly influence PA levels.[27] However, regardless of the close relationship between PA, pubertal development, brain development, and cognitive skills, few longitudinal studies have investigated independent associations of PA and pubertal development with academic achievement in adolescents.[7,29]

The evidence on the associations of PA and pubertal development with academic achievement in adolescents remains limited. Furthermore, there is even less evidence on the longitudinal associations of PA and pubertal development during the transition from primary school to lower secondary school in adolescents. Therefore, we first investigated the cross-sectional associations of PA and pubertal development in the 5th grade (baseline) and end of 7th grade (follow-up) in a large sample of Finnish adolescents. We then studied longitudinal associations of PA and pubertal development with changes in academic achievement from baseline to follow-up.

2. Methods

2.1. Study design and study population

The present data are based on the STAIRWAY study, which is a longitudinal study on the individual- and environmental-related determinants of learning, school well-being, and successful transition from primary school to lower secondary school during early adolescence. The participant sample in the STAIRWAY study consisted of 848 adolescents (457 girls, 391 boys, aged 11–13 years, median age 12 years) who participated in baseline assessments. The adolescents were recruited from 1 large town and 1 middle-sized town in central Finland. The towns included schools in semi-rural area. Target schools ($n = 30$) were selected according to their locations and size, with the aim of achieving a sufficient sample size and enabling extensive data collections throughout the whole research project. For more details about the sample and its recruitment, see Hirvonen et al.[30] and Mauno et al.[31] The primary aim of the study was to follow students through the transition from primary school to lower secondary school; thus, primary schools were selected from areas where all children transfer to particular secondary schools instead of dispersing to different locations. The selection and recruitment of the schools were done in cooperation with local school authorities. The children came from 56 school classes, ranging in size from 7 and 30 pupils (21.1 ± 4.7, mean ± SD). The sample was fairly representative of the Finnish general population regarding the demographic characteristics.[30,31]

The data on PA and pubertal development were collected in classrooms on 2 normal schooldays at the beginning of the 6th grade (the last grade of primary school; baseline) and at the end of 7th grade (the end of the first year of lower secondary school; follow-up). Data on grade point average (GPA) as a measure of academic achievement were acquired from school registries. Data were collected during the academic years

2014−2016. Complete data on variables used in the present analyses were available for 635 children (283 boys, 352 girls). There were no statistically significant differences in moderate-to-vigorous PA (MVPA), Pubertal Development Scale (PDS) score, or parental education between those who were included to the present study and those who were excluded because of incomplete data ($n = 212$). However, adolescents who had complete data for the present analyses were slightly younger ($p = 0.017$, Cohen's $d = 0.25$) and had a higher GPA at baseline ($p < 0.001$, Cohen's $d = -0.512$) and follow-up ($p = 0.015$, Cohen's $d = -0.251$) than those who had incomplete data. The study protocol was approved by the Ethics Committee of the University of Jyväskylä, Finland. Parents provided their informed written consent and children gave their assent to participate in the study.

2.2. Assessment of academic achievement

Data on grades in all school subjects were acquired from school registers at the end of the 5th grade and follow-up (7th grade), and GPA as a measure of academic achievement was computed. The baseline data on GPA was acquired at the end of the 5th grade because it better reflects academic achievement at the beginning of the 6th grade than GPA at the end of autumn semester of the 6th grade. In Finnish school, the grades range from 5 to 10, with 5 being the lowest accepted grade and 10 being the highest.

2.3. Assessment of PA

Self-reported habitual MVPA was assessed at baseline and at follow-up by the question previously used in the World Health Organization's Health Behaviour in School-aged Children study. Participants in the present study were asked to respond to the following question: "Physical activity is defined as any activity that increases your heart rate and makes you get out of breath some of the time. Over the past 7 days, on how many days were you physically active for a total of at least 60 minutes per day?"[32] Examples included running, walking quickly, rollerblading, biking, dancing, skate-boarding, swimming, snowboarding, cross-country skiing, football, basketball, and Finnish baseball. Participants answered using an 8-point scale ranging from 0 to 7 days, with higher counts reflecting higher levels of PA. This measure has been reported to have relatively good reproducibility (intraclass correlation coefficient = 0.77−0.82)[32,33] and moderate agreement with accelerometry-based estimates of MVPA (intraclass correlation coefficient = 0.44).[32]

2.4. Assessment of pubertal development

A Finnish version[34] of the 5-item PDS[35] was used to assess self-reported pubertal development among adolescents at baseline and follow-up. For both sexes, the questionnaire assessed auxiliary body hair, growth spurt, and skin changes. For girls, additional items measured menarche and breast development, whereas for boys, 2 additional items assessed facial hair and voice change. Development on each characteristic was rated on a 4-point scale ranging from 0 (*no development*) to 3 (*development is completed*), with the exception of menarche, which was scored dichotomously (0 = *has not occurred* or 3 = *has occurred*). The Cronbach's α reliability for the PDS score was acceptable (0.73, for more information of the reliability and validity of PDS, please see Dick et al.[34] and Petersen et al.[36]). A total of 25 boys (9%) and 7 girls (2%) reported a lower PDS score at follow-up than at baseline. We categorized them as "no change" in the PDS score during the follow-up.

2.5. Other assessments

Parents were asked to report their highest level of education in a questionnaire, and the education was coded as: 1 = vocational school or less, 2 = polytechnic, and 3 = higher university degree.[37]

2.6. Statistical methods

All statistical analyses were performed using the SPSS Statistical software Version 24.0 (IBM Corp., Armonk, NY, USA). We investigated the differences in basic characteristics at baseline between boys and girls by Student's t test and Mann-Whitney U test for continuous variables, or the χ^2 test for categorical variables. Change in MVPA from baseline to follow-up was investigated by Wilcoxon sign-rank test because of skewed distributions. We investigated bivariate associations between MVPA, PDS score, and GPA at baseline and follow-up by Spearman correlation coefficients. We studied whether sex modified the associations of MVPA or PDS score with GPA using analyses of covariance. Because we found that sex modified the association between PDS and GPA at baseline ($p = 0.011$ for interaction), we also analyzed the data separately for boys and girls.

We investigated the cross-sectional associations of MVPA and PDS score with GPA at baseline and follow-up by linear regression analyses adjusted for age and sex. Similarly, we investigated the longitudinal associations of MVPA and PDS score at baseline with GPA at follow-up by linear regression analyses adjusted for age and sex. The associations of changes in MVPA and PDS score with changes in GPA during follow-up were analyzed by linear regression analyses adjusted for age, GPA, and MVPA or PDS score at baseline. We computed changes in MVPA and PDS score as subtracting MVPA or PDS score at baseline from the corresponding measure at follow-up.

We used analysis of covariance adjusted for age and sex to investigate cross-sectional differences in GPA at baseline and follow-up between adolescents who were inactive (reporting 60 min of MVPA on 0−2 days/week), moderately active (3−5 days/week), and highly active (6−7 days/week). The differences in GPA among adolescents with different longitudinal MVPA profiles were analyzed using analysis of covariance with repeated measures adjusted for age and sex. For these analyses, we categorized changes in MVPA as continuously inactive or inactive at baseline (0−2 days/week at baseline or at baseline and follow-up), continuously highly active (6−7 days/week at baseline and follow-up), and other

(decreased or increased MVPA, or continuously moderately active). To investigate the differences in GPA across more varied MVPA profiles, we also categorized MVPA as continuously inactive (0−2 days/week at baseline and follow-up), increased MVPA, decreased MVPA, continuously moderately active (3−5 days/week at baseline and follow-up), and continuously highly active (6−7 days/week at baseline and follow-up).

All data were additionally adjusted for maternal or paternal education, which were entered into the model separately. Because the school location and size may modify the associations of PA and PDS score with GPA, cross-sectional and longitudinal data were adjusted for schools using dichotomized dummy variables. The longitudinal data were also adjusted for the school type, that is, whether adolescents transitioned from baseline to follow-up within the same comprehensive school consisting of Grades 1−9 together or whether adolescents transitioned from Grade 6 to Grade 7 from a separate primary school consisting Grades 1−6 to a separate lower secondary school consisting of Grades 7−9.

We estimated statistical power for our analyses using the G*Power software, Version 3.1.9.2.[38,39] A total of 191 observations was needed to observe the correlation of 0.2 at the power of 0.80 when the α level was set at 0.05. Moreover, to observe statistically significant differences at an α level of 0.05 at the power of 0.80 between 5 groups, a total sample size of 269 was needed.

3. Results

3.1. Basic characteristics

Boys who were less mature as indicated by a lower PDS score had higher levels of MVPA and lower GPA at baseline and follow-up than girls (Table 1). GPA decreased in boys ($p < 0.001$) but increased in girls ($p = 0.048$), while MVPA decreased in both boys ($p < 0.001$) and girls ($p < 0.001$) during the follow-up. PDS score was not statistically significantly associated with MVPA in boys or girls at baseline or follow-up (Table 2).

3.2. Cross-sectional associations of PA and pubertal development with academic achievement at baseline

For all participants, MVPA was positively associated with GPA after adjustment for age and sex (Table 3). The association between MVPA and GPA slightly attenuated after further adjustment for maternal education ($\beta = 0.073$, 95%CI: −0.002 to 0.145, $p = 0.044$). Inactive adolescents had lower GPA than other adolescents (Fig. 1A). Further adjustment for paternal education, school, or PDS had no effect on these associations. PDS score was not associated with GPA (Table 3).

In boys, MVPA was positively associated with GPA at baseline after adjustment for age (Table 3). Further adjustment for maternal education slightly weakened this association ($\beta = 0.114$, 95%CI: 0.003−0.224, $p = 0.044$). Inactive boys had lower GPA than highly active boys (mean difference = −0.224, 95%CI: −0.577 to 0.001, $p = 0.051$ for main effect, $p = 0.038$), but this difference attenuated after further adjustment for maternal education ($p = 0.065$). Adjustment for paternal education, school, or PDS score had no effect on this association and differences between inactive and highly active boys. PDS score was not associated with GPA.

In girls, MVPA was not associated with GPA (Table 3) and there were no differences in GPA among inactive, moderately active, and highly active girls ($p = 0.087$ for main effect). The association between PDS score and GPA was not statistically significant after adjustment for age. Further adjustment for MVPA ($\beta = 0.109$, 95%CI: 0.002−0.216, $p = 0.046$) or maternal education ($\beta = 0.111$, 95%CI: 0.010−0.211, $p = 0.031$) strengthened the positive association of PDS score with GPA. Paternal education or school had no effect on the magnitude of this association.

Table 1
Characteristics of participants.

	All ($n = 635$)	Boys ($n = 283$)	Girls ($n = 352$)	p
Age (year)	12.3 ± 0.3	12.3 ± 0.4	12.3 ± 0.3	0.063
PDS at baseline[a]	0.8 (0.4−1.2)	0.6 (0.2−0.8)	1.0 (0.6−1.4)	<0.001
PDS at follow-up	1.4 (1.0−2.0)	1.0 (0.6−1.4)	1.8 (1.4−2.2)	<0.001
Maternal education (%)				0.655
Vocational school or less	31.9	31.3	32.4	
Polytechnic	39.8	41.9	38.2	
University	28.3	26.8	29.4	
Paternal education (%)				0.531
Vocational school or less	50.5	52.7	48.7	
Polytechnic	28.9	26.6	30.8	
University	20.6	20.7	20.5	
Days of MVPA at baseline	6.0 (4.0−7.0)	6.0 (4.0−7.0)	5.0 (4.0−7.0)	0.002
Days of MVPA at follow-up	5.0 (3.0−7.0)	5.0 (3.0−6.0)	5.0 (3.0−6.0)	0.004
Grade point average at baseline	8.3 ± 0.6	8.1 ± 0.6	8.4 ± 0.6	<0.001
Grade point average at follow-up	8.2 ± 0.9	7.8 ± 0.9	8.5 ± 0.7	<0.001

Note: Data are from the Student t test or Mann-Whitney U test for continuous variables and χ^2 test for categorical variables and are displayed as means ± SD, medians (interquartile range), or percentages (%).

[a] Refers to IQR and interquartile range.

Abbreviations: MVPA = moderate-to-vigorous physical activity; PDS = Pubertal Development Score.

Table 2
Spearman correlations between PDS score, GPA, and MVPA at baseline and follow-up in boys and girls.

	PDS at baseline	PDS at follow-up	GPA at baseline	GPA at follow-up	Days of MVPA at baseline	Days of MVPA at follow-up
PDS at baseline	1	0.669***	0.086	0.075	−0.071	−0.023
PDS at follow-up	0.524***	1	0.185***	0.118*	−0.070	−0.030
GPA at baseline	−0.102	−0.032	1	0.815***	0.056	0.002
GPA at follow-up	−0.064	−0.010	0.840***	1	0.081	0.066
Days of MVPA at baseline	0.009	0.043	0.128*	0.023	1	0.503***
Days of MVPA at follow-up	0.005	−0.009	0.076	0.041	0.510***	1

Note: Lower part of the table (below 1:s) are boys, upper part of the table (above 1:s) are girls.
*$p < 0.05$; ***$p < 0.001$.
Abbreviations: GPA = grade point average; MVP = moderate-to-vigorous physical activity; PDS = Pubertal Development Scale.

3.3. Cross-sectional associations of PA and pubertal development with academic achievement at follow-up

For all participants or for boys and girls separately, MVPA was not associated with GPA and there were no differences in GPA among inactive, moderately active, and highly active adolescents (Fig. 1B). In girls, the association of PDS score with GPA was not statistically significant after adjustment for age, but further adjustment for MVPA strengthened this association ($\beta = 0.106$, 95%CI: 0.000−0.213, $p = 0.050$). Additional adjustment for maternal education ($\beta = 0.093$, 95%CI: −0.014 to 0.186, $p = 0.093$) and PDS score at baseline ($\beta = 0.093$, 95%CI: −0.049 to 0.235, $p = 0.199$) attenuated the association between PDS score and GPA in girls at follow-up.

3.4. Longitudinal associations of PA and pubertal development with changes in academic achievement

For all participants, neither MVPA or PDS score at baseline nor changes in MVPA or PDS score during follow-up were not associated with GPA at follow-up or changes in GPA during follow-up (Table 4). However, adolescents who were inactive at baseline or who were inactive both at baseline and follow-up had lower GPA during follow-up than their continuously highly active peers (mean difference = −0.301, 95%CI: −0.543 to −0.058, $p = 0.009$) and all other adolescents (mean difference = −0.247, 95%CI: −0.475 to −0.019, $p = 0.029$, Fig. 1C). Furthermore, adolescents whose MVPA levels increased from baseline to follow-up had a lower GPA over the follow-up than continuously highly active adolescents (mean difference = −0.374, 95%CI: −0.723 to −0.024, $p = 0.027$, Fig. 1D). Further adjustments had no effect on these differences.

In boys, MVPA or PDS score at baseline was not associated with GPA at follow-up. Change in MVPA or PDS score during follow-up was not associated with change in GPA after adjustment for age, GPA, and MVPA or PDS score at baseline (Table 4). However, MVPA at baseline was negatively associated ($p = 0.049$) and GPA at baseline was positively associated with change in GPA during follow-up ($p < 0.001$). Further adjustments had no effect on these associations.

In girls, MVPA or PDS score at baseline was not associated with GPA at follow-up. Changes in MVPA or PDS score, or MVPA, PDS score, or GPA at baseline, were not associated with changes in GPA (Table 4). Girls who were inactive at baseline or at baseline and follow-up had lower GPA during follow-up than continuously highly active girls (mean difference = −0.334, 95%CI: −0.635 to −0.033, $p = 0.024$) and other girls (mean difference = −0.288, 95%CI: −0.562 to −0.015, $p = 0.035$; $p = 0.013$ for main effect).

Girls whose MVPA increased during follow-up had continuously lower GPA than always moderately active (mean difference = −0.464, 95%CI: −0.888 to −0.040, $p = 0.022$) or highly active girls (mean difference = −0.466, 95%CI: −0.883 to −0.048, $p = 0.018$; $p = 0.029$ for main effect). Further adjustments had no effect on these differences.

GPA at baseline was positively related to GPA at follow-up after adjustment for age, PDS score, MVPA, and maternal education at 6th grade in boys ($\beta = 0.801$, 95%CI: 0.737−0.881, $p < 0.001$) and girls ($\beta = 0.793$, 95%CI: 0.728−0.871, $p < 0.001$).

Table 3
Cross-sectional associations of physical activity and pubertal development with GPA at baseline and follow-up.

	All			Boys			Girls		
	β	95%CI	p	β	95%CI	p	β	95%CI	p
Baseline									
MVPA	0.101	0.026 to 0.179	0.009	0.144	0.028 to 0.260	0.028	−0.015	−0.120 to 0.090	0.780
PDS	0.015	−0.065 to 0.095	0.713	−0.095	−0.214 to 0.024	0.116	0.104	−0.004 to 0.211	0.058
Follow-up									
MVPA	0.058	−0.020 to 0.136	0.144	0.059	−0.058 to 0.177	0.321	0.057	−0.048 to 0.163	0.285
PDS	0.044	−0.036 to 0.124	0.279	−0.033	−0.155 to 0.088	0.592	0.104	−0.002 to 0.211	0.055

Note: Data are standardized regression coefficients, and their 95% CIs are adjusted for age and sex.
Abbreviations: CI = confidence interval; GPA = grade point average; MVPA = moderate-to-vigorous physical activity; PDS = Pubertal Development Scale.

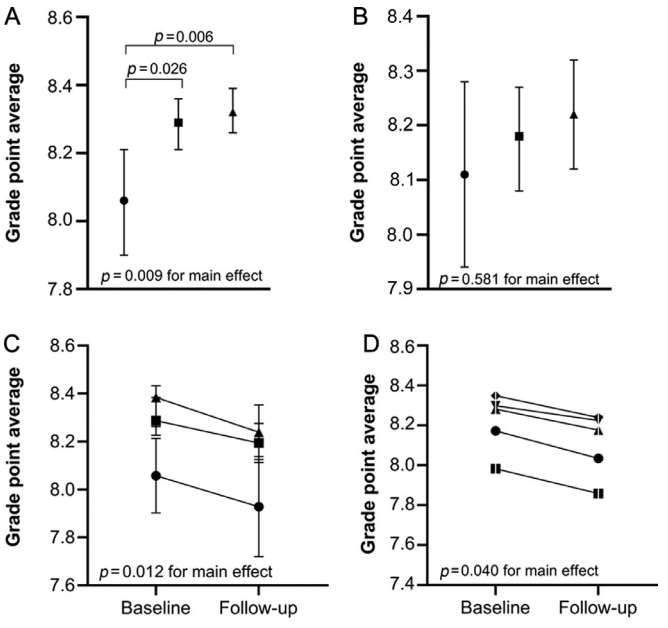

Fig. 1. Differences in grade point average among all adolescents with different levels of moderate-to-vigorous physical activity (MVPA) in cross-sectional at baseline (A) and follow-up (B) and in longitudinal analyses from baseline to follow-up (C and D). Data were presented as estimated marginal means and their 95% confidence intervals.

For A and B: ● 60 min of MVPA for 0−2 days/week (inactive); ■ 3−5 days/week (moderately active); ▲ 6−7 days/week (highly active).

For C: ● continuously inactive or inactive at baseline (0−2 days/week at baseline or at baseline and follow-up); ■ other (decreased, increased, or continuously moderate levels of MVPA); ▲ continuously active (6−7 days/week at baseline and follow-up).

For D: ● continuously inactive (0−2 days/week at baseline and follow-up); ■ increased MVPA; ▲ decreased MVPA; ▼ continuously moderately active (3−5 days/week at baseline and follow-up); ◆ continuously highly active (6−7 days/week at baseline and follow-up).

Note: 95% confidence interval bars have been removed from D for clarity.

4. Discussion

We found that MVPA was positively associated with GPA in cross-sectional analyses at baseline and that this association was mainly driven by a strong positive association between MVPA and GPA in boys. However, we found no association between MVPA and GPA at follow-up either in boys or in girls. We also observed that adolescents who were continuously inactive during follow-up or inactive at baseline had a continuously lower GPA over the follow-up period than continuously highly active adolescents and that these differences were stronger in girls than in boys. Furthermore, we found that increased MVPA during follow-up was associated with a continuously lower GPA over follow-up. These associations of MVPA with GPA were independent of pubertal development. Finally, higher PDS score, indicating more advanced pubertal status, was related to higher GPA at baseline and follow-up in girls.

Our cross-sectional findings at baseline are in line with previous studies showing a positive association between self-reported PA and academic achievement in children and adolescents.[4] In contrast with the results of some previous studies,[4,8,9] we found no relationship between MVPA at baseline and academic achievement at follow-up. Furthermore, increased MVPA during follow-up has been associated with better academic achievement at follow-up in adolescents,[40] but we found no evidence on the association between change in MVPA and change in GPA as a continuous variable during follow-up. The reason for the contrasting findings may be that previous studies did not control for academic achievement at baseline. In the present study, academic achievement at baseline was controlled for and it was found to be the strongest predictor of academic achievement at follow-up. Similarly, Aaltonen et al.[11] found in their longitudinal study that previous academic achievement was the strongest predictor of subsequent academic achievement and educational attainment. In line with our findings, they observed a positive cross-sectional association between PA and academic

Table 4
Associations of changes in physical activity and pubertal development with change in GPA.

	All			Boys			Girls		
	β	95%CI	*p*	*β*	95%CI	*p*	*β*	95%CI	*p*
Physical activity									
Age	0.039	−0.036 to 0.115	0.303	0.101	−0.012 to 0.214	0.080	0.012	−0.094 to 0.117	0.830
Sex	−0.223	−0.300 to −0.144	<0.001	–	–	–	–	–	–
MVPA at baseline	0.015	−0.070 to 0.100	0.732	−0.128	−0.256 to −0.001	0.048	0.089	−0.031 to 0.209	0.147
GPA at baseline	0.148	0.070 to 0.226	<0.001	0.262	0.148 to 0.377	<0.001	0.044	−0.062 to 0.149	0.417
Change in MVPA	0.028	−0.057 to 0.112	0.517	0.049	−0.077 to 0.175	0.448	0.087	−0.017 to 0.110	0.154
Pubertal development									
Age	0.052	−0.026 to 0.129	0.273	0.094	−0.025 to 0.212	0.120	0.013	−0.095 to 0.121	0.814
Sex	−0.256	−0.348 to −0.164	<0.001	–	–	–	–	–	–
PDS at baseline	−0.048	−0.135 to 0.039	0.279	0.030	−0.094 to 0.154	0.637	−0.036	−0.167 to 0.096	0.593
GPA at baseline	0.152	0.075 to 0.230	<0.001	0.245	0.130 to 0.360	<0.001	0.057	−0.050 to 0.163	0.298
Change in PDS	−0.049	−0.132 to 0.033	0.244	−0.017	−0.139 to 0.106	0.789	−0.055	−0.183 to 0.073	0.398

Notes: Data are standardized regression coefficients, and their 95%CIs adjusted for age and sex. Age, sex, MVPA, or PDS at baseline, GPA at baseline, and change in MVPA, or PDS were first entered into the same model.
Abbreviations: CI = confidence interval; GPA = grade point average; MVPA = moderate-to-vigorous physical activity; PDS = Pubertal Development Score.

achievement. They also found that academic achievement predicted future PA but not *vice versa*.

We observed that adolescents, particularly girls, who were inactive at baseline or both at baseline and follow-up had a continuously lower GPA over follow-up than those who were continuously highly active. These results are supported by a few previous longitudinal studies showing that children and adolescents with continuously low cardiorespiratory fitness have poorer academic achievement than their more fit peers.[41,42] Furthermore, adolescents, especially girls, who were inactive at baseline but increased their MVPA over follow-up had a continuously lower GPA than those who were continuously active. These results suggest that low levels of MVPA are related to poorer academic achievement, particularly if low MVPA is sustained over a longer period of time before transition from primary to lower secondary school. It is also possible that adolescents who increased their MVPA during the follow-up increased it in addition to school-related commitments that may have led to time constraints or insufficient sleep, which could have negatively affected their academic achievement.[43]

Our results, along with previous results from prospective studies, suggest that the longitudinal associations between PA and academic achievement may be explained by neuroselection, that is, adolescents with better academic achievement may choose a physically more active lifestyle, rather than neuroprotection, that is, the direct positive association of PA with academic achievement.[11,44] The neuroprotective mechanisms that may explain why adolescents with higher levels of MVPA had continuously better GPA may be that PA has been found to increase brain-derived neurotropic factors, insulin-like growth factor 1, and vascular endothelial growth factors. These factors improve neuroelectric processing and executive functions that may support normal brain development, thereby contributing to academic achievement during growth and maturation.[45] Furthermore, low levels of MVPA may also reflect poor peer relations, social constructs, and health behaviors,[46,47] which may also have adverse effects on academic achievement.

We found that girls with earlier pubertal development had a higher GPA at baseline and follow-up compared with their later-maturing peers and that these associations were partly modified by PA. The reason for this observation may be that gonadal hormones such as estrogen have been linked to neurogenesis, dendritic growth, synapse formation and elimination, apoptosis, neuropeptide expression, and sensitivity of neurotransmitter receptors, which together may enhance academic achievement.[12] However, in contrast with our findings, previous studies suggest that early-maturing girls have more psychosocial problems that may harm academic achievement.[23,24] These partly contrasting findings on the associations between pubertal development and academic achievement may be related not only to cultural differences, but also to the assessment of maturity among the studies. Whereas we assessed maturity indirectly using several questions related to the development of secondary sex characteristics, previous studies have used self-reported age at menarche.[23,24] However, when we compared girls whose menarche had started at baseline with other girls, no differences in academic achievement were found (data not shown). More studies are warranted to further investigate how and why PA may modify the associations of pubertal development with academic achievement in girls.

We found a stronger cross-sectional association of PA with academic achievement at baseline in boys than in girls but stronger longitudinal associations of PA with academic achievement in girls compared with boys. Furthermore, we observed that pubertal development was positively associated with academic achievement only in girls. The results of some previous studies suggest a positive association of PA and fitness with academic achievement and cognition in prepubertal boys but not in girls,[7,29,48] whereas higher levels of vigorous PA have been linked to better academic achievement in adolescent girls but not in boys.[49] The reason for these sexually dimorphic and partly contrasting associations is not completely understood. It is possible that PA is more important for academic achievement in prepubertal boys than in prepubertal girls, while the importance of PA increases during puberty in girls. However, further longitudinal studies are warranted to confirm these findings. One reason for the positive association between pubertal development and academic achievement only in girls may also be related to differences in the rate and stage of maturation between boys and girls. In girls, grey matter density increases steeply from the ages of 10 to 15 years,[50] and brain maturation in conjunction with sexual maturation may therefore have a stronger link with performance in school in girls than in boys.

The strengths of the present study include the large sample of adolescents who were followed during transition from primary school to lower secondary school. We also investigated the independent associations MVPA and pubertal development with academic achievement. However, it would have been optimal to use both device-based and self-reported PA assessment to further investigate the associations of PA with academic achievement. Using only self-reported measure of PA may have caused over-reporting or under-reporting of PA because of an inability to recall incidental MVPA or reporting socially desirable levels of MVPA.[51] Furthermore, overweight and obesity has been related to poorer academic achievement in youth,[52] and it is possible that overweight and obese adolescents overestimated their MVPA, attenuating the true magnitude of the association between MVPA and academic achievement. We did not control for season during assessment of MVPA, and this factor may have had an effect on PA in adolescents. However, we believe that this had no effect on our results because the assessment was conducted within a relatively short time frame. Furthermore, although we used a validated measure of pubertal development, our results are not comparable with studies using pubertal stages described by Tanner[53] or that estimated or measured age at peak height velocity.[16] We did not measure PA before the 6th grade; therefore, it is not possible to say whether measuring PA earlier in life would have affected our results. PA has been positively related to academic achievement in prepubertal children,[3] and some evidence suggests that higher cumulative PA exposure

from childhood to adulthood is positively related to cognition in adulthood.[54] Therefore, it is possible that changes in habitual PA during a relatively short period of time have only small effects on academic achievement in adolescents. We also used the GPA as a measure of academic achievement instead of more direct measures of academic skills.[7] The GPA reflects academic skills, but it also reflects behaviors and attitudes towards learning. The follow-up period was also relatively short, although it did cover an important transition phase. Finally, we were not able to study whether other health-related correlates of academic achievement, such as overweight and obesity, motor competence, or cardiorespiratory fitness, modify these associations.

5. Conclusion

We found that lower levels of MVPA at baseline were cross-sectionally associated with a lower GPA, particularly in boys. Furthermore, girls who were inactive at baseline or at baseline and follow-up had a lower GPA over the follow-up period than those who were continuously active. Furthermore, earlier pubertal development was associated with better academic achievement only in girls. Our results suggest that there are sexually dimorphic cross-sectional and longitudinal associations of MVPA and pubertal development with academic achievement. Further longitudinal studies are warranted to confirm our findings and to provide better physiological and psychosocial explanations for the independent and combined associations of PA and pubertal development with academic achievement.

Acknowledgments

This work was supported by the Academy of Finland (#266851).

Authors' contributions

EAH designed the study, carried out the statistical analyses, and drafted the manuscript; HLH, HS, THT, and TF all contributed to the interpretation of the results and significantly contributed to drafting the manuscript; NK, who is the principal investigator of the STAIRWAY study, helped design the present study, and contributed significantly to interpreting the results and drafting the manuscript. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

Competing interests

The authors declare that they have no competing interests.

References

1. Poitras VJ, Gray CE, Borghese MM, Carson V, Chaput J, Janssen I, et al. Systematic review of the relationships between objectively measured physical activity and health indicators in school-aged children and youth. *Appl Physiol Nutr Metab* 2016;**41**:197–239.
2. Väistö J, Haapala EA, Viitasalo A, Schnurr TM, Kilpeläinen TO, Karjalainen P, et al. Longitudinal associations of physical activity and sedentary time with cardiometabolic risk factors in children. *Scand J Med Sci Sports* 2019;**29**:113–23.
3. Donnelly JE, Hillman CH, Castelli D, Etnier JL, Lee S, Tomporowski P, et al. Physical activity, fitness, cognitive function, and academic achievement in children: a systematic review. *Med Sci Sport Exerc* 2016;**48**:1197–222.
4. Marques A, Santos DA, Hillman CH, Sardinha LB. How does academic achievement relate to cardiorespiratory fitness, self-reported physical activity and objectively reported physical activity: a systematic review in children and adolescents aged 6-18 years. *Br J Sports Med* 2018;**52**:1039. doi:10.1136/bjsports-2016-097361.
5. Esteban-Cornejo I, Tejero-Gonzalez CM, Sallis JF, Veiga OL. Physical activity and cognition in adolescents: a systematic review. *J Sci Med Sport* 2015;**18**:534–9.
6. Syväoja HJ, Kantomaa MT, Ahonen T, Hakonen H, Kankaanpää A, Tammelin TH. Physical activity, sedentary behavior, and academic performance in Finnish children. *Med Sci Sports Exerc* 2013;**45**:2098–104.
7. Haapala EA, Väistö J, Lintu N, Westgate K, Ekelund U, Poikkeus AM, et al. Physical activity and sedentary time in relation to academic achievement in children. *J Sci Med Sport* 2017;**20**:583–9.
8. Haapala EA, Poikkeus AM, Kukkonen-Harjula K, Tompuri T, Lintu N, Väistö J, et al. Associations of physical activity and sedentary behavior with academic skills – a follow-up study among primary school children. *PLoS One* 2014;**9**: e107031. doi:10.1371/journal.pone.0107031.
9. Booth JN, Leary SD, Joinson C, Ness AR, Tomporowski PD, Boyle JM, et al. Associations between objectively measured physical activity and academic attainment in adolescents from a UK cohort. *Br J Sports Med* 2014;**48**:265–70.
10. Corder K, Atkin AJ, Bamber DJ, Brage S, Dunn VJ, Ekelund U, et al. Revising on the run or studying on the sofa: prospective associations between physical activity, sedentary behaviour, and exam results in British adolescents. *Int J Behav Nutr Phys Act* 2015;**12**:106. doi:10.1186/s12966-015-0269-2.
11. Aaltonen S, Latvala A, Rose RJ, Kujala UM, Kaprio J, Silventoinen K. Leisure-time physical activity and academic performance: cross-lagged associations from adolescence to young adulthood. *Sci Rep* 2016;**6**:39215. doi:10.1038/srep39215.
12. Patton GC, Viner R. Adolescent health 1: pubertal transitions in health. *The Lancet* 2007;**369**:1130–9.
13. Rosenfeld RG, Nicodemus BC. The transition from adolescence to adult life: physiology of the "transition" phase and its evolutionary basis. *Horm Res* 2003;**60**:74–7.
14. Marshall WA, Tanner JM. Variations in the pattern of pubertal changes in boys. *Arch Dis Child* 1970;**45**:13–23.
15. Marshall WA, Tanner JM. Variations in pattern of pubertal changes in girls. *Arch Dis Child* 1969;**44**:291–303.
16. Moore SA, McKay HA, Macdonald H, Nettlefold L, Baxter-Jones AD, Cameron N, et al. Enhancing a somatic maturity prediction model. *Med Sci Sports Exerc* 2015;**47**:1755–64.
17. Malina RM, Bouchard C, Bar-Or O. *Growth, maturation, and physical activity*. 2nd ed. Champaign, IL: Human Kinetics; 2004.
18. Lenroot RK, Giedd JN. Brain development in children and adolescents: insights from anatomical magnetic resonance imaging. *Neurosci Biobehav Rev* 2006;**30**:718–29.
19. Grigorenko E. Brain development: the effect of interventions on children and adolescents. In: Bundy DAP, Silva N de, Horton S, Jamison DT, Patton GC, editors. *Child and Adolescent Health and Development*. Washington, DC: World Bank Group; 2017.p.119–31.
20. Määttä S, Säisänen L, Kallioniemi E, Lakka TA, Lintu N, Haapala EA, et al. Maturation changes the excitability and effective connectivity of the frontal lobe: a developmental TMS–EEG study. *Hum Brain Mapp* 2019;**40**:1–16.
21. Chaddock-Heyman L, Weng TB, Kienzler C, Erickson KI, Voss MW, Drollette ES, et al. Scholastic performance and functional connectivity of brain networks in children. *PLoS One* 2018;**13**: e0190073. doi:10.1371/journal.pone.0190073.
22. Koivusilta L, Rimpelä A. Pubertal timing and educational careers: a longitudinal study. *Ann Hum Biol* 2004;**31**:446–65.

23. Gill D, Del Greco MF, Rawson TM, Sivakumaran P, Brown A, Sheehan NA, et al. Age at menarche and time spent in education: a mendelian randomization study. *Behav Genet* 2017;**47**:480–5.
24. Cavanagh SE, Riegle-Crumb C, Crosnoe R. Puberty and the education of girls. *Soc Psychol Q* 2007;**70**:186–98.
25. Ingram DK. Age-related decline in physical activity: generalization to nonhumans. *Med Sci Sports Exerc* 2000;**32**:1623–9.
26. Sallis JF. Age-related decline in physical activity: a synthesis of human and animal studies. *Med Sci Sport Exer* 2000;**32**:1598–600.
27. Eisenmann JC, Wickel EE. The biological basis of physical activity in children: revisited. *Pediatr Exerc Sci* 2009;**21**:257–72.
28. Diamond A. Executive functions. *Annu Rev Psychol* 2013;**64**:135–68.
29. Haapala EA, Poikkeus AM, Tompuri T, Kukkonen-Harjula K, Leppänen PHT, Lindi V, et al. Associations of motor and cardiovascular performance with academic skills in children. *Med Sci Sports Exerc* 2014;**46**:1016–24.
30. Hirvonen R, Väänänen J, Aunola K, Ahonen T, Kiuru N. Adolescents' and mothers' temperament types and their roles in early adolescents' socioemotional functioning. *Int J Behav Dev* 2017;**42**:453–63.
31. Mauno S, Hirvonen R, Kiuru N. Children's life satisfaction: the roles of mothers' work engagement and recovery from work. *J Happiness Stud* 2017;**19**:1–21.
32. Prochaska JJ, Sallis JF, Long B. A physical activity screening measure for use with adolescents in primary care. *Arch Pediatr Adolesc Med* 2001;**155**:554–9.
33. Liu Y, Wang M, Tynjälä J, Lv Y, Villberg J, Zhang Z, et al. Test-retest reliability of selected items of Health Behaviour in School-aged Children (HBSC) survey questionnaire in Beijing, China. *BMC Med Res Methodol* 2010;**10**:73. doi:10.1186/1471-2288-10-73.
34. Dick DM, Rose RJ, Pulkkinen L, Kaprio J. Measuring puberty and understanding its impact: a longitudinal study of adolescent twins. *J Youth Adolesc* 2001;**30**:385–99.
35. Petersen AC. Adolescent development. *Annu Rev Psychol* 1988;**39**:583–607.
36. Petersen AC, Crockett L, Rirchards M, Boxer A. A self-report measure of pubertal status: reliability, validity, and initial norms. *J Youth Adolesc* 1988;**17**:117–33.
37. Eloranta AM, Lindi V, Schwab U, Kiiskinen S, Kalinkin M, Lakka HM, et al. Dietary factors and their associations with socioeconomic background in Finnish girls and boys 6−8 years of age: the PANIC Study. *Eur J Clin Nutr* 2011;**65**:1211–8.
38. Faul F, Erdfelder E, Buchner A, Lang AG. Statistical power analyses using G*Power 3.1: tests for correlation and regression analyses. *Behav Res Methods* 2009;**41**:1149–60.
39. Faul F, Erdfelder E, Lang AG, Buchner A. G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behav Res Methods* 2007;**39**:175–91.
40. Suchert V, Hanewinkel R, Isensee B. Longitudinal relationships of fitness, physical activity, and weight status with academic achievement in adolescents. *J Sch Health* 2016;**86**:734–41.
41. Wittberg RA, Northrup KL, Cottrell LA. Children ' s Aerobic fitness and academic achievement : a longitudinal examination of students during their fifth and seventh grade years. *Am J Public Health* 2012;**102**:2303–7.
42. London RA, Castrechini S. A longitudinal examination of the link between youth physical fitness and academic achievement. *J Sch Health* 2011;**81**:400–8.
43. Syväoja HJ, Kankaanpää A, Kallio J, Hakonen H, Kulmala J, Hillman CH, et al. The relation of physical activity, sedentary behaviors, and academic achievement is mediated by fitness and bedtime. *J Phys Act Heal* 2018;**15**:135–43.
44. Belsky DW, Caspi A, Israel S, Blumenthal JA, Poulton R, Moffitt TE. Cardiorespiratory fitness and cognitive function in midlife: neuroprotection or neuroselection. *Ann Neurol* 2015;**77**:607–17.
45. Cotman CW, Berchtold NC, Christie LA. Exercise builds brain health: key roles of growth factor cascades and inflammation. *Trends Neurosci* 2007;**30**:464–72.
46. Crosnoe R. Friendships in childhood and adolescence : the life course and new directions. *Soc Psychol Q* 2000;**63**:377–91.
47. Spring B, Moller AC, Coons MJ. Multiple health behaviours: overview and implications. *J Public Health (Bangkok)* 2012;**34**:3–10.
48. Drollette ES, Scudder MR, Raine LB, Davis Moore R, Pontifex MB, Erickson KI, et al. The sexual dimorphic association of cardiorespiratory fitness to working memory in children. *Dev Sci* 2016;**19**:90–108.
49. Kwak L, Kremers SP, Bergman P, Ruiz JR, Rizzo NS, Sjöström M. Associations between physical activity, fitness, and academic achievement. *J Pediatr* 2009;**155**:914–8.
50. Gennatas ED, Avants BB, Wolf DH, Satterthwaite TD, Ruparel K, Ciric R, et al. Age-related effects and sex differences in gray matter density, volume, mass, and cortical thickness from childhood to young adulthood. *J Neurosci* 2017;**37**:5065–73.
51. Dollman J, Okely AD, Hardy L, Timperio A, Salmon J, Hills AP. A hitchhiker's guide to assessing young people's physical activity: deciding what method to use. *J Sci Med Sport* 2009;**12**:518–25.
52. Kamijo K, Khan NA, Pontifex MB, Scudder MR, Drollette ES, Raine LB, et al. The relation of adiposity to cognitive control and scholastic achievement in preadolescent children. *Obesity* 2012;**20**:2406–11.
53. Tanner J. *Growth at adolescence*. Oxford: Blackwell; 1962.
54. Hakala JO, Rovio SP, Pahkala K, Nevalainen J, Juonala M, Hutri-Kähönen N, et al. Physical activity from childhood to adulthood and cognitive performance in midlife. *Med Sci Sports Exerc* 2019;**51**:882–90.