Cross-Lagged Associations between Physical Activity, Motor Performance, and Academic Skills in Primary School Children

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ABSTRACT

HAAPALA, E. A., A. WIDLUND, A.-M. POIKKEUS, R. A. LIMA, S. BRAGE, P. AUNIO, and T. A. LAKKA. Cross-Lagged Associations between Physical Activity, Motor Performance, and Academic Skills in Primary School Children *Med. Sci. Sports Exerc.*, Vol. 55, No. 8, pp. 1465–1470, 2023. **Purpose:** Few longitudinal studies have investigated the interwoven longitudinal dynamics between physical activity (PA), motor performance, and academic skills in middle childhood. Therefore, we investigated the cross-lagged associations between PA, motor performance, and academic skills from grade 1 to grade 3 in Finnish primary school children. **Methods:** A total of 189 children 6–9 yr old at baseline comprised the study sample. Total PA was assessed using a questionnaire filled out by parents, moderate-to-vigorous PA by combined heart rate and body movement monitor, motor performance by 10 × 5-m shuttle run test, and academic skills by arithmetic fluency and reading comprehension tests in grade 1 and grade 3. Data were analyzed using structural equation modeling adjusted for gender, parental education, and household income. **Results:** The final model fitted the data very well (χ^2_{37} = 68.516, P = 0.0012, root-mean-square error of approximation = 0.067, comparative fit index = 0.95, Tucker–Lewis Index = 0.89) and explained 91% of variance in the latent academic skills variable, 41% of the variance in the latent PA variable, and 32% of variance in motor performance in grade 3. Better motor performance in grade 1 was associated with higher academic skills in grade 3, but it did not predict PA. PA was not directly or indirectly associated with academic skills. However, higher levels of PA in grade 1 predicted better motor performance in grade 3. Academic skills did not predict PA or motor performance. **Conclusions:** These results suggest that better motor performance, but not PA, predicts later academic skills. Academic skills in grade 1 do not contribute to PA or motor performance in the early school years. **Key Words:** EXERCISE, MOTOR SKILLS, ACADEMIC PERFORMANCE, SCHOOL PERFORMANCE

Basic academic skills, including reading fluency, reading comprehension, and acquisition of arithmetic skills, create the foundation for academic performance. Although ensuring basic academic skills are critical for future academic achievement and education, national reports in Finland and other countries suggest a recent decline in acquiring these skills (1–3). Moreover, less than half of school-age children achieve recommended levels of physical activity (PA) (4), and their motor performance has deteriorated by 0.9%–6.4% during past decades (5). Insufficient levels of PA and declining motor performance are alarming because they may increase the risk of several health problems (6,7). Physical inactivity and poor motor performance may also impair academic performance (8). However, few longitudinal studies have investigated the interwoven longitudinal dynamics between PA, motor performance, and academic skills in middle childhood. Such evidence would be important to increase knowledge on this issue and generating information for tools and models to prevent potential developmental risks.

PA and motor performance have been associated with prerequisites of academic skills in children, such as beneficial changes in brain and cognitive functions (8,9). Accordingly, cross-sectional and longitudinal studies suggest positive

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associations of PA and motor performance with academic performance in children (8,10,11). The results of some intervention studies also indicate a small beneficial effect of PA on academic performance in children, but the evidence is far from conclusive (12).

Previous studies typically assume a unidirectional association from increased PA and motor performance to enhanced academic performance (13,14). However, the developmental dynamics between PA, motor performance, and academic performance are unlikely to be unidirectional. Nevertheless, the results of studies exploring the developmental dynamics between PA, motor performance, and academic performance have been mixed, and to the best of our knowledge, no previous studies have integrated both PA and motor performance in their analyses. Syväoja et al. (10) observed that motor performance was associated with later academic performance and that academic performance was associated with motor performance a year later in children 12 yr of age. However, Aaltonen et al. (15) found that better academic performance was associated with higher levels of PA in later years among adolescents and young adults, but not *vice versa*. Therefore, the associations between PA, motor performance, and academic performance could be bidirectional. Although increased PA and motor performance may relate to better academic performance, it is equally possible that children and adolescents with better academic achievement choose a lifestyle improving motor performance and PA levels (16). However, few longitudinal studies have explored the associations between PA, motor performance, and academic performance, and none of them have studied their developmental dynamics in middle childhood.

Developmental dynamics between PA, motor performance, and academic skills could have a different pattern of relationship in middle childhood compared with adolescence (17). However, little is known about these cross-lagged associations in middle childhood (14). Furthermore, previous studies on the associations between PA, motor performance, and academic performance have mostly used grade point averages or achievement test scores as measures of academic performance (8,10,15). These measures are only crude indicators of skill development and miss the sensitivity to changes in learning progress (18). We, therefore, investigated the cross-lagged associations between PA, motor performance, and academic skills, measuring learning progress and assessed by arithmetic fluency and reading comprehension, among Finnish children across the first 3 yr of primary school.

METHODS

Participants and Procedure

The present longitudinal analyses on PA and motor performance are based on the baseline (grade 1) and 2-yr (grade 3) assessments of the Physical Activity and Nutrition in Children (PANIC) study (19). Data on academic skills were derived from the First Steps study, as described in detail previously (20). The PANIC study and the First Steps study are independent studies conducted simultaneously among primary school children in the city of Kuopio, Finland. The PANIC study is a PA and diet intervention and follow-up study aiming to investigate the associations between lifestyle and cardiometabolic risk factors. The First Steps study was a 5-yr follow-up study in a population sample of 2000 children from four municipalities. The main purpose of the First Steps study was to investigate the developmental pathways between learning, motivation, and problem behavior. Altogether 207 children participated in both studies. The present study sample includes 189 children (81 girls [43%] and 108 boys [57%]) with data from two measurement waves.

The Research Ethics Committee of the Hospital District of Northern Savo approved the PANIC study protocol, and the Research Ethics Committee of the University of Jyväskylä approved the First Steps study protocol. The parents or caregivers of the children gave their written informed consent, and the children provided their assent to participation.

Assessments

Academic skills. Reading comprehension and arithmetic fluency as measures of academic skills were assessed at the end of grades 1 and 3 using group-administered tests in classrooms by trained research assistants who were supervised by a senior researcher. Reading comprehension was assessed with a group-administered subtest from the ALLU test battery (21). After reading a short text, children were asked to answer 12 multiple-choice questions concerning facts, causal relationships, interpretations, or conclusions drawn from the text. The test score was the number of correct answers, ranging from 0 to 12, during the 30-min test period when the children were allowed to refer to the original text. Reading comprehension in the ALLU test battery has been validated against reading skills evaluated by the children's classroom teachers. Reading comprehension tests in grade 1 had relatively strong correlations ($r \approx 0.50$, $P < 0.001$) with reading skills rated by teachers in grade 1 (21). Reading comprehension in grades 1–3 assessed by ALLU tests has been reported to have a moderate to high Kuder–Richardson reliability coefficient (>80), suggesting good internal consistency. Arithmetic fluency was assessed using a basic arithmetic fluency test with addition and subtraction tasks (22). Children were asked to perform as many calculations as possible during the 3-min time limit. The test score was the number of correct answers, ranging from 0 to 28. The Cronbach's alphas for the addition and subtraction tasks were >0.70 in grades 1 and 2 (23).

PA. The extent of participation in various types of PA was assessed using the PANIC Physical Activity Questionnaire filled by the parents together with their child, as described previously (24). The types of PA included 1) unsupervised PA, 2) supervised PA (organized sports and organized exercise other than sports), 3) physically active school transportation (such as walking and bicycling), 4) PA during school recess, and 5) physical education. The questionnaire items focused on the frequency of each type of PA and the average duration of the sessions. Time spent in each type of PA was calculated by

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multiplying the frequency of the PA with the average duration of the PA session and was expressed in hours per week. Total PA volume was computed by summing up the time spent in each PA type. PA questionnaires with a similar structure to the PANIC Physical Activity Questionnaire, such as the Youth Physical Activity questionnaire, have shown good short–term repeatability over 4 d with an intraclass correlation of 0.86–0.92 (25).

Moderate to vigorous PA was assessed using a combined heart rate and movement sensor (Actiheart®; CamNtech Ltd., Papworth, UK), which was attached to the chest with two standard ECG electrodes (26). The children were asked to wear the sensor continuously for a minimum of 4 d (including sleep and water-based activities) without changing their usual behavior. The heart rate data were individually calibrated using the data from a maximal cycle ergometer exercise test. We defined moderate to vigorous PA as activities exceeding the intensity of four metabolic equivalents of tasks (METs). Combined heart rate and movement sensing has been found to be more accurate in estimating PA energy expenditure than either method alone in children (27,28), explaining 86% of variance in PA energy expenditure variance (28).

Motor performance. Speed and agility as a measure of motor performance were assessed by the 10 × 5-m shuttle run test (29). The children were asked to run 5 m from a starting line to another line as fast as possible, to turn on the line, to run back to the starting line, and to continue until five shuttles were completed. The test score was the running time in seconds, with a longer time indicating poorer performance. The 10 × 5-m shuttle run test has been found to be reliable with an intraclass correlation of 0.69 between the measurements taken 1 wk apart (30), and the 4 × 10-m speed and agility shuttle run test has been reported to have moderate to good reproducibility with a 0.1 s intertrial difference (31).

Other assessments. Stature and weight were measured by standard procedures, as described in detail previously (20). Body mass index standard deviation score was calculated based on the Finnis reference data (32). The parents were asked to report their annual household income, which was categorized as ≤30 000€, 30 001–60 000€, and >60 000€ for the analyses. The parents were also asked to report their highest completed or ongoing educational degrees (e.g., vocational school or less, polytechnic and university), and the education of the more educated parent was used in the analyses.

Statistical Analyses

Differences between boys and girls were investigated using the Student's *t*-test, and the correlations between study variables were analyzed using Pearson's coefficients of correlation. Because of slightly skewed distributions of and missing data in some variables, full information maximum likelihood with robust standard errors using all available information was used in the structural equation model analyses. A series of structural equation models were fitted to the data to explore cross-lagged associations between PA, motor performance, and academic skills from grade 1 to grade 3. All analyses were conducted using the MPLUS (version 8) (33).

In building the structural equation model, a model was specified in which the total score from the questionnaire- and device-based PA, which were specified to load on one PA factor to represent overall PA (latent variable), and reading comprehension and arithmetic fluency were specified to represent overall academic skills in grades 1 and 3 (latent variables). At the next step, autoregressive and cross-lagged paths were drawn from PA, motor performance, and academic skills from grade 1 to grade 3. Based on our previous findings suggesting that motor performance mediates the association of PA with academic skills in children (34), we examined indirect pathways from PA and motor performance in grade 1 to academic skills in grade 3. We also investigated whether PA mediates the associations between motor performance and academic skills in a separate model, but that pathway was not statistically significant. Because of the relatively small sample size in relation to the complexity of our model, we opted not to include this pathway in the final model. The residual variance of arithmetic fluency in grade 1 and grade 3 and the residual variances of device-based PA in grade 1 and grade 3 were allowed to be correlated in the model. Last, gender, parental education, and household income were added as covariates to the model. These possible confounding factors were all specified to have a direct effect on PA, motor performance, and academic skills in grade 1.

In all analyses, chi-square (χ^2), the comparative fit index (CFI; cutoff value >0.95), the Tucker–Lewis Index (TLI; cutoff value close to >0.95), and the root-mean-square error of approximation (RMSEA; a cutoff value close to <0.05) were used as indices of model fit (35). The 95% bootstrap confidence intervals with 1000 bootstrap draws were used to test the statistical significance of indirect effects.

RESULTS

Characteristics of Children and Correlations between Variables. Boys were physically more active and had

TABLE 1. Basic characteristics in grade 1.

	All, Mean (SD)	Boys, Mean (SD)	Girls, Mean (SD)	*P*
Background characteristics				
Age (yr)	7.67 (0.4)	7.7 (0.4)	7.6 (0.3)	0.030
Stature (cm)	129 (5.6)	130.0 (6.0)	128.5 (5.1)	0.056
Weight (kg)	27.2 (5.3)	27.6 (5.5)	26.9 (4.9)	0.349
BMI-sds	−0.17 (1.1)	−0.18 (1.1)	−0.15 (1.1)	0.834
Household income (%)				0.831
≤30,000	22.5	13.0	9.5	
>30,000–60,000	43.5	23.0	20.5	
>60,000	34.0	20.0	14.0	
Parental education (%)				0.711
Vocational school or less	20.6	13.7	6.9	
Polytechnic	39.7	19.1	20.6	
University	39.7	23.5	16.2	
PA (min·d^{-1})				
Total PA[a]	106 (39.1)	113.5 (42.3)	95.4 (32.0)	<0.001
Moderate to vigorous PA[b]	104 (62.5)	122.8 (66.1)	79.9 (48.0)	<0.001
Motor performance				
Shuttle run test time (s)	24.1 (2.2)	23.6 (2.1)	24.8 (2.2)	<0.001
Academic performance				
Arithmetic fluency	10.3 (4.2)	10.0 (4.5)	10.5 (3.8)	0.445
Reading comprehension	4.9 (2.2)	4.6 (3.4)	5.2 (3.3)	0.217

[a]Total PA assessed by questionnaire.
[b]Moderate to vigorous PA assessed by combined heart rate and movement sensor.
BMI-sds, body mass index standard deviation score.

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TABLE 2. Correlations between academic skills, PA, motor performance, and the measures of socioeconomic status.

	1	2	3	4	5	6	7
Arithmetic fluency		0.36*	−0.03	0.00	−0.15	0.10	0.20*
Reading comprehension	0.47*		−0.04	−0.03	−0.05	0.11	0.25*
Total PA[a]	−0.05	0.03		0.26*	−0.18*	−0.02	−0.05
Moderate to vigorous PA[b]	0.03	−0.03	0.36*		−0.20*	0.00	0.05
Motor performance	−0.25*	−0.12	−0.17*	−0.27*		−0.06	−0.12
Household income	0.10	0.06	0.02	0.08	0.02		0.55*
Parental education	0.05	0.24*	0.00	0.03	−0.05	0.55*	

Correlations between grade 1 measures are presented to the left side of the diagonal, and grade 3 correlations are to the right.
[a]Total PA assessed by questionnaire.
[b]Moderate to vigorous PA assessed by combined heart rate and movement monitor.
*$P < 0.05$.

better motor performance than girls (Table 1). There were no other differences between boys and girls. Bivariate correlations between the main study variables are presented in Table 2.

Cross-Lagged Associations between PA, Motor Performance, and Academic Skills. The final model fit was strong (χ^2_{37} = 68.516, P = 0.0012, RMSEA = 0.067, CFI = 0.95, TLI = 0.89) and explained 91% of the variance in the latent academic skills variable, 41% of the variance in the latent PA variable, and 32% of the variance in motor performance in grade 3. Statistically significant pathways are depicted in Figure 1.

Better motor performance in grade 1 was associated with higher academic skills in grade 3. PA was not directly or indirectly associated with academic skills (β = −0.13, 95% CI = −0.003 to 0.002). However, higher levels of PA in grade 1 predicted better motor performance in grade 3. Academic skills did not predict PA or motor performance. Parental education or household income was not associated with PA, motor performance, or academic skills in grade 1. However, girls had slightly better academic skills but lower levels of PA and poorer motor performance than boys.

DISCUSSION

We found that motor performance in grade 1 predicted academic skills in grade 3. On the other hand, PA was not associated with academic skills. Furthermore, academic skills did not predict PA or motor performance. Finally, we found that PA predicted motor performance but not *vice versa*. These results, thus, suggest that better motor performance, but not PA, predicts academic skills later in the early school years, whereas academic skills do not contribute to later PA or motor performance.

Our findings do not support the premise of bidirectional relationships among PA, motor performance, and academic skills in middle childhood, although the findings of some previous studies in older children and adolescents partly support this hypothesis (10,11,15,16). In their conceptual model, Stodden et al. (36) suggested that the developmental dynamics between PA, motor performance, and related health outcomes could differ at different stages of childhood and adolescence. Because school beginners' awareness of habits promoting health may be limited, it can be expected that the level of early stages of very fundamental academic skills, such as arithmetic fluency and reading comprehension, reflecting the ability for understanding verbal language and being fast and accurate in addition and subtraction tasks, does not necessarily show relations to later PA or motor performance (17,37,38). Increased knowledge of the benefits of PA may become a more important determinant of PA and motor performance in adolescence (17). Children may have less freedom to choose to be physically active, and their knowledge and mental processes may need to be developed to make decisions to become more active (37). Children may also be more motivated to seek unhealthy activities that cause immediate feelings of pleasure compared with adolescents and adults (39). However, more studies are needed to confirm these age-related findings.

Better motor performance may predict advanced academic skills through shared characteristics and skill basis involved

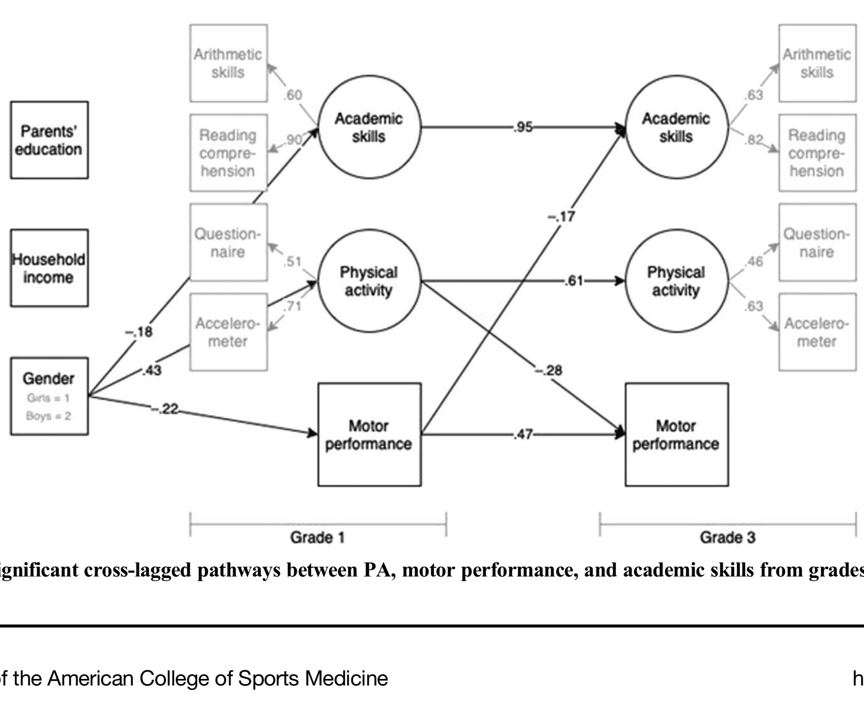

FIGURE 1—Statistically significant cross-lagged pathways between PA, motor performance, and academic skills from grades 1 to 3.

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in motor control and prerequisites of learning, such as attention, working memory, and on-task behavior (40–42). These associations could also be explained by better social acceptance, school connectedness, or school readiness among children with higher levels of motor performance (43). Versatile and motor skill-challenging PA has also been found to improve motor performance (44,45). PA during early childhood may partly explain the association between motor performance and academic skills (34), although motor performance was associated with academic skills independently of PA. Our findings suggest that the developmental pathways between PA, motor performance, and academic skills could be multifaceted and depend on the age of the children. However, the interpretation of these results should be conducted cautiously because this study examined cross-lagged associations using only two time points.

A strength of our study was the population sample of children followed up from grade 1 to grade 3. The academic skill measures used in the present study can be considered to be more sensitive indicators of academic performance than grade point averages or standardized test scores (46). However, reading comprehension and arithmetic fluency describe only a narrow aspect of academic learning. Therefore, more comprehensive measures of academic performance should be prioritized in future studies, providing a more holistic representation of academic skills. Moreover, we used overall habitual PA as a latent variable. However, some studies suggest that the associations between PA and academic performance could be context specific, and it is possible that some specific types of PA, such as sports participation (46), have a pronounced effect on academic skills. Such activities may involve a structured and motivating environment, higher PA intensity, cognitive challenges, and social aspects contributing to academic performance (46). Based on the approach of the AlphaFit test battery, we used a shuttle run test as a measure of motor fitness (47). However, future studies should investigate whether using different measures of motor performance provides similar results. Although the aims of the PANIC study and the First Steps study were different, it is plausible that participation in the PANIC study did not affect to results of the First Steps study and *vice versa*. However, we cannot completely rule out the cross-contamination of the effects. Finally, although a strength of this paper was that we investigated the longitudinal associations between PA, motor performance, and academic skills, more research is needed to understand better the causal relations between these factors among different age-groups and by using randomized control trials are needed.

CONCLUSIONS

In conclusion, we found that higher motor performance, but not PA, predicts academic skills 2 yr later among Finnish primary school beginners. We also observed that academic skills in grade 1 did not predict later PA or motor performance. These results suggest that good motor performance could reflect school readiness and could be relevant for academic success, even compared with that of overall PA in the very early grades.

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E. A. H., A. W., R. A. L., P. A., and T. A. L. participated the conception of the study. A. M. P., S. B., and T. A. L. collected the data. A. W. conducted the analyses, and A.W. together with E. A. H. produced the first draft of the manuscript. All authors participated in drafting and revising the manuscript, provided significant intellectual contribution to the manuscript, and approved the final version of the manuscript. All authors agree to be accountable for the work and to ensure that any questions relating to the accuracy and integrity of the paper are investigated and properly resolved. All authors contributed to the article and approved the submitted version.

The results of this study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation. The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest. The results of the present study do not constitute endorsement by the American College of Sports Medicine.

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