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OPEN

The Longitudinal Associations of Fitness and Motor Skills with Academic Achievement

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ABSTRACT

SYVÄOJA, H. J., A. KANKAANPÄÄ, L. JOENSUU, J. KALLIO, H. HAKONEN, C. H. HILLMAN, and T. H. TAMMELIN. The Longitudinal Associations of Fitness and Motor Skills with Academic Achievement. *Med. Sci. Sports Exerc.*, Vol. 51, No. 10, pp. 2050–2057, 2019. **Purpose:** This study aimed to examine both independent and dependent longitudinal associations of physical fitness (PF) components with academic achievement. **Methods:** A total of 954 fourth to seventh graders (9–15 yr [M_{age} = 12.5 yr], 52% girls) from nine schools throughout Finland participated in a 2-yr follow-up study. Register-based academic achievement scores (grade point average [GPA]) and PF were assessed in the spring of 2013–2015. Aerobic fitness was measured with a maximal 20-m shuttle run test, muscular fitness with curl-up and push-up tests, and motor skills with a 5-leaps test and a throwing–catching combination test. Structural equation modeling was applied to examine the longitudinal associations adjusting for age, gender, pubertal stage, body fat percentage, learning difficulties, and mother's education. **Results:** The changes in aerobic and muscular fitness were positively associated with the changes in GPA (B = 0.27, 99% confidence interval [CI] = 0.06–0.48; B = 0.36, 99% CI = 0.11–0.63, respectively), whereas the changes in motor skills were not associated with the changes in GPA. Better motor skills in year 2 predicted better GPA a year later (B = 0.06, 99% CI = 0.00–0.11; B = 0.06, 99% CI = 0.01–0.11), whereas aerobic and muscular fitness did not predict GPA. GPA in year 1 predicted both aerobic (B = 0.08, 99% CI = 0.01–0.15) and muscular (B = 0.08, 99% CI = 0.02–0.15) fitness, and motor skills (B = 0.08, 99% CI = 0.02–0.15) a year later. **Conclusion:** The changes in both aerobic and muscular fitness were positively associated with the changes in academic achievement during adolescence, whereas the changes in motor skills had only borderline significant association. However, better motor skills, although not systematically, independently predicted better academic achievement 1 yr later, whereas aerobic or muscular fitness did not. Better academic achievement predicted better motor skills, aerobic fitness, and muscular fitness. Developmental changes in adolescence may induce parallel and simultaneous changes in academic achievement and PF. **Key Words:** AEROBIC FITNESS, MUSCULAR FITNESS, FUNDAMENTAL MOVEMENT SKILLS, ACADEMIC PERFORMANCE

Physical fitness (PF), including aerobic fitness, muscular fitness, and motor skills in childhood and adolescence, predicts many aspects of health later in life (1–3). In addition, higher levels of PF have been associated with better academic achievement in children and adolescents using both cross-sectional (4–6) and longitudinal (7–9) studies. More specifically, aerobic fitness (10–13) and motor skills (14–17), but not muscular fitness (12,18), have been positively associated with academic achievement (17). However, the associations of muscular fitness (19) and motor skills (17) with academic achievement have not been as extensively studied and are far less reported, to date. Despite previous literature indicating a largely positive relationship between PF and academic achievement, there remain inconsistencies in the findings as well as a lack of longitudinal studies adjusting for important confounding factors (20) to better understand the direct and indirect relationships among these variables. Importantly, no studies have examined independent or dependent predictive effects of aerobic or muscular fitness and motor skills on academic achievement.

Accordingly, the purpose of this study was to examine the longitudinal association of different components of PF with academic achievement while accounting for other factors (e.g., age, gender, pubertal stage, body fat percentage, learning

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difficulties, and mother's education) that have been found to relate to physical and academic outcomes. We further examined whether PF components in previous years independently or dependently predicted future academic achievement and *vice versa*. We predicted that changes in PF would be positively associated with changes in academic achievement and that PF components would independently predict future academic achievement. From a public health perspective, it is important to understand whether these health factors may also underline academic achievement, linking physical and cognitive health.

METHODS

Study Population and Design

The study was a part of the follow-up on the Finnish Schools on the Move program. The students were recruited from nine primary and lower secondary schools, five of which were participating in the program and four were not. Of the 1710 students in grades 4–7 (9–15 yr old) who were invited to participate in the study, 970 (12.6 ± 1.3 yr) volunteered their participation. Students' academic achievement and PF were assessed three times in the spring of 2013 (T1), 2014 (T2), and 2015 (T3). Student had his/her successive spring measurements in the same month. Both the students and their guardians gave written informed consent to participate. Children, who needed specialized support with individualized educational plan, were excluded from the analyses, and the final sample size was 954 (9–15 yr [M_{age} = 12.5 yr], 52% girls). The study protocol was approved by the Ethics Committee of the University of Jyväskylä.

Academic Achievement

The academic achievement scores (teacher-rated grades in individual school subjects) were provided by education services. Grade point averages (GPA) were calculated as the mean of the ollowing grades to indicate overall academic achievement: native language (in most cases, Finnish or Swedish), first foreign language (beginning in grade 3), mathematics, physics, chemistry, biology, geography, history, and religion or ethics. The grades refer to numerical assessment on a scale of 4–10, where 4 denotes failure and 10 denotes excellent knowledge and skills.

PF

Aerobic fitness, muscular fitness, and motor skills were assessed via measurements included in the Move!—a monitoring system for physical functional capacity (21,22). The measurements and reliability statistics are described in more detail in the study of Joensuu et al. (22). Measurements were performed on students by trained research staff. Students were able to practice the measurement techniques before the assessment. Students reported issues performing tests due to injuries and lack of motivation. In such instances, the student's test scores were recorded as missing values.

Aerobic fitness. Aerobic fitness was measured with a maximal 20-m shuttle run test (23). Running speed was gradually increased with 1-min intervals until maximal voluntary exhaustion. Measurement follows the Eurofit protocol (24) with slight modifications to the number of laps per stage, see supplement document in the study of Joensuu et al. (22). Initial speed was 8.0 $km{\cdot}h^{-1}$, next speed 9.0 $km{\cdot}h^{-1}$, and increment after that 0.5 $km{\cdot}h^{-1}$ per stage. Result was counted as the number of laps run during the test. The results were standardized according to gender and age-group.

Muscular fitness. Abdominal strength was measured with a curl-up test, which used a modified version of the FitnessGram curl-up (25) with slightly faster cadence. The number of curl-ups performed was counted with the maximal number of repetitions limited to 75. Upper-body muscle strength was measured with a push-up test (26). Boys and girls perform push-ups with different techniques; boys had hands and toes on the ground, whereas girls had hands and knees on the ground. The number of push-ups performed during a 1-min period was counted. The number of curl-ups and push-ups was standardized according to gender and age-group, and muscular fitness was calculated as a sum of the standardized scores.

Motor skills (fundamental movement skills). Locomotor skills were measured with the 5-leaps test (27). Students performed five consecutive leaps with the instruction to jump as far as they can. The first leap was performed with double legs and then followed by single leg leaps with alternating legs. Landing was performed on double legs. The length of the performance is recorded with 0.1-m accuracy. Manipulative skills were measured with a throwing–catching combination test (21). Students attempted to throw a tennis ball from a set distance with an overhand throw to a target placed on the wall and then catch the ball after one bounce. The number of correctly performed attempts out of 20 was counted. Both test results were standardized according to gender and age-group, and motor skills were calculated as a sum of the standardized scores.

Potential Confounding Factors

All potential confounding factors were assessed at the baseline assessment in spring 2013. A parent or guardian reported children's learning difficulties and mother's education by answering the following questions in a web-based survey: "Does your child have any diagnosed learning difficulties?" (categorization, yes [1] and no [0]). "What is the level of mother's education?" (categorization, tertiary level education [1] and basic or upper secondary education [0]). Children's body fat percentage was measured via body composition analyzer InBody 720 and pubertal stage via the self-assessment questionnaire and categorized according to the Tanner puberty stage (28).

Statistical Analyses

Descriptive statistics were calculated using the Statistical Package for the Social Sciences for Windows (version 20.0; SPSS Inc., Chicago, IL), and all further analyses were conducted using Mplus statistical package (version 7) (29). The descriptive statistics are presented as mean and SD or percentages. Differences in the study variables between girls and boys were tested via Student's *t*-test or Pearson's chi-squared test.

To study longitudinal associations of PF with academic achievement, data were analyzed in two ways using structural equation modeling. Linear growth curve modeling (LGM) was used to study whether the level and the development of PF were associated with the development of GPA over time. LGM allows capturing individual differences in development over time in the growth parameters, latent variables of level and slope. Level represents the initial status of the outcome and slope represents the rate of change of the outcome over time. The slope of GPA was separately regressed on the growth parameters of each PF test (Fig. 1). Furthermore, a cross-lagged path model was used to investigate bivariate predictive associations between PF and GPA and finally reciprocal associations among PF components and GPA in the same model. Indirect effects of interest were calculated and tested for significance. All the models were adjusted for potential confounding variables, including age, gender, pubertal stage, body fat percentage, mother's education, and learning difficulties. Details of the modeling procedure are presented in the Appendix (see Appendix, Supplemental Digital Content 1, Statistical Analysis, http://links.lww.com/MSS/B620). The significance level for the study was set at 0.01.

RESULTS

Table 1 presents gender-specific distributions and gender differences in observed variables at baseline. Information on

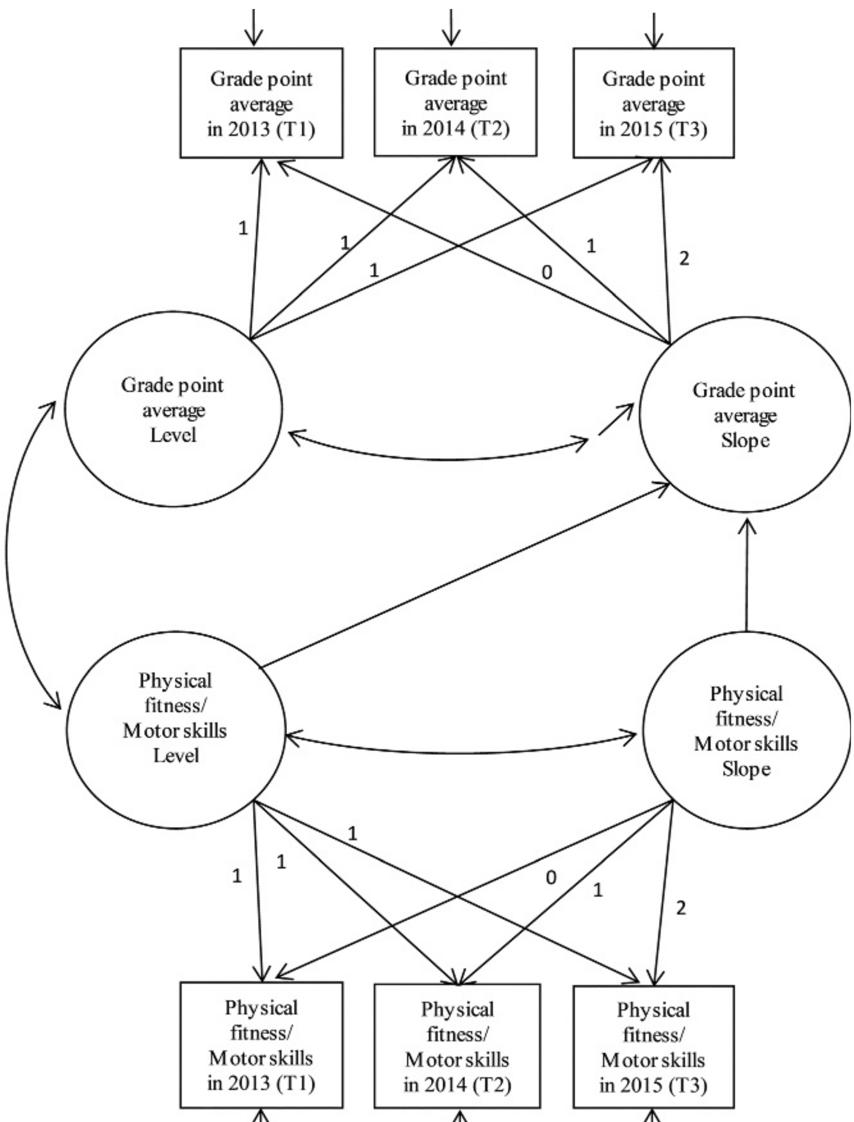

FIGURE 1—Path diagram of the final LGM. Circles denote latent variables and squares denote observed variables. The slope of GPA was regressed separately on growth factors of each PF and motor skills. All the regressions were adjusted for age, gender, mother's education, learning difficulties, and additionally body fat percentage.

TABLE 1. Gender-specific distributions and gender differences in observed variables at baseline.

	Total (*N* = 954)		Boys (*n* = 458)		Girls (*n* = 496)		
	n	Mean ± SD	*n*	Mean ± SD	*n*	Mean ± SD	*P*
Age (yr)	953	12.5 ± 1.3	462	12.6 ± 1.3	507	12.5 ± 1.3	0.57
Academic achievement (GPA)[a]	837	8.2 ± 0.7	403	8.0 ± 0.9	446	8.3 ± 0.9	<0.001
Aerobic fitness (laps)[b]	857	41.9 ± 18.9	407	47.5 ± 20.4	461	37.0 ± 15.9	<0.001
Muscular fitness							
Abdominal strength (repetitions)[c]	881	37.0 ± 20.5	422	39.6 ± 21.0	471	34.9 ± 19.9	0.001
Upper-body muscle strength (repetitions)[d]	864	20.5 ± 13.0	411	16.7 ± 11.7	464	22.1 ± 13.2	<0.001
Motor skills							
Locomotor skills (m)[e]	872	8.2 ± 1.1	415	8.5 ± 1.2	466	8.0 ± 1.0	<0.001
Manipulative skills (repetitions)[f]	886	12.0 ± 4.9	424	12.6 ± 5.0	474	11.5 ± 4.8	0.001
Body fat percentage (%)	899	18.4 ± 8.4	426	15.3 ± 8.3	485	21.2 ± 7.5	<0.001
Pubertal stage[g]	898	2.7 ± 1.0	426	2.7 ± 1.0	472	2.6 ± 0.9	0.14
Learning difficulties (yes)	607	10.4%	299	12.7%	308	8.1%	0.06
Mothers education (tertiary level education)	609	71.1%	299	74.6%	310	67.7%	0.06
Number of schools	9						
Number of classes	84						

P value for gender differences (Student's *t*-test or Pearson's chi-squared test).
[a]Academic achievement, GPA (a mean of the school grades with a scale of 4–10, where 4 denotes a failure and 10 denotes excellent knowledge and skills).
[b]Aerobic fitness, a maximal 20-m shuttle run test (the number of laps run).
[c]Abdominal strength, a curl-up test (the number of curl-ups performed).
[d]Upper-body muscle strength, a push-up test (the number of push-ups performed).
[e]Locomotor skills, a 5-leaps test (the length of the performance [m]).
[f]Manipulative skills, a throwing–catching combination test (the number of correctly performed attempts).
[g]Pubertal stage, based on self-assessment questionnaire and categorized according to the Tanner puberty stage, range 1–5.

missing data is provided in the Appendix (see Results, Missing data, Supplemental Digital Content 1, http://links.lww.com/MSS/B620).

LGM

The correlation coefficients among the growth parameters are presented in Table 2, and the estimation results of the final models are presented in Table 3 (see Results, LGM, and Tables S1–S3, Supplemental Digital Content 1, for details on modeling procedure, http://links.lww.com/MSS/B620). The changes in aerobic fitness and muscular fitness were positively associated with the changes in GPA (*B* = 0.27, 99% confidence interval [CI] = 0.06–0.48; *B* = 0.36, 99% CI = 0.11–0.63, respectively). In addition, the association between the change in motor skills and the change in GPA was borderline significant (*B* = 0.22, 99% CI = −0.06–0.50). These associations were adjusted for age, gender, pubertal stage, body fat percentage, mother's education, and learning difficulties.

Cross-Lagged Path Models

The estimation results of the bivariate cross-lagged path models revealed that better motor skills at T2 predicted better GPA a year later (*B* = 0.06, 99% CI = 0.01–0.11), but not *vice versa*, whereas aerobic and muscular fitness had a borderline significant predictive effect on GPA (*B* = 0.05, 99% CI = 0.00–0.10 and *B* = 0.04, 99% CI = −0.01–0.09, respectively) (see Results, Cross-Lagged Path Models, and Tables S1 and S3, Supplemental Digital Content 1, for details on the modeling procedure, http://links.lww.com/MSS/B620, and Table S4, Supplemental Digital Content 1, for results, http://links.lww.com/MSS/B620). Better GPA at T1 predicted better aerobic and muscular fitness (*B* = 0.08, 99% CI = 0.03–0.13 and *B* = 0.08, 99% CI = 0.00–0.16, respectively) and motor skills (*B* = 0.09, 99% CI = 0.01–0.17) a year later, but not *vice versa*. The following results are the estimated results of the final models, including GPA, motor skills, and aerobic fitness or muscular fitness in the same model (see text and Tables S1 and S3, Supplemental Digital Content 1, for details on the modeling procedure, http://links.lww.com/MSS/B620). All the regressions were adjusted for age, gender, pubertal stage, body fat percentage, mother's education, and learning difficulties.

GPA. Better GPA at T1 predicted better aerobic fitness at T2 (*B* = 0.08, 99% CI = 0.01–0.15, Fig. 2A). Furthermore, a predictive effect of GPA at T2 on better aerobic fitness at T3

TABLE 2. The correlation coefficients between the growth parameters (*n* = 954).

		GPA		Aerobic Fitness		Muscular Fitness		Motor Skills	
		Level	Slope	Level	Slope	Level	Slope	Level	Slope
GPA	Level	1							
	Slope	0.21**	1						
Aerobic fitness	Level	0.29***	0.07	1					
	Slope	0.03	0.24*	−0.23**	1				
Muscular fitness	Level	0.30***	0.01	0.75***	−0.16	1			
	Slope	0.09	0.46**	−0.11	0.95***	0.02	1		
Motor skills	Level	0.19***	0.11	0.68***	−0.20*	0.65***	−0.06	1	
	Slope	0.06	0.17	−0.08	0.57**	−0.02	0.61**	−0.23**	1

****P* < 0.001.
***P* < 0.01.
**P* < 0.05.

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TABLE 3. The estimation results of LGM (n = 954).

	Aerobic Fitness			Muscular Fitness			Motor Skills		
	B	99% C1	*P*	*B*	99% CI	*P*	*B*	99% CI	*P*
The regression model for the slope of GPA[a]									
Level of fitness/skills[b]	0.13	−0.07 to 0.32	0.10	0.00	−0.26 to 0.25	0.99	0.16	−0.05 to 0.32	0.058
Slope of fitness/skills[b]	**0.27**	**0.06** to **0.48**	**0.001**	**0.36**	**0.11** to **0.63**	**<0.001**	0.22	−0.06 to 0.50	0.046
The correlation coefficients between the growth factors									
Level of GPA									
Slope of GPA	0.12	−0.04 to 0.28	0.05	0.15	−0.03 to 0.33	0.031	0.03	−0.23 to 0.27	0.85
Level of fitness/skills[b]	0.28	0.19 to 0.38	<0.001	0.29	0.19 to 0.39	<0.001	0.17	0.07 to 0.28	<0.001
Slope of fitness/skills[b]	0.03	−0.15 to 0.20	0.69	0.07	−0.12 to 0.25	0.37	0.33	−0.04 to 1.02	0.016

Change of academic achievement (slope of GPA). *B*, standardized regression coefficient.
[a]The final model was adjusted for gender, age, pubertal status, body fat percentage, 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, and motor skills).

was borderline significant (B = 0.07, 99% CI = −0.01–0.15; Fig. 2A). Better GPA at T1 predicted better muscular fitness at T2 (B = 0.08, 99% CI = 0.02–0.15; Fig. 2B), but GPA at T2 did not predict muscular fitness at T3. Similarly, better GPA at T1 predicted better motor skills at T2 (B = 0.08, 99% CI = 0.01–0.15, Fig. 2A; B = 0.08, 99% CI = 0.02–0.15, Fig. 2B), but GPA at T2 did not predict motor skills at T3.

Aerobic and muscular fitness. Aerobic fitness or muscular fitness did not predict GPA. Better aerobic fitness predicted better motor skills at every time point (B = 0.09, 99% CI = 0.02–0.17; B = 0.08, 99% CI = 0.01–0.16), and motor skills at T1 predicted better aerobic fitness at T2 (B = 0.07, 99% CI = 0.00–0.15) (Fig. 2A). Likewise, better muscular fitness predicted better motor skills (B = 0.08, 99% CI = 0.02–0.15; B = 0.13, 99% CI = 0.06–0.20), and *vice versa* at T1 (B = 0.13, 99% CI = 0.04–0.21) (Fig. 2B).

Motor skills. Better motor skills at T2 predicted better GPA at T3 (B = 0.06, 99% CI = 0.00–0.11, Fig. 2A; B = 0.06, 99% CI = 0.01–0.11, Fig. 2B). However, motor skills at T1 did not predict GPA at T2.

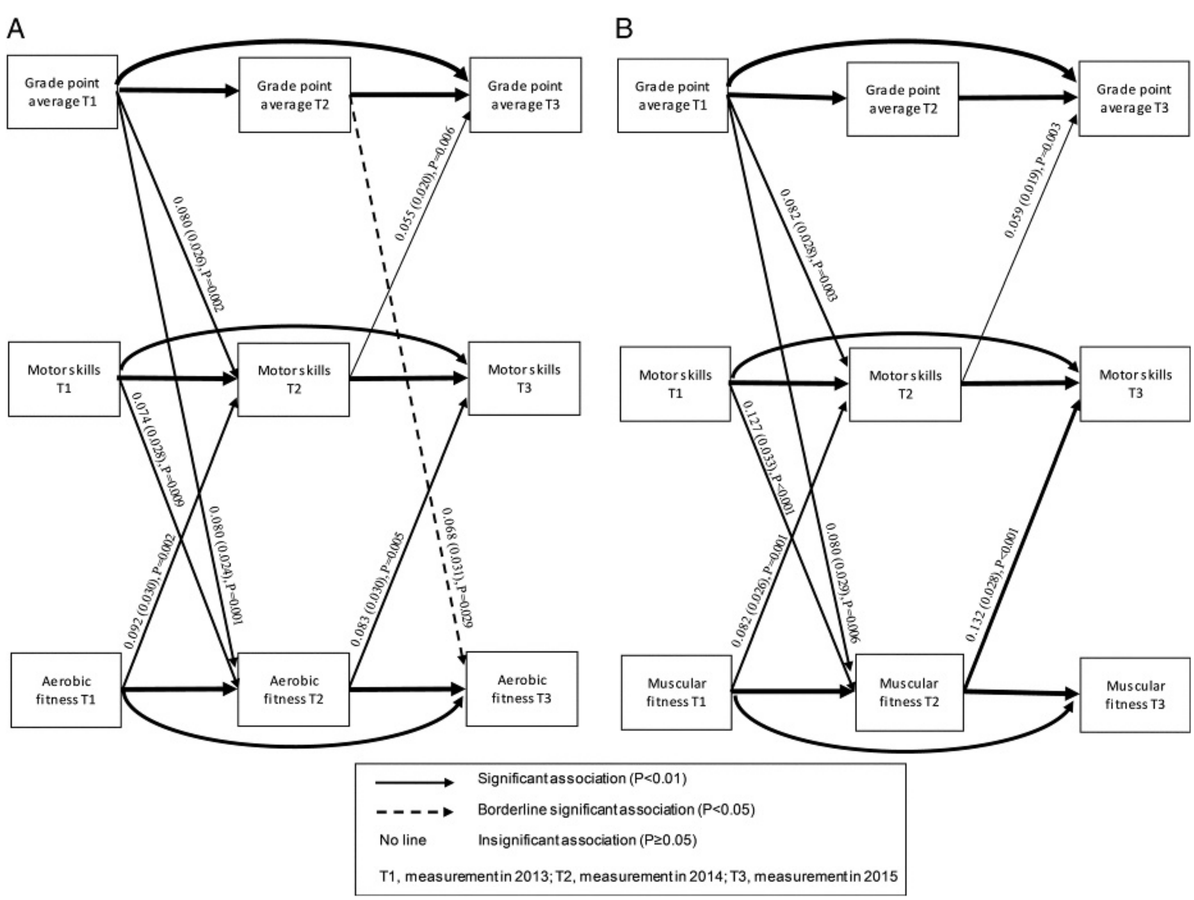

FIGURE 2—The estimation results of the final cross-lagged path models for GPA, motor skills, and aerobic fitness (A) and for GPA, motor skills, and muscular fitness (B) (n = 954). The standardized regression coefficients (standard errors) are presented. The thicknesses of the lines are proportional to the size of coefficients.

Indirect Effects

A positive predictive effect of aerobic fitness on GPA through motor skills was borderline significant (B = 0.005, SE = 0.002, P = 0.029). Likewise, a positive predictive effect of muscular fitness on GPA through motor skills was borderline significant (B = 0.003, SE = 0.001, P = 0.028).

DISCUSSION

Main study findings. This 2-yr longitudinal study showed that changes in both aerobic and muscular fitness were positively associated with changes in academic achievement during adolescence, whereas changes in motor skills had only borderline significant association with changes in academic achievement. However, better motor skills at T2 independently predicted better academic achievement 1 yr later, whereas aerobic or muscular fitness did not. Further, better academic achievement at T1 predicted better motor skills, aerobic fitness, and muscular fitness at T2. In addition to direct analyses, indirect analyses suggest that both aerobic and muscular fitness may have a positive predictive effect on academic achievement through motor skills performance.

Motor skills and academic achievement. Previous studies have shown that better motor skills in childhood and adolescence predict better academic achievement later in adolescence (14,16). Kantomaa et al. (14) showed that compromised motor skills (fundamental movement skills and fine motor skills) in childhood predicted lower academic achievement in adolescence. Similarly, Jaakkola et al. (16) showed that higher fundamental movement skills measured in grade 8 predicted better academic achievement in grade 9. Although the change in motor skills was not clearly associated with the change in academic achievement, our results support previous findings by showing that better motor skills at T2 predicted better academic achievement 1 yr later. However, a similar association was not seen during the year before (T1). Furthermore, our results are in line with Muntader-Mas et al. (17), who showed that speed–agility had a strongest and most independent (of other fitness components) association with academic achievement.

Aerobic and muscular fitness and academic achievement. Previous longitudinal studies have shown that higher fit adolescents have higher academic achievement scores compared with lower fit adolescents; however, these studies have not been able to demonstrate a significant effect of the fitness trajectory on academic achievement scores across time (7,8). The latest longitudinal studies demonstrated that improvements in aerobic fitness (13) and PF in general (9) were associated with improvements in academic achievements. Bezold et al. (9) indicated that an increase in fitness expressed as a composite of three fitness test (aerobic capacity, muscle strength, and endurance) was associated with an increase in academic scores and, importantly, that a decrease in fitness was also associated with a decrease in academic scores.

Our results are in line with these previous studies showing that change in both aerobic and muscular fitness was positively associated with change in academic achievement. However, given the nature the study design, our findings from linear growth curve analysis do not yet indicate a causal relationship. That is, the observed changes in fitness measures and academic achievement that occur around the same point in development suggest a beneficial relationship between physical health and cognition, but such an observation may be due to other (unidentified) factors and, thus, may be independent of each other. Our cross-lagged analyses strengthen this idea. Aerobic or muscular fitness did not predict academic achievement independently. The predictive association of both aerobic and muscular fitness with future academic achievement became marginally significant when body fat percentage were added to the bivariate models (see Results, Table S5 and Fig. S1, Supplemental Digital Content 1, for details, http://links.lww.com/MSS/B620). Although body fat and aerobic or muscular fitness did not have statistically significant interaction effects on academic achievement in this study, body fat appears to hinder the predictive effect of fitness on some level. The related study of Esteban-Cornejo et al. (30) showed that even in a homogeneous sample of overweight and obese children, body fat mediated the association of aerobic fitness and overall cortical thickness and suggested that body fat may hinder the beneficial effect of fitness on brain health. Furthermore, when motor skills were added to the models along with aerobic or muscular fitness and body fat, the predictive effect of aerobic fitness and muscular fitness became nonsignificant (Fig. 2), illustrating the strong role of motor skills. These findings differ from previous findings, which suggest that aerobic fitness is independently associated with academic achievement (12,13). More longitudinal research is needed to clarify the independent and dependent predictive effects of PF on academic achievement and cognitive health.

Indirect associations. In this study, we also examined the indirect effects of aerobic and muscular fitness with academic achievement through motor skills. The findings herein suggest that aerobic and muscular fitness did not predict academic achievement directly but may have a positive predictive effect on academic achievement via motor skills performance. These results suggest that motor skills performance is a stronger factor in association with academic achievement than aerobic or muscular fitness and may underlie the associations of aerobic and muscular fitness with academic success. Previous studies have shown that low perceptions of motor competence predict physical inactivity, poor fitness, and obesity, whereas low levels of physical activity may lead to low motor skills and poor fitness (31). These results highlight the importance of such physical activity, which enhances motor skills.

Other possible factors mediating the association between fitness and academic achievement are brain functioning and cognition. That is, better aerobic fitness has been positively associated with enhanced cerebrovascular function and increased molecular and cellular factors in the brain (32), as well as structural and functional changes in subcortical and cortical structures (33–36). Such changes in neural architecture and function enhance cognitive functions (37) and in that way may affect academic achievement.

Bidirectional association of PF and academic achievement. Our results also show that higher academic achievement at T1 predicted better motor skills during the next year. Although motor fitness did not systematically predict academic achievement or *vice versa*, the results suggest that a positive bidirectional loop may exist between motor fitness and academic achievement, with better academic achievement predicting better motor fitness and better motor fitness predicting better academic achievement. Previous studies have shown that motor skills are not fully developed until adolescence; likewise, complex cognitive functions, especially executive functions important for learning and academic success, continue to develop throughout childhood and adolescence (38–40). In addition, motor development and cognitive development are closely interrelated (38,40), which may explain the close relationship between motor fitness and academic achievement.

In a related study, Aaltonen et al. (41) indicated that better academic performance in adolescence modestly predicted more frequent leisure-time physical activity in late adolescence and young adulthood. According to neuroselection hypothesis, intelligence enhances individuals' ability to make better choices related to physical health (42). Furthermore, adolescence is a period of the life span characterized by the rapid development of life management skills, including physical, behavioral, and cognitive skills, needed in every life (43). Better cognitive ability and higher-level of life management skills may drive the motivation to succeed in both academics and PF tests, and therefore explain the association of physical health and academic success. In conclusion, it is possible that the associations of PF and activity with academic performance is bidirectional.

Strengths and limitations. This study contributes to the current paucity of research in the literature examining the longitudinal association of aerobic fitness, muscular fitness, and motor skills with academic achievement in adolescence. This study has several strengths in that we used a large and representative study sample, a large range of PF components were assessed, several important confounding factors were considered, and we used a comprehensive analytical approach that utilized structural equation modeling. Further, this study is the first study showing the dependent predictive role of the motor skills and PF in association with academic performance. The major limitation herein was that academic achievement scores were based on teacher ratings. However, to counter potential biases of individual teacher ratings, class and school were also considered in the analyses. There remains a need for intervention studies to confirm these results.

CONCLUSIONS

In this study, the changes in both aerobic and muscular fitness were positively associated with change in academic achievement during adolescence, whereas the change in motor skills had only borderline significant association with the change in academic achievement. However, better motor skills, although not systematically, independently predicted better academic achievement 1 yr later, whereas aerobic or muscular fitness did not. Further, better academic achievement predicted better motor skills, aerobic fitness, and muscular fitness. Developmental changes, both biological and behavioral, during adolescence may induce parallel and simultaneous changes in academic achievement and PF, and understanding such relationships may be important for our understanding of public health during adolescence.

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