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1 **The Associations between Leisure-Time Physical Activity and Academic**  
2 **Performance: A Twin Study**

3

4 **ABSTRACT**

5 **Background** Both genetic and environmental influences have been shown to contribute to  
6 the association between physical activity and overall academic performance. We examined  
7 whether leisure-time physical activity (LTPA) shares genetic and environmental variances  
8 between spelling, essay writing, reading aloud, reading comprehension and mathematics in  
9 early adolescence. Moreover, we investigated whether genetic polymorphisms associated  
10 with physical activity behavior affect these academic skills.

11 **Methods** Participants were 12-year-old Finnish twins (n=4356–4370 twins/academic skill,  
12 49% girls). Academic skills were assessed by teachers and LTPA was self-reported. Polygen-  
13 ic scores for physical activity behavior were constructed from the UK Biobank. Quantitative  
14 genetic modeling and linear regression models were used to analyze the data.

15 **Results** The trait correlations between LTPA and academic skills were significant but weak  
16 ( $r=0.05-0.08$ ). The highest trait correlation was found between LTPA and mathematics. A  
17 significant genetic correlation was revealed between LTPA and essay writing ( $r_A=0.14$ ). Re-  
18 garding polygenic scores of physical activity, the highest correlations were found with read-  
19 ing comprehension, spelling and essay writing, but these results only approached statistical  
20 significance (p-values 0.09–0.15).

21 **Conclusions** Our results suggest that reading and writing are the academic skills that most  
22 likely share a common genetic background with LTPA.

23 There is a strong body of research on the association between physical activity and academic  
24 performance<sup>1-4</sup>. However, recent systematic reviews have concluded that the levels of associ-  
25 ations between physical activity and different academic skills vary greatly<sup>5,6</sup>. The strongest  
26 evidence for the association with physical activity was found for mathematics by Singh et al.  
27 (2019)<sup>5</sup>, while Haverkamp et al. (2020)<sup>6</sup> only demonstrated a significant effect of physical  
28 activity on academic skills within the language domain. In addition to these conflicting asso-  
29 ciation findings within different academic skills, the direction of the potential association and  
30 the nature of causality between physical activity and academic performance has also re-  
31 mained under debate without any clear results on whether the association constitutes a causal  
32 effect<sup>7-10</sup>.

33

34 Previous studies have also shown that similar to overall academic performance, mathematic-  
35 and reading-specific academic skills are highly heritable<sup>11,12</sup>. Moreover, physical activity has  
36 been shown to be moderately heritable<sup>13,14</sup>. We have also shown, contrary to the idea of cau-  
37 sality, that the association between leisure-time physical activity (LTPA) and grade point  
38 average can partly reflect overlapping genetic and familial influences<sup>7</sup>. Therefore, a better  
39 understanding of common genetic and familial background that potentially account for the  
40 associations between physical activity and different academic skills would be warranted.

41

42 In this study, we aimed to examine to what extent LTPA and academic performance in  
43 spelling, essay writing, reading aloud, reading comprehension and mathematics share genetic  
44 and environmental influences in early adolescence using genetic twin modeling and polygen-  
45 ic scores (PGS). By using these two different methods, each making different methodological  
46 assumptions, we are able to analyze the genetic background of LTPA and academic perfor-  
47 mance more comprehensively than when relying on only one method.

**48 METHODS**

49 The participants of this study were drawn from the FinnTwin12 study, which is a population-  
50 based longitudinal study of health and behavior in Finnish twins born in 1983–1987<sup>15</sup>. The  
51 twins and their parents completed study questionnaires on health, behavior, lifestyle and so-  
52 cial/interpersonal environments when the twins were 11–12 years old (age range 10.8–12.3  
53 years). The response rate was 90%. Most of the twins were in the same class and had the  
54 same teacher who usually had a long-term teaching relationship with the twins. The teachers  
55 assessed the twins' behavior and academic skills at school. In this study, we had data availa-  
56 ble on LTPA and academic skills from 4356 to 4370 twins per skill (51% boys and 49%  
57 girls) including 2102 full twin pairs. DNA was extracted from blood and saliva samples col-  
58 lected when the twins were young adults (mean age 24.4 years). Within the sample, 32% of  
59 the twins were monozygotic, while 31% were same-sex dizygotic and 31% were opposite-sex  
60 dizygotic twins.

61

**62 ASSESSMENT OF ACADEMIC PERFORMANCE**

63 The teachers of the twins assessed spelling, essay writing, reading aloud, reading comprehen-  
64 sion and mathematics when the twins were at the mean age of 11.4 years with the following  
65 question specifically tailored for the study: "Please, evaluate a twin's performance in the fol-  
66 lowing academic skills compared to the average pupil in your class?". The response options  
67 were categorized as follows: 1) clearly below the average, 2) slightly below the average, 3)  
68 average, 4) slightly above the average, and 5) clearly above the average.

69

70

**71 ASSESSMENT OF LEISURE-TIME PHYSICAL ACTIVITY**

72 Twins self-reported their LTPA based on a structured question on the frequency of LTPA  
73 excluding physical education classes at school: “How often do you exercise in your leisure  
74 time?”. There were five response options: 1) not at all 2) two to three times in six months, 3)  
75 two to three times a month, 4) two to three times a week, and 5) just about every day.

76

**77 DEMOGRAPHIC VARIABLES**

78 The age of the twins was calculated based on their date of birth obtained from the Finnish  
79 Population Register Centre and the date of return of the study questionnaire. The sex of the  
80 twins was also provided by the Finnish Population Register Centre and cross-checked with  
81 the self-reported questionnaire data. The zygosity of the twins was mainly based on measured  
82 genotypes. However, there were a few twins who did not have a DNA sample and their  
83 zygosity was based on questions on physical similarity at age 11–12. This method has been  
84 shown to have high validity in this twin cohort<sup>16</sup>.

85

**86 POLYGENIC SCORES**

87 Genome-wide genotype data were used to produce PGS for physical activity behavior. The  
88 PGSs were constructed for self-reported and accelerometer-measured physical activity from  
89 the UK Biobank data that is based on the general UK population between ages 40–69<sup>17,18</sup>.  
90 The self-reported questions based on the “number of days/week of walked 10+ minutes”  
91 (PGS<sub>WALKING</sub>), “number of days/week of moderate physical activity 10+ minutes”  
92 (PGS<sub>MODERATE</sub>) and “number of days/week of vigorous physical activity 10+ minutes”  
93 (PGS<sub>VIGOROUS</sub>). The accelerometer-measured physical activity based on walking activity  
94 (PGS<sub>MEASURED WALKING</sub>), moderate intensity activity (PGS<sub>MEASURED MODERATE</sub>) and overall  
95 activity (PGS<sub>MEASURED TOTAL</sub>) was tracked with Axivity AX3 wrist accelerometer over 7

96 days<sup>19</sup>. Kujala et al. (2020)<sup>20</sup> have reported the details of the genotyping and polygenic scor-  
97 ing.

98

## 99 **STATISTICAL METHODS**

100 First, we estimated intra-class correlation coefficients to quantify the degrees to which  
101 monozygotic and dizygotic twins resemble each other for LTPA and academic skills (Sup-  
102 plementary table 1). The genetic twin modeling began by decomposing the trait variation in  
103 LTPA and academic skills into three components (additive genetic variation (A), shared envi-  
104 ronmental variation (C), and unique environmental variation (E)) and comparing different  
105 univariate models to select the best-fitting model (Supplementary table 2)<sup>21</sup>. Based on the  
106 best-fitting univariate model, we estimated genetic and environmental contributions to LTPA  
107 and academic skills by sex (Supplementary table 3): the contributions of genetic influences to  
108 LTPA were 30% in boys and 17% in girls, whereas the heritability estimates for the academic  
109 skills ranged from 64% to 77% in boys and from 53% to 69% in girls. Next, bivariate  
110 Cholesky decompositions were conducted to estimate trait correlations between LTPA and  
111 academic skills<sup>22</sup>. We further decomposed these trait correlations into genetic and environ-  
112 mental correlations and estimated to what extent the proportions of the trait correlations are  
113 explained by genetic and environmental factors. The bivariate Cholesky decompositions were  
114 also used to derive a test of causality between these two traits: a causal association should  
115 appear as both genetic and environmental correlations<sup>23</sup>. The correlations were initially per-  
116 formed based on the univariate model-fitting results. However, decompositions for boys and  
117 girls separately could not be reliably estimated; thus, we present the bivariate Cholesky de-  
118 composition results for both sexes as main findings. The findings for boys and girls separate-  
119 ly are shown in Supplementary table 4. OpenMx software (version 2.0.1) was used for these  
120 quantitative genetic analyses<sup>24</sup>.

121

122 We used linear regression models to analyze whether the academic skills were associated  
123 with genetic susceptibility to physical activity behavior (presented as PGSs). The physical  
124 activity-related PGSs and academic skills were scaled to obtain standardized normal distribu-  
125 tion with a mean of 0 and standard deviation of 1. The regression models were adjusted for  
126 sex and the first 10 genetic principal components to control for population stratification. Be-  
127 cause we analyzed twins as individuals, the regression models were controlled for the cluster-  
128 ing of twins within pairs because the observations between co-twins may be correlated. We  
129 used Stata 14.1 software (StataCorp, College Station, Texas, USA) to produce linear regres-  
130 sion models as well as baseline statistics. Descriptive statistics are presented in Supplemen-  
131 tary table 5. The means and standard deviations of LTPA and academic skills stratified by  
132 zygosity and sex are provided in Supplementary table 6.

133

#### 134 **ETHICS OF THE STUDY**

135 The ethics committee of the Department of Public Health of the University of Helsinki (Fin-  
136 land), the ethics committee of the Helsinki University Central Hospital District (Finland) and  
137 the Institutional Review Board of Indiana University (USA) approved the FinnTwin12 study  
138 protocol. The parents of the twins initially provided written informed consent for study par-  
139 ticipation, but as young adults, the twins themselves provided written informed consent for  
140 genetic analyses.

141

#### 142 **RESULTS**

143 The trait correlations between LTPA and academic skills were positive and statistically sig-  
144 nificant but weak (from 0.05 to 0.08) (Table 1). The highest trait correlation was found be-  
145 tween LTPA and mathematics. Based on the Cholesky decomposition, common genetic in-

146 fluences statistically significantly contributed to the association between LTPA and essay  
147 writing ( $r_A=0.14$ ), supporting a genetically-influenced mechanism underlying the association.  
148 The next highest genetic correlations were found between LTPA and reading aloud as well as  
149 between LTPA and mathematics (both  $r_A=0.11$ ), but these findings did not reach statistical  
150 significance. Even though the importance of familial factors in explaining the associations  
151 between LTPA and academic skills was highlighted by intra-class correlation coefficients and  
152 by the fact that shared environmental influences could not be dropped from the best-fitting  
153 final models (Supplementary table 2), no significant shared environmental correlations were  
154 found between LTPA and different academic skills. Furthermore, no significant unique envi-  
155 ronmental correlations between LTPA and academic skills were found.

156

157 The associations between genetic susceptibility to physical activity behavior (i.e., PGSs) and  
158 academic skills are shown in Table 2. The analyses revealed weak and non-significant associ-  
159 ations between the PGSs for physical activity behavior and academic skills: positive within  
160 PGSs based on the accelerometer-measured physical activity and mostly negative within  
161 PGSs based on the questionnaire-based physical activity. With regard to accelerometer-  
162 measured physical activity, the highest associations were found between  $PGS_{MEASURED\ WALK-}$   
163  $ING$  and spelling and essay writing (both  $r=0.05$ ), but these results only lean toward statistical  
164 significance ( $p=0.13$  and  $p=0.15$ , respectively). Although many associations related to PGSs  
165 based on the questionnaire-based physical activity were even lower than those based on the  
166 accelerometer-measured physical activity, the association between  $PGS_{VIGOROUS}$  and reading  
167 comprehension ( $r=-0.06$ ) approached statistical significance ( $p=0.09$ ). The next highest asso-  
168 ciations regarding the PGSs based on the questionnaire-based physical activity behavior were  
169 found between  $PGS_{VIGOROUS}$  and spelling ( $r=-0.05$ ,  $p=0.15$ ) as well as between  $PGS_{VIGOROUS}$   
170 and essay writing ( $r=-0.06$ ,  $p=0.15$ ).



171 **DISCUSSION**

172 By using genetically informative twin data, we examined the genetic and familial associa-  
173 tions between LTPA and academic skills in spelling, essay writing, reading aloud, reading  
174 comprehension and mathematics in early adolescence. Regarding the twin modeling, the most  
175 apparent finding to emerge was that all academic skills were positively associated with  
176 LTPA. We found the highest association between LTPA and mathematics. However, these  
177 observed associations between LTPA and academic skills shared genetic influences to a small  
178 extent; only the association between LTPA and essay writing was found to have a significant  
179 genetic component. Reading aloud and mathematics showed the next highest genetic correla-  
180 tion with LTPA, but without statistical significance. We found no significant environmental  
181 correlations (neither shared nor unique environmental correlations) between LTPA and aca-  
182 demic skills.

183

184 Contrary to the twin modeling results, PGSs for physical activity behavior were not signifi-  
185 cantly associated with academic skills – however, the results related to reading comprehen-  
186 sion, spelling and essay writing approached a customary level of statistical significance. It is  
187 important to note that PGSs were based on age groups older (i.e., 40–69-year-olds) than our  
188 study participants (i.e., 11–12-year-olds). This may potentially affect the associations found  
189 between PGSs and academic skills. The reality of the associations may be represented more  
190 accurately by PGSs based on the accelerometer-measured physical activity than based on the  
191 questionnaire-based physical activity because accelerometers may better reflect voluntary  
192 physical activity behavior and inherent physical activity abilities of the individual, regardless  
193 of the individual's age.

194

195 This study supports evidence from previous observations indicating a positive association  
196 between LTPA and academic performance<sup>1-3</sup>. We found the highest trait correlation between  
197 LTPA and mathematics, which reflects the results of the meta-analysis of Singh et al.  
198 (2019)<sup>5</sup>. Moreover, our study confirms the results of the previous studies indicating that  
199 LTPA is moderately<sup>13,14</sup> and academic performance highly heritable<sup>11,12,25,26</sup>. We found a sta-  
200 tistically significant genetic correlation ( $r_A=0.14$ ) regarding the association between LTPA  
201 and essay writing. This result, along with the non-overlapping shared environmental and non-  
202 overlapping unique environmental influences between LTPA and essay writing, challenges  
203 the assumption of a potential causal relationship between LTPA and essay writing by indicat-  
204 ing that there is a genetic relationship between these two traits (a causal association between  
205 LTPA and essay writing should appear as both genetic and environmental correlations). The  
206 genetic correlation of 0.14 we found between LTPA and essay writing is also in line with the  
207 genetic correlation estimate we found in our previous study between LTPA and grade point  
208 average for boys at age 12 ( $r_A=0.17$ ) when using the same data-set<sup>7</sup>. Overall, our twin model-  
209 ing and analyses related to PGSs show that reading and writing are the academic skills that  
210 most likely share a common genetic background: results are systematic yet not statistically  
211 significant regarding all estimates. Speculatively, these common genetic backgrounds might  
212 explain the trait correlations found between these traits as well as suggest that reading and  
213 writing represent, to a great extent, a grade point average.

214

215 In light of our previous study<sup>7</sup>, showing that the association between LTPA and grade point  
216 average was also partly explained by the overlapping familial environmental influences, it is  
217 somewhat surprising that common familial background was not found to exist between LTPA  
218 and any academic skill. It is possible that the academic performance data used in the current  
219 study did not reliably estimate shared environmental influences: the confidence intervals of

220 shared environmental correlations are wide, which may indicate that our data are underpow-  
221 ered to decompose shared environmental influences explaining the proportions of the trait  
222 correlations between LTPA and academic skills.

223

224 We focused on twins' frequency of LTPA, which greatly reflects voluntary behavior. Our  
225 assessment may be a restricted picture of the total LTPA, but it still represents twins' physical  
226 activity behavior in their leisure time. The validity of physical activity questionnaires used in  
227 Finnish twins have been demonstrated<sup>27,28</sup>. Academic skills were reported by teachers. The  
228 measurements were not standardized and not totally comparable but teachers evaluated the  
229 twins' skills as objectively as possible. In Finland, practically all teachers have undergone  
230 Master's level training and schools follow a national curriculum meaning that teachers' eval-  
231 uations are based on similar principles.

232

233 A further limitation is that our study design was cross-sectional. Even though our cross-  
234 sectional twin data contain genetic information that can be used to derive a test of causality  
235 between leisure-time physical activity and academic skills<sup>23,29</sup>, longitudinal studies would be  
236 more informative about the genetic and environmental influences behind the long-term asso-  
237 ciations between LTPA and academic skills. This is because the twin modeling results are  
238 always age- and time-specific, as well as sensitive to changes in the overall and environmen-  
239 tal variances. For example, we have shown in our previous study that an emotionally warm,  
240 supportive, and encouraging family environment in childhood can enhance children's genetic  
241 potential for voluntary physical activity even years after the influence of the home environ-  
242 ment in childhood<sup>30</sup>.

243

244 Major strengths of our study are the population-based sample and its large size and relatively  
245 equal sex representation. Due to the very high participation rate, various selection biases are  
246 also unlikely in our study. Thus, the generalizability of our study findings is good but limited  
247 to individuals at age 11–12 years. A further strength is that we were able to use two different  
248 measures to assess genetic influences affecting physical activity behavior: twin modeling and  
249 PGSs.

250

251 Despite some limitations, our study certainly adds to the understanding of the association  
252 between LTPA and academic performance. The most obvious finding to emerge from this  
253 study is that the roots of the associations between LTPA and academic skills related to writ-  
254 ing and reading may be due to common genetic influences rather than causality as previously  
255 speculated. However, it is important to be cautious interpreting our results because our sam-  
256 ple size may not have been large enough for the bivariate twin modeling analyses. Thus, this  
257 study should be repeated using larger twin or family samples – this may enable a more relia-  
258 ble assessment of potential overlapping shared environmental influences between LTPA and  
259 academic skills.

260

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268

269 **AUTHOR CONTRIBUTIONS**

270 R.J.R. and J.K. designed and contributed to the data collection of the FinnTwin12 study.  
271 S.A., U.M.K., J.K., and K.S. designed the present study. S.A., T.P. and K.S. conducted the  
272 statistical analyses. S.A. drafted the manuscript and T.P., R.J.R., J.K., U.M.K. and K.S. criti-  
273 cally revised the manuscript. All authors approved the final manuscript. The authors declare  
274 no conflict of interest.

275

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357



Physical Activity and Academic Performance

358 **Table 1** Trait correlations ( $r_{\text{trait}}$ ) as well as the correlations between additive genetic ( $r_A$ ), shared environmental ( $r_C$ ) and unique environmental ( $r_E$ )  
 359 influences for LTPA and academic skills with 95% confidence intervals at age 12.

Trait 1	Trait 2	Model	Trait correlation			Additive genetic correlation		Shared environmental factors		Unique environmental factors	
			$r_{\text{trait}}$ (95% CI)	$r_A$ (95% CI)	% Explained of $r_{\text{trait}}$	$r_C$ (95% CI)	% Explained of $r_{\text{trait}}$	$r_E$ (95% CI)	% Explained of $r_{\text{trait}}$		
Spelling	LTPA	Sexes combined	0.05 (0.01 to 0.09)	0.08 (-0.06 to -0.22)	80%	0.03 (-0.35 to 0.40)	11%	0.02 (-0.05 to 0.09)	9%		
Essay writing	LTPA	Sexes combined	0.06 (0.02 to 0.09)	0.14 (0.00 to 0.28)	*	-0.13 (-0.66 to 0.25)	*	0.03 (-0.05 to 0.10)	11%		
Reading aloud	LTPA	Sexes combined	0.05 (0.01 to 0.09)	0.11 (-0.03 to 0.25)	*	-0.06 (-0.41 to 0.24)	*	0.05 (-0.02 to 0.12)	22%		
Reading comprehension	LTPA	Sexes combined	0.05 (0.01 to 0.09)	0.01 (-0.13 to 0.14)	7%	0.16 (-0.11 to 0.44)	78%	0.03 (-0.04 to 0.11)	14%		
Mathematics	LTPA	Sexes combined	0.08 (0.04 to 0.12)	0.11 (-0.04 to 0.26)	74%	0.06 (-0.37 to 0.46)	14%	0.04 (-0.03 to 0.11)	12%		

360 CI=confidence intervals, LTPA=leisure-time physical activity, \*= cannot be calculated reliably

361

362 **Table 2** Associations between genetic susceptibility to physical activity behavior (presented as polygenic scores) and academic skills when sex  
 363 and the first 10 principal components are taken into account.

	Genetic susceptibility to physical activity behavior											
	Accelerometer-measured physical activity						Questionnaire-based physical activity					
	PGS <sub>MEASURED WALKING</sub>		PGS <sub>MEASURED MODERATE</sub>		PGS <sub>MEASURED TOTAL</sub>		PGS <sub>WALKING</sub>		PGS <sub>MODERATE</sub>		PGS <sub>VIGOROUS</sub>	
	B-coeff.	p-value	B-coeff.	p-value	B-coeff.	p-value	B-coeff.	p-value	B-coeff.	p-value	B-coeff.	p-value
Spelling	0.05	0.13	0.04	0.24	0.04	0.26	0.004	0.91	-0.01	0.76	-0.05	0.15
Essay writing	0.05	0.15	0.04	0.24	0.02	0.65	-0.04	0.31	-0.05	0.58	-0.06	0.15
Reading aloud	0.03	0.32	0.03	0.37	0.03	0.44	-0.01	0.71	-0.004	0.92	-0.04	0.27
Reading comprehension	0.04	0.19	0.01	0.75	0.02	0.60	-0.01	0.67	-0.03	0.34	-0.06	0.09
Mathematics	0.02	0.48	0.02	0.61	0.03	0.32	-0.001	0.97	0.006	0.86	-0.03	0.32

364 PGS=polygenic scores