Supplemental Digital Content 1: Appendix

THE LONGITUDINAL ASSOCIATIONS OF FITNESS AND MOTOR SKILLS WITH ACADEMIC ACHIEVEMENT

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Statistical analysis

In the first step, linear latent growth curve model (LGM) was specified separately for three-wave longitudinal data of GPA and PF (aerobic fitness, muscular fitness and motor skills) (unconditional model). Second, LGM for parallel processes were estimated to evaluate correlations among the growth parameters of GPA and PF. Third, the latent slope representing rate of change of GPA was separately regressed on growth parameters of each PF test (see Figure 1). The model was adjusted for potential confounding variables, including age, gender, pubertal stage, mother's education, learning difficulties and additionally for body fat percentage. Furthermore, interaction effects of body fat percentage and latent variables of level and slope of PF on GPA were tested for significance. If the interaction terms were not significant, they were dropped from the model. The level of GPA was allowed to correlate with all the explanatory variables.

The bivariate cross-lagged path models for GPA and each PF included all the autoregressive stability paths and cross-lagged effects between the measures (GPA was regressed on PF at previous time point and vice versa). The final models included GPA, motor skills and aerobic fitness / muscular fitness in the same model (GPA was regressed on aerobic fitness / muscular fitness and motor skills at previous time point and vice versa, and motor

skills was regressed on aerobic fitness / muscular fitness at previous time point and vice versa). Contemporal measurements were allowed to correlate in bivariate and final models. All regressions were adjusted for potential confounding factors, including age, gender, pubertal stage, mother's education, learning difficulties and additionally for body fat percentage. Furthermore, interaction effect of body fat percentage and PF (at T1 and T2) on GPA were tested for significance. If the interaction terms were not significant, they were dropped from the model.

At the first stage, all the regression models were estimated freely for girls and boys by using multi-group modeling (before entering the confounders). Equality of the regression coefficients across the gender groups were tested by using Wald test.

Because the data were clustered within classes, the standard errors of the parameter estimates of all the models were calculated using the special feature of Mplus (TYPE=COMPLEX).

Missing data were assumed to be missing at random (MAR). Before the modeling, the data were imputed. Multiple imputed data sets (n=20) were created and the data sets were analysed by using special feature of Mplus. The correlations and the parameters of the models were estimated by using the maximum likelihood with robust standard errors (MLR). The chi-squared (χ^2), the comparative fit index (CFI), the Tucker-Lewis Index (TLI), the root mean square error of approximation (RMSEA), and the standardized root-mean-square residual (SRMR) were used to evaluate the goodness-of-fit of the models. The model fits the data well if the ratio of the χ^2 to degrees of freedom is less than 3, CFI and TLI values are close to 0.95, the RMSEA value is below 0.06, and the SRMR value is below 0.08 [29].

Results

Missing data

Of the participants, 76.6% had complete GPA data from three measurement points, 16.1% had data from two measurement points, 6.6% had data from one measurement point and 0.6% of participant did not have information on academic achievement at all. Participants having complete GPA data were older (Mean=12.8, SD=1.1 vs. Mean=11.6, SD=1.2; $p<0.001$) and were at a more advanced pubertal stage (Mean=2.80, SD=0.96 vs. Mean=2.18, SD=0.86; $p<0.001$). The groups did not differ according to gender, body fat percentage, mother's education, learning difficulties, academic achievement or PF at baseline.

Of all the participants, 62.7% had valid PF data (at least one valid test result of PF) from all the measurement points, 25.7% from two measurement points, 10.8% from one measurement point and 0.8% did not have valid PF data at all. Participants having complete PF data were slightly younger compared to participants having incomplete data (Mean=12.4, SD=1.3 vs. Mean=12.7, SD=1.2; $p<0.001$) and were at a less advanced pubertal stage (Mean=2.59, SD=0.98 vs. Mean=2.77, SD=0.94; $p=0.008$). The groups did not differ according to gender, body fat percentage, mother's education, learning difficulties, academic achievement or PF at baseline.

Linear growth curve models (LGM)

The associations of the final LGM did not differ between girls and boys according to multi-group analyses (Table S1). Therefore, all the models were fitted for the whole sample. In order to avoid negative insignificant residual variances of GPA, these residual variances were assumed to be equal across measurement points. The unconditional models fitted the data well and there was significant variability in the growth parameters of each outcome (Table S2). Finally, GPA was regressed separately on growth parameters of PF and the model was controlled for potential confounding variables. The final models fitted the data well (Table S3).

The estimation results before entering body fat percentage in the model are presented in Table S4. The estimation results of the model including both the main effect body fat percentage and interaction effects of body fat percentage and growth factors of PF revealed no statistically significant interactions on the slope of GPA (data not shown). Therefore, interaction terms were dropped from the model.

Cross-lagged path models

Because the associations were similar for boys and girls based on multi-group analyses (see Table S1), the models were fitted for the whole sample. All the cross-lagged models fitted the data well (Table S3). The estimation results of the bivariate models controlled for age, gender, pubertal stage, mother's education, learning difficulties (Model 1) and additionally for body fat percentage (Model 2) are presented in Table S5. The estimation results of the models including interaction effects of body fat percentage and PF revealed no significant interaction effects on GPA (data not shown). Therefore, the interaction terms were dropped from the model. The estimation results of the final model including GPA, motor skills and aerobic fitness / muscular fitness in the same model before entering body fat percentage in the model are presented in the Figure S1.

Before entering body fat percentage in the model, positive indirect effect of aerobic fitness and muscular fitness on GPA through motor skills was observed (*B*=0.007, standard error *SE*=0.003, *p*=0.010 and *B*=0.004, *SE*=0.001, *p*=0.008; respectively)

Table S1. The results of multi-group analyses to examine gender differences in the associations.

	χ^2 (df) [d]	*p*
Linear growth models [a]		
Aerobic fitness	$\chi^2(2)=0.02$	0.99

Muscular fitness	$\chi^2(2)=0.13$	0.94
Motor skills	$\chi^2(2)=0.19$	0.91
Cross-lagged path models		
Bivariate models [b]		
Aerobic fitness (AF)	$\chi^2(10)=5.3$	0.87
Muscular fitness (MF)	$\chi^2(10)=12.3$	0.27
Motor skills (MS)	$\chi^2(10)=4.27$	0.93
Final models [c]		
MS + AF	$\chi^2(21)=8.6$	0.99
MS + MF	$\chi^2(21)=15.0$	0.82

[a] The rate of change (slope) of grade point average was regressed on growth parameters of physical fitness / motor skills.

[b] The bivariate cross-lagged path models for grade point average and physical fitness / motor skills.

[c] The cross-lagged path model for reciprocal associations among grade point average, motor skills and aerobic / muscular fitness

[d] Wald test for equality of the regression coefficients across gender groups

Table S2 Unconditional linear growth models. Model-fit statistics and the variance estimates of the growth parameters.

	Grade point average	Aerobic fitness	Muscular fitness	Motor skills
Model-fit statistics				
χ^2(df)	$\chi^2(3)=6.2$	$\chi^2(1)=0.92$	$\chi^2(1)=0.30$	$\chi^2(1)=0.26$
CFI	1.00	1.00	1.00	1.00
TLI	1.00	1.00	1.00	1.00
RMSEA	0.033	0.011	0.001	0.001
SRMR	0.048	0.005	0.004	0.003
Variance estimate (standard error)				
Level	0.69 (0.04)***	0.93 (0.07)***	2.30 (0.17)***	2.48 (0.18)***
Slope	0.03 (0.01)***	0.07 (0.03)**	0.24 (0.07)***	0.16 (0.06)**

*** $p < 0.001$; **$p < 0.01$, *$p < 0.05$

Table S3: Model fit statistics of the models (n=954).

	χ^2(df)	CFI	TLI	RMSEA	SRMR
Latent growth curve models [a, d]					
Aerobic fitness	$\chi^2(21)=47.6$	0.99	0.99	0.036	0.016
Muscular fitness	$\chi^2(21)=49.5$	0.99	0.98	0.037	0.016
Motor skills	$\chi^2(21)=54.0$	0.99	0.98	0.040	0.017
Cross-lagged path models					
Bivariate models [b, d]					
Aerobic fitness (AF)	$\chi^2(2)=0.90$	1.00	1.01	0.000	0.002
Muscular fitness (MF)	$\chi^2(2)=1.68$	1.00	0.99	0.008	0.001
Motor skills (MS)	$\chi^2(2)=0.80$	1.00	1.01	0.000	0.001
Final models [c, d]					
MS + AF	$\chi^2(6)=2.50$	1.00	1.01	0.000	0.002
MS + MF	$\chi^2(6)=7.10$	1.00	1.00	0.014	0.004

[a] Rate of change of grade point average (slope) was regressed on growth parameters of physical fitness / motor skills.

[b] The bivariate cross-lagged path models for grade point average and physical fitness / motor skills.

[c] The cross-lagged path model for reciprocal associations among grade point average, motor skills and physical fitness.

[d] The model was adjusted for gender, age, pubertal stage, body fat percentage, mother's high education and learning difficulties.

Table S4. The estimation results of linear latent growth curve models (n=954). Change of academic achievement (Slope of grade point average)

	Aerobic fitness			Muscular fitness			Motor skills		
	B	*SE*	*p*	*B*	*SE*	*p*	*B*	*SE*	*p*
The regression model for the slope of grade point average [a]									
Level of fitness / skills [b]	0.12	0.07	0.08	0.03	0.08	0.73	0.13	0.06	0.045
Slope of fitness / skills [b]	**0.28**	**0.09**	**0.002**	**0.34**	**0.10**	**<0.001**	0.21	0.11	0.051
The correlation coefficients between the growth factors									
Level of grade point average									
Slope of grade point average	0.12	0.07	0.07	0.15	0.07	0.028	0.13	0.06	0.038
Level of fitness / skills [b]	0.28	0.04	<0.001	0.29	0.04	<0.001	0.19	0.04	<0.001
Slope of fitness / skills [b]	0.03	0.07	0.68	0.06	0.07	0.37	0.06	0.07	0.42

Note. *B*, standardized regression coefficient; *CI*, confidence interval.

[a] The model was adjusted for gender, age, pubertal stage, mother's high education and learning difficulties.

[b] The name of the test corresponds case wisely the name presented in the columns (aerobic fitness, muscular fitness, motor skills)

Table S5. The estimation results of bivariate cross-lagged path models (n=954). The standardized regression coefficients are presented.

	Aerobic fitness						Muscular fitness						Motor skills					
	Model 1			Model 2			Model 1			Model 2			Model 1			Model 2		
	B	*SE*	*p*	*B*	*SE*	*p*	*B*	*SE*	*p*	*B*	*SE*	*p*	*B*	*SE*	*p*	*B*	*SE*	*p*
Grade point average T3																		
Physical fitness T2 [a]	0.05	0.02	0.009	0.05	0.02	0.013	0.04	0.02	0.009	0.04	0.02	0.037	0.06	0.02	<0.001	0.06	0.02	<0.001
Grade point average T2	0.71	0.04	<0.001	0.71	0.04	<0.001	0.71	0.04	<0.001	0.71	0.04	<0.001	0.71	0.04	<0.001	0.71	0.04	<0.001
Grade point average T1	0.20	0.05	<0.001	0.20	0.05	<0.001	0.20	0.04	<0.001	0.20	0.04	<0.001	0.19	0.04	<0.001	0.19	0.04	<0.001
Grade point average T2																		
Physical fitness T1 [a]	-0.01	0.02	0.44	-0.01	0.02	0.54	-0.04	0.02	0.05	-0.04	0.02	0.07	-0.03	0.02	0.08	-0.03	0.02	0.10
Grade point average T1	0.87	0.02	<0.001	0.87	0.02	<0.001	0.87	0.02	<0.001	0.87	0.02	<0.001	0.87	0.02	<0.001	0.87	0.02	<0.001
Physical fitness T3 [a]																		
Grade point average T2	0.07	0.03	0.032	0.07	0.03	0.026	0.05	0.03	0.14	0.05	0.03	0.14	0.02	0.02	0.39	0.02	0.02	0.41
Physical fitness T2 [a]	0.58	0.05	<0.001	0.56	0.05	<0.001	0.64	0.03	<0.001	0.63	0.04	<0.001	0.57	0.04	<0.001	0.56	0.04	<0.001
Physical fitness T1 [a]	0.24	0.05	<0.001	0.22	0.05	<0.001	0.21	0.04	<0.001	0.20	0.04	<0.001	0.29	0.04	<0.001	0.28	0.04	<0.001
Physical fitness T2 [a]																		
Grade point average T1	0.08	0.02	0.001	0.08	0.02	0.001	0.09	0.03	0.004	0.08	0.03	0.005	0.10	0.03	<0.001	0.09	0.03	<0.001
Physical fitness [a]	0.81	0.02	<0.001	0.75	0.02	<0.001	0.72	0.02	<0.001	0.65	0.03	<0.001	0.80	0.02	<0.001	0.75	0.02	<0.001

B, standardized regression coefficient; SE, standard error; T1, measurement in 2013; T2, measurement in 2014; T3, measurement in 2015;

Model 1 was adjusted for gender, age, pubertal stage, mother's high education, and learning difficulties.

Model 2 was adjusted for gender, age, pubertal stage, mother's high education, learning difficulties, and additionally for body fat percentage.

[a] The name of the test corresponds case wisely the name presented in the columns (aerobic fitness, muscular fitness or motor skills)

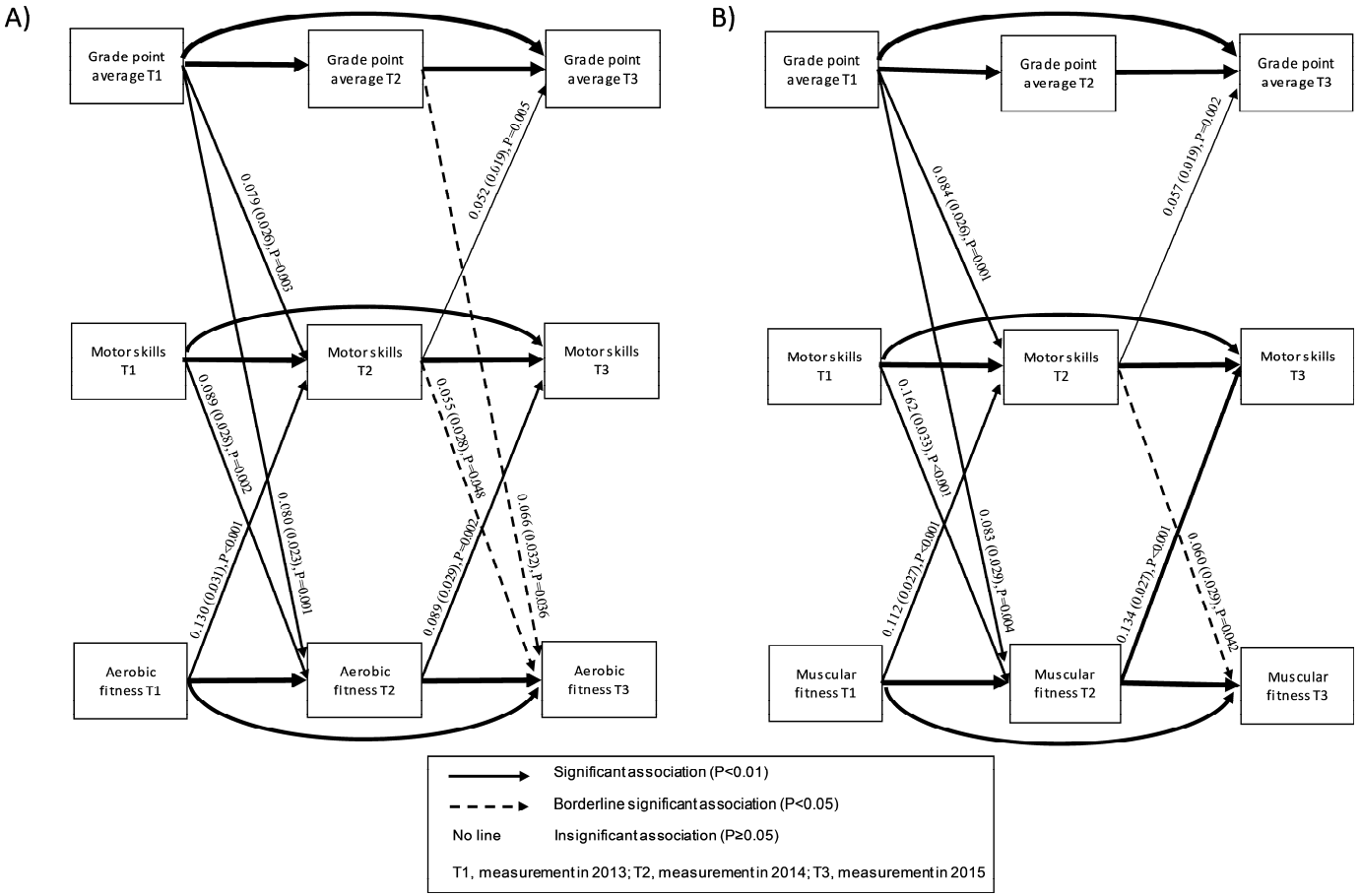
A)
Grade point average T1
Grade point average T2
Grade point average T3
Motor skills T1
Motor skills T2
Motor skills T3
Aerobic fitness T1
Aerobic fitness T2
Aerobic fitness T3
0.079 (0.026), P=0.003
0.052 (0.019), P=0.005
0.089 (0.028), P=0.002
0.055 (0.028), P=0.048
0.130 (0.031), P<0.001
0.080 (0.023), P=0.001
0.089 (0.029), P=0.002
0.096 (0.032), P=0.026
B)
Grade point average T1
Grade point average T2
Grade point average T3
Motor skills T1
Motor skills T2
Motor skills T3
Muscular fitness T1
Muscular fitness T2
Muscular fitness T3
0.084 (0.026), P=0.001
0.057 (0.019), P=0.002
0.162 (0.033), P<0.001
0.083 (0.029), P=0.004
0.112 (0.027), P<0.001
0.134 (0.027), P<0.001
0.060 (0.029), P=0.042
Significant association (P<0.01)
Borderline significant association (P<0.05)
No line
Insignificant association (P≥0.05)
T1, measurement in 2013; T2, measurement in 2014; T3, measurement in 2015

Figure S1. The estimation results of the final cross-lagged path models, before entering body fat percentage in the model for A) GPA, motor skills and aerobic fitness, and for B) GPA, motor skills and muscular fitness. The standardized regression coefficients (standard errors) are presented. The thicknesses of the lines are proportional to the size of coefficients.