Associations of Motor and Cardiovascular Performance with Academic Skills in Children

Eero A. Haapala,¹ Anna-Maija Poikkeus,² Tuomo Tompuri,¹,³ Katriina Kukkonen-Harjula,¹,⁴ Paavo H.T. Leppänen,⁵ Virpi Lindi,¹ and Timo A. Lakka¹,⁶

¹Department of Physiology, Institute of Biomedicine, University of Eastern Finland, Kuopio, Finland, ²Department of Teacher Education, University of Jyväskylä, Jyväskylä, Finland, ³Department of Clinical Physiology and Nuclear Medicine, Kuopio University Hospital, Kuopio, Finland, ⁴UKK Institute for Health Promotion Research, Tampere, Finland, ⁵Department of Psychology, University of Jyväskylä, Jyväskylä, Finland, ⁶Kuopio Research Institute of Exercise Medicine, Kuopio, Finland

Accepted for Publication: 6 October 2013

Medicine & Science in Sports & Exercise® Published ahead of Print contains articles in unedited manuscript form that have been peer reviewed and accepted for publication. This manuscript will undergo copyediting, page composition, and review of the resulting proof before it is published in its final form. Please note that during the production process errors may be discovered that could affect the content.

Copyright © 2013 American College of Sports Medicine
Associations of Motor and Cardiovascular Performance with Academic Skills in Children

Eero A. Haapala, Anna-Maija Poikkeus, Tuomo Tompuri, Katriina Kukkonen-Harjula, Paavo H.T. Leppänen, Virpi Lindi, and Timo A. Lakka

1Department of Physiology, Institute of Biomedicine, University of Eastern Finland, Kuopio, Finland, 2Department of Teacher Education, University of Jyväskylä, Jyväskylä, Finland, 3Department of Clinical Physiology and Nuclear Medicine, Kuopio University Hospital, Kuopio, Finland, 4UKK Institute for Health Promotion Research, Tampere, Finland, 5Department of Psychology, University of Jyväskylä, Jyväskylä, Finland, 6Kuopio Research Institute of Exercise Medicine, Kuopio, Finland

Corresponding author:
Eero A. Haapala, MSc in Exercise Medicine, University of Eastern Finland, Institute of Biomedicine / Physiology, PO Box 1627, FI-70211 Kuopio, Finland,
e-mail: ehaapala@student.uef.fi, telephone: +358 40 725 4025, fax: +358 17 162 131

Sources of funding:
This study was funded by grants from the Ministry of Social Affairs and Health of Finland, the Ministry of Education and Culture of Finland, the University of Eastern Finland, the Finnish Innovation Fund Sitra, the Social Insurance Institution of Finland, the Finnish Cultural Foundation, the JuhoVainio Foundation, the Foundation for Paediatric Research, the Paulo Foundation, the Paavo Nurmi Foundation and the Kuopio University Hospital (EVO funding number 5031343).

Running title: Physical performance and academic skills

The authors declare no conflicts of interest
ABSTRACT

**Purpose:** We investigated the associations of cardiovascular and motor performance in Grade 1 with academic skills in Grades 1–3.

**Methods:** The participants were 6–8-year-old children with complete data in Grades 1–2 for 174 children and in Grade 3 for 167 children. Maximal workload during exercise test was measure of cardiovascular performance. Shuttle run test (SRT) time, errors in balance test and number of cubes moved in box and block test (BBT) were measures of motor performance. Academic skills were assessed using reading fluency, reading comprehension and arithmetic skill tests.

**Results:** Among boys, longer SRT time was associated with poorer reading fluency in Grades 1–3 (β=-0.29 to -0.39, \( P<0.01 \)), reading comprehension in Grades 1–2 (β=-0.25 to -0.29, \( P<0.05 \)) and arithmetic skills in Grades 1–3 (β=-0.33 to -0.40, \( P<0.003 \)). Poorer balance was related to poorer reading comprehension (β=-0.20, \( P=0.042 \)). Smaller number of cubes moved in BBT was related to poorer reading fluency in Grades 1–2 (β=0.23 to 0.28, \( P<0.03 \)), reading comprehension in Grade 3 (β=0.23, \( P=0.037 \)) and arithmetic skills in Grades 1–2 (β=0.21 to 0.23, \( P<0.043 \)). Among girls, longer SRT time was related to poorer reading fluency in Grade 3 (β=-0.27, \( P=0.027 \)) and arithmetic skills in Grade 2 (β=-0.25, \( P=0.040 \)). Smaller number of cubes moved in BBT was associated with worse reading fluency in Grade 2 (β=0.26, \( P=0.030 \)). Cardiovascular performance was not related to academic skills.

**Conclusions:** Poorer motor performance was associated with worse academic skills in children, especially among boys. These findings emphasize early identification of children with poor motor performance and actions to improve these children’s motor performance and academic skills during the first school years.

**Key words:** Physical activity, exercise, cognition, childhood
INTRODUCTION

Physical activity has decreased and sedentary activity, such as watching television and using computer, has increased during the past decades among children (37). This trend may explain the worsened cardiovascular and motor performance of children (14, 32, 33). Aerobic exercise particularly improves cardiovascular performance (2), whereas neuromuscular activity, e.g. physically active play, more likely improves motor performance (29). Lower levels of physical activity and cardiovascular and motor performance have been associated with an increased cardiometabolic risk (1, 23, 32), but there is also some evidence suggesting that they are related to a poorer cognitive function and academic achievement in children (13, 16).

Children with poorer cardiovascular performance show more weaknesses in cognitive functions required for school success, such as executive control and working memory, than children with better cardiovascular performance (6, 7). Moreover, lower levels of cardiovascular performance have been linked to smaller hippocampal and basal ganglia volumes (4, 5) and a less efficient neuroelectric processing (15) accompanied with a poorer cognitive function among prepubertal children.

Some studies have documented associations between a poorer motor performance and a poorer academic achievement among children (13). Also, a poorer gross-motor performance has been linked to larger learning deficits among children with learning disabilities (38). An interwoven relationship between motor performance and academic skills is indicated by findings showing an association between infant motor development and language development (17) which, in turn, predicts school-age reading skills (28).

The association of cardiovascular performance with cognitive function has been investigated in many studies, but little is known about the relation of motor performance to cognition or
academic skills (40). Although cardiovascular and motor performance are known to be interrelated (23), their independent associations with academic skills remain unclear. To our knowledge, there are no prospective studies on the independent associations of cardiovascular and motor performance with academic skills in children. We therefore investigated whether cardiovascular and motor performance in Grade 1 independently predict reading and arithmetic skills in Grades 1–3 among primary school children.

METHODS

Study design and study population

Data were derived from two independent studies being conducted simultaneously among primary school children in the City of Kuopio, Finland. Cardiovascular and motor performance were assessed in Grade 1 at the baseline examinations of The Physical Activity and Nutrition in Children (PANIC) Study, which is an ongoing exercise and diet intervention study in a population sample of children (11). Of the 736 invited children, 512 (70%) participated in the baseline examinations in 2007–2009. Reading and arithmetic skills were assessed at the end of Grades 1–3 in The First Steps Study (26). This five-year study following a population-based sample of 2000 children was conducted in 2006–2011. Altogether 207 children from the City of Kuopio participated in The PANIC Study and The First Steps Study. Complete data from the PANIC baseline examinations in Grade 1 and the First Steps follow-up examinations in Grade 2 were available for 174 children (99 boys, 75 girls), and complete data from the First Steps follow-up examinations in Grade 3 were available for 167 children (96 boys, 71 girls).

Boys in the study sample had less errors in the balance test ($P = 0.001$), a lower maximal workload per kg of lean body mass in the exercise test ($P = 0.046$) and a poorer reading comprehension in Grade 1 ($P = 0.01$) and Grade 2 ($P = 0.012$) than boys who were not in the
study sample. Girls in the study sample had a lower maximal workload per kg of lean body mass in the exercise test ($P = 0.006$) and had lower levels of total physical activity ($P = 0.003$) than girls who were not in the study sample. There were no differences in other measures used in the present analyses between children in the study sample and those who were not in the study sample.

The PANIC Study protocol was approved by the Research Ethics Committee of the Hospital District of Northern Savo, Kuopio, and The First Steps Study protocol was approved by the Research Ethics Committee of the University of Jyväskylä. All participating children and their parents provided written informed consent.

**Assessments**

All assessments in The PANIC Study and The First Steps Study were supervised and performed by trained and qualified research personnel. An exercise specialist or a nutritionist instructed the parents to fill out the PANIC questionnaires that included items on a number of topics, including physical activity, parent’s education and parents’ body height. A physician, a research nurse or a nutritionist of The PANIC Study assessed body height and weight, pubertal status, cardiovascular performance and motor performance at Institute of Biomedicine, University of Eastern Finland. A physician or an exercise specialist of The PANIC Study supervised the shuttle run tests that were performed at gyms of the schools of the City of Kuopio. A research nurse assessed body fat mass, fat percentage and lean mass in Department of Clinical Physiology and Nuclear Medicine in Kuopio University Hospital. Trained university students with a bachelor’s degree assessed the academic skills and the risk of reading disabilities under supervision of a research coordinator in The First Steps Study in the schools of the City of Kuopio.
Body composition

Body fat mass, fat percentage and lean mass were measured with the child empty-bladdered, in a supine position and wearing light clothing using a Lunar® dual-energy X-ray absorptiometry (DXA) device (Lunar Prodigy Advance; GE Medical Systems, Madison, WI) (39). Body weight was measured twice after overnight fasting, empty bladdered, and standing in light underwear using a calibrated InBody® 720 bioelectrical impedance device (Biospace, Seoul, Korea) to an accuracy of 0.1 kg. The mean of these two values was used in the analyses. Body height was measured three times in the Frankfurt plane without shoes using a wall-mounted stadiometer to an accuracy of 0.1 cm. Body mass index (BMI) was calculated as body weight (kg) divided by height (m) squared. Overweight and obesity were defined using the age and sex-specific BMI cut off points proposed by Cole and coworkers (8).

Cardiovascular performance

Cardiovascular performance was assessed using a maximal exercise test with an electromagnetically-braked Ergoline® cycle ergometer (Ergoselect 200 K; Ergoline, Bitz, Germany). The exercise test protocol included a 3-minute warm-up period at 5 Watts, a 1-minute steady-state period at 20 Watts, an exercise period with a workload increase of 1 Watt every 6 seconds until exhaustion and a 4-minute cooling-down period at 5 Watts (36). The exercise test was considered maximal if it was continued until exhaustion. Maximal workload at the end of the exercise test, as expressed in Watts per kilograms of lean body mass or in Watts per kilograms of body weight, was used as measures of cardiovascular performance. Maximal workload had a very strong correlation with maximal oxygen uptake in a subsample of 38 children from the present study population ($r = 0.90$, $P < 0.001$), indicating that maximal workload is a valid measure of cardiovascular performance among children.
Motor performance

The shuttle run test was used to assess speed and agility (12). The children were asked to run five meters as fast as possible, to turn on a mark, to run back to the starting line and to continue until five shuttles were completed. The test score was the running time, a longer time indicating a poorer performance.

The flamingo balance test was used to assess static balance (12). The children were asked to stand on one leg with eyes closed for 30 seconds. The test score was the number of floor touches with a free foot or eye openings during 30 seconds, a larger number of floor touches and eye openings indicating a poorer static balance.

The box and block test was used to assess manual dexterity (25). The children were asked to pick up small wooden cubes one by one with the dominant hand from one side of a wooden box and to move as many cubes as possible to the other side of the box for one minute and to repeat the same task with the non-dominant hand. The test score was the total number of cubes moved to the other side of the box, a smaller number of cubes moved indicating a poorer manual dexterity.

The overall motor performance was calculated as the sum of a reversed shuttle run test Z-score, a reversed flamingo balance test Z-score and a box and block test Z-score. The Z-scores were computed using the current study sample. A lower score indicated a poorer overall motor performance.

Academic skills

Reading fluency was assessed using a group-administered speeded subtest of the nationally-normed reading achievement battery (ALLU) (21). The test score was the number of correct
answers, ranging from 0 to 80, during a two-minute time limit for items that involved identifying the correct word from four phonologically similar alternatives linked to an adjoining picture.

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-minute test period when the children were allowed to refer to the original text.

Arithmetic skills were assessed using a basic arithmetic test (31) with a set of visually presented addition and subtraction tasks. The test score was the number of correct answers, ranging from 0 to 28, within the 3-minute time limit.

**Confounding factors**

The parents were asked to report in a questionnaire their completed or ongoing educational degrees (vocational school or less, polytechnic or university). The degree of the more educated parent was used in the analyses. Habitual physical activity was assessed by the PANIC Physical Activity Questionnaire filled out by the parents. Total physical activity was calculated by summing up the amounts of different types of physical activity (organized sports, organized exercise, unsupervised physical activity, physically active school transport, physical activity during recess, physical education) and was expressed in minutes per day. Total physical activity in Grade 1 had a strong positive correlation with total physical activity in Grade 3 using the same questionnaire among children in the control group of the PANIC Study ($r = 0.49$, $P < 0.001$), indicating a good long-term reproducibility for the PANIC Physical Activity Questionnaire. The correlation of total physical activity with maximal workload per body weight during a maximal
exercise test in Grades 1 and 3 was also relatively strong \( (r = 0.39–0.41, P < 0.001) \), indicating validity for the PANIC Physical Activity Questionnaire.

The research physician performed a standard clinical examination, including the assessment of pubertal status. The boys were classified as having entered clinical puberty if their testicular volume assessed by an orchidometer was \( >3 \) ml and the girls were defined as having entered puberty if their breast development in scales described by Tanner was \( >B1 \) (24). Because only few children had entered clinical puberty, we also used the current height as a percentage of predicted adult height as a measure of maturity. We calculated the boy’s predicted adult height (cm) as follows: the mean of the height of Finnish men (178.6 cm) + [the standard deviation of the height of Finnish men (6.0 cm) x the deviation of the child’s predicted adult height from the average of the predicted adult height of Finnish children]. The girl’s predicted adult height was calculated as follows: the mean of the height of Finnish women (165.3 cm) + [the standard deviation of the height of Finnish women (5.4 cm) x the deviation of the child’s predicted adult height from the average of the predicted adult height of Finnish children]. The deviation of the child’s predicted adult height from the average of the predicted adult height of Finnish children was calculated according to the national guidelines as follows: \( \frac{(\text{the arithmetic mean of the father’s and mother’s height}-171)}{10} \).

The risk of reading disabilities was determined based on children’s scores in kindergarten-age assessments of letter knowledge, phonemic awareness and rapid automatized naming, and parental self-report of reading difficulties (i.e., the mother or father indicated on a questionnaire whether she/he had had “mild” or “severe” problems in reading at school age) indicating family risk (20). The children were defined as being at risk of reading disabilities if their score was at or below the 15th percentile (about one SD below mean of the sample of approximately 2000
children in the follow-up) in at least two of the three skills or in one skill in the presence of family risk.

**Statistical methods**

We performed the statistical analyses using the SPSS software, version 17.0 (SPSS Inc., Chicago, IL, USA). We used the Student’s t-test, the Mann-Whitney U-test and the Chi-square test to compare the means and percentages of the variables between the sexes and between the children in the final study sample and the rest of children from the original PANIC Study and First Steps Study samples. We examined the associations of the measures of cardiovascular and motor performance in Grade 1 with academic skills in Grades 1-3 using multiple hierarchical linear regression analyses. These analyses were performed separately in boys and girls because of large differences in the associations between sexes. Age, sex, parental education and the PANIC study group were forced into the linear regression models and the measures of cardiovascular and motor performance were entered stepwise into the models. If the associations were statistically significant with these adjustments, the data were additionally adjusted for body fat percentage, physical activity, a clinical puberty, the current height as a percentage of predicted adult height and the risk of reading disabilities. We used the PANIC study group (intervention vs. control) as a covariate, because the intervention in The PANIC Study had started before the assessment of academic skills in The First Steps Study. The associations of cardiovascular and motor performance in Grade 1, as expressed in sex-specific thirds, with academic skills in Grades 1–3 were investigated using analysis of covariance (ANCOVA) with repeated measures. These analyses were performed combining data on boys and girls because of a limited statistical power to analyze differences among the thirds separately in boys and girls. Adjustments for multiple comparisons were made using the Sidak correction. The data for the
ANCOVA analyses were adjusted for age, parental education and the PANIC study group. If the associations were statistically significant with these adjustments, the data were additionally adjusted for other measures of cardiovascular and motor performance, body fat percentage, physical activity, a clinical puberty, the current height as a percentage of predicted adult height and the risk of reading disabilities.

RESULTS

Basic characteristics
In comparison to girls, boys had attained a smaller percentage of their predicted adult height and had a higher maximal workload in the exercise test, a shorter shuttle run test time, more lean mass, a lower body fat percentage and higher levels of physical activity in Grade 1 and poorer reading fluency in Grades 1 and 3 (Table 1). As expected, reading fluency, reading comprehension and arithmetic skills improved every year in Grades 1-3 among boys and girls.

Speed and agility and academic skills
Among boys, a longer time in the shuttle run test in Grade 1 was associated with a poorer reading fluency in Grades 1-3, a poorer reading comprehension in Grades 1 and 2 and poorer arithmetic skills in Grades 1-3 after adjustment for age, parental education, the PANIC study group and other measures of cardiovascular and motor performance (Table 2). Further adjustment for body fat percentage, physical activity, a clinical puberty, the current height as a percentage of predicted adult height and the risk of reading disabilities had no effect on these associations (data not shown). Among girls, a longer shuttle run test time in Grade 1 was related to a poorer reading fluency in Grade 3 and poorer arithmetic skills in Grade 2 (Table 2). However, the association between shuttle run test time and arithmetic skills in Grade 2 were no longer statistically significant after additional adjustment for the current height as a percentage of
predicted adult height (data not shown). Other adjustments had no effect on these relationships (data not shown).

Among all children, shuttle run test time in Grade 1, as expressed in sex-specific thirds, was inversely associated with reading fluency ($F(2, 161) = 4.68, P = 0.011$) and arithmetic skills ($F(2, 161) = 6.50, P = 0.002$) in Grades 1–3 after adjustment for age, parental education and the PANIC study group (Figure 1A). Children in the slowest third of the shuttle run test time in Grade 1 had poorer reading fluency in Grades 1–3 compared to children in the fastest third ($P = 0.014$). Children in the slowest third of shuttle run test time in Grade 1 had poorer arithmetic skills in Grades 1–3 than children in the middle third ($P = 0.016$) or the fastest third ($P = 0.004$). Further adjustments had no effect on these associations (data not shown).

**Static balance and academic skills**

Among boys, a larger number of errors in the flamingo balance test in Grade 1 was associated with poorer reading comprehension in Grade 1 after adjustment for age, parental education, the PANIC study group and other measures of cardiovascular and motor performance (Table 2). Further adjustments had no effect on this association (data not shown). Among girls, flamingo balance test score was not associated with academic skills (Table 2). There were no statistically significant differences in academic skills among children in the sex-specific thirds of the flamingo balance test score (Figure 1B).

**Manual dexterity and academic skills**

Among boys, a smaller number of cubes moved in the box and block test in Grade 1 was associated with poorer reading fluency in Grades 1-2, a poorer reading comprehension in Grade 3 and poorer arithmetic skills in Grades 1-2 after adjustment for age, parental education, the PANIC study group and other measures of cardiovascular and motor performance (Table 2).
Further adjustments had no effect on these associations (data not shown). Among girls, a smaller number of cubes moved in the box and block test in Grade 1 was related to a poorer reading fluency in Grade 2 (Table 2). This association was no longer statistically significant after additional adjustment for the current height as a percentage of predicted adult height (data not shown). Other adjustments had no effect on this relationship (data not shown).

Among all children, the smaller number of cubes moved in the box and block test in Grade 1 as expressed in sex-specific thirds was associated with poorer reading fluency \((F(2, 161) = 3.86, P = 0.023)\) and poorer arithmetic skills \((F(2, 161) = 3.88, P = 0.023)\) in Grades 1-3 after adjustment for age, parental education and the PANIC study group (Figure 1C). Children in the lowest third of the number of cubes moved in the box and block test in Grade 1 had poorer reading fluency in Grades 1–3 than children in the highest third \((P = 0.030)\). Children in the lowest third of the number of cubes moved in the box and block test in Grade 1 also had poorer arithmetic skills in Grades 1–3 than children in the highest third \((P = 0.020)\). However, these associations were no longer statistically significant after further adjustment for the shuttle run test time in Grade 1 (both \(P \geq 0.07\)). Other adjustments had no effect on these associations (data not shown).

**Overall motor performance and academic skills**

Among boys, a poorer overall motor performance in Grade 1 was associated with poorer reading fluency, reading comprehension and arithmetic skills in Grades 1-3 after adjustment for age, parental education, the PANIC study group and cardiovascular performance (Table 2). Further adjustments had no effect on these associations (data not shown). Among girls, a poorer overall motor performance in Grade 1 was associated with poorer reading fluency in Grade 3 and poorer arithmetic skills in Grade 2. However, the latter association was no longer statistically significant
after additional adjustment for the current height as a percentage of predicted adult height (data not shown). Other adjustments had no effect on these associations (data not shown). Among all children, a worse overall motor performance in Grade 1, as expressed in sex-specific thirds, was associated with poorer reading fluency ($F(2, 161) = 5.94, P = 0.003$), reading comprehension ($F(2, 161) = 3.95, P = 0.021$) and arithmetic skills ($F(2, 161) = 10.01, P < 0.001$) in Grades 1-3 after adjustment for age, parental education and the PANIC study group (Figure 2). Children in the lowest third of overall motor performance in Grade 1 had poorer reading fluency ($P = 0.003$) and reading comprehension ($P = 0.025$) in Grades 1–3 compared to children in the highest third. Children in the lowest third of overall motor performance in Grade 1 had poorer arithmetic skills in Grades 1-3 than children in the middle third ($P = 0.002$) or the highest third ($P < 0.001$). Further adjustments had no effect on these associations (data not shown).

**Maximal workload in exercise test and academic skills**
Maximal workload per lean body mass in Grade 1 was not associated with academic skills in Grades 1-3 (Table 2). There were no statistically significant differences in academic skills in Grades 1-3 between children in the sex-specific thirds of maximal workload in the exercise test in Grade 1 (data not shown).

**DISCUSSION**
To our knowledge, this is the first prospective study on the associations of cardiovascular and motor performance with academic skills in primary school children. A longer shuttle run test time, a smaller number of cubes moved in the box and block test and a poorer overall motor performance in Grade 1 were associated with poorer academic skills in Grades 1-3 in boys. The measures of motor performance had much weaker and generally statistically nonsignificant associations with academic skills in girls. However, when data on boys and girls were combined,
children in the slowest third of the shuttle run test time, in the lowest third of the number of cubes moved in the box and block test and in the lowest third of overall motor performance in Grade 1 had poorer reading fluency and arithmetic skills than children in other thirds of these measures of motor performance. Maximal workload in the exercise test as a measure of cardiovascular performance was not related to academic skills in children.

Regular physical activity that includes neuromuscular training and informal physically active play increases possibilities to rehearse and learn various motor skills and has been suggested to form the foundation for the normal development of motor performance during childhood (29, 32). Moreover, a better motor performance has predicted a more active engagement in physical activity during childhood and adolescence (32). There is also some evidence that physical activity mediates the association between motor performance in childhood and academic achievement in adolescence (19). Higher levels of physical activity may improve brain functions through several plausible mechanisms, such as increased synaptic plasticity, cerebral circulation, hippocampal neurogenesis and efficiency of the prefrontal and parietal cortices (16). We found that children with moderate to high levels of motor performance in Grade 1 had better reading and arithmetic skills in Grades 1-3 than children with low levels of motor performance independent of physical activity. Therefore it is also possible that our results represent a continuum of motor and cognitive development from early childhood to school age, because motor proficiency has been linked to language, cognitive and academic skills during early childhood (17, 35). These findings suggest that a better motor performance, presumably in conjunction with a physically active lifestyle during early childhood, may enhance academic skills in school age.
We found stronger associations of motor performance with academic skills in boys than in girls. There are a number of possible explanations for our observations. The results of one study suggested that there are differences in neural networks related to motor functions and language between boys and girls (22). Some evidence suggests that maturity plays a role in the level of motor activity and motor performance in children, and that the effect of maturity on motor activity and motor performance is different in boys than in girls (10, 24). We found that variation in biological maturation, assessed by the current height as a percentage of predicted adult height, partly explained the relationships of motor performance to academic skills in girls but not in boys. One reason for this may be that biological maturation occurs earlier in girls than in boys and thus has a stronger effect on motor performance and academic skills in girls than in boys. Another explanation for the stronger associations of motor performance with academic skills in boys than in girls may be that motor training improves motor performance more in boys than in girls (27) and that a better motor performance makes school adjustment easier during the first school year and thereby improves school success (2). Moreover, reading disabilities, that are often accompanied with coordination problems (9), are more prevalent in boys than in girls (30). However, the risk of reading disability did not account for the associations of motor performance with academic skills in our study.

In contrast to the results of some earlier studies (3, 13, 34), we found no associations of cardiovascular performance assessed by maximal workload during exercise test on cycle ergometer with academic skills in children. There was also no association of cardiovascular performance, assessed by cycle ergometer exercise test, with academic achievement in another study in Finland (19). Most studies that have found the association between cardiovascular performance and academic achievement have used field-based running tests, such as endurance
shuttle run test (13). One reason for these observations may be that cardiovascular performance, assessed by cycle ergometer exercise tests is unrelated to motor problems (18), whereas running test performance is partly explained by motor performance and running economy. Our results partly support these findings, because shuttle run test time, which had the strongest association with academic skills, is not only a measure of motor performance but also cardiovascular performance both of which may have an effect on children’s academic skills. Our results suggest that motor performance is more important for academic skills than cardiovascular performance among children.

The strengths of our study include a relatively large population sample of children followed up across the first three school years as well as comprehensive, objective and valid measures for motor and cardiovascular performance and academic skills. However, the flamingo balance test is a relatively crude measure of static balance. It would have been valuable to have a measure of dynamic balance, because dynamic balance may have a stronger association with academic skills than static balance. Moreover, it would have been optimal to use maximal oxygen uptake as a measure of cardiovascular performance, because it is the golden standard for assessing cardiovascular performance. However, maximal workload had a very strong correlation with maximal oxygen uptake in a subsample of the present study population, indicating that it is a valid measure of cardiovascular performance in children. Although we had prospective data on academic skills, we only had baseline data on motor and cardiovascular performance. Therefore, changes in motor and cardiovascular performance could be a source of residual confounding in our analyses. However, it is likely that children who had a poor motor performance at baseline also had a poor performance during follow-up and thereby had worse academic skills not only in Grade 1 but also in Grades 2-3. Finally, we cannot draw conclusions about a possible causal
relationship between motor performance and academic skills based on our follow-up data. More robust study designs and methods are needed to provide adequate evidence of causality.

A poorer motor performance was associated with poorer academic skills in children and especially in boys. These findings emphasize the early identification of children with poor motor performance and actions to improve their motor performance and academic skills during the first school years. Intervention studies comparing the effects of motor and cardiovascular training are needed to develop better strategies to improve academic skills among children.

ACKNOWLEDGEMENTS

We thank the voluntary children and their families who participated in this study and Helena Viholainen, PhD, and Professor Charles H. Hillman, PhD, for their valuable comments.

This work has been financially supported by grants from the Ministry of Social Affairs and Health of Finland, the Ministry of Education and Culture of Finland, the University of Eastern Finland, the Finnish Innovation Fund Sitra, the Social Insurance Institution of Finland, the Finnish Cultural Foundation, the JuhoVainio Foundation, the Foundation for Paediatric Research, the Paulo Foundation, the Paavo Nurmi Foundation and the Kuopio University Hospital (EVO funding number 5031343).

The authors have no professional relations with companies or manufacturers who will benefit from the results of the present study. The results of the present study do not constitute endorsement by American College of Sports Medicine.
REFERENCES


FIGURE CAPTIONS

**Figure 1.** The associations of measures of motor performance, expressed in sex-specific thirds, in Grade 1 with academic skills in Grades 1–3 among 167 children. The estimates are based on the analyses of covariance with repeated measures. Data were adjusted for age, parental education and the PANIC study group (intervention vs. control). HP = High performance, MP = moderate performance, LP = Low performance

**Figure 2.** The associations of overall motor performance, expressed in sex-specific thirds, in Grade 1 with academic skills in Grades 1–3 among 167 children. The estimates are based on the analyses of covariance with repeated measures. Data were adjusted for age, parental education and the PANIC study group (intervention vs. control). HP = High performance, MP = moderate performance, LP = Low performance
Figure 1
Figure 2

Overall motor performance

Reading fluency

Grade 1 Grade 2 Grade 3

LP vs. HP = P=0.003

Reading comprehension

Grade 1 Grade 2 Grade 3

LP vs. HP = P=0.025

Arithmetic skills

Grade 1 Grade 2 Grade 3

LP vs. HP = P<0.001
LP vs. MP = P=0.002

High Performance
Moderate Performance
Low Performance

Copyright © 2013 by the American College of Sports Medicine. Unauthorized reproduction of this article is prohibited.
Table 1. The characteristics of the children

<table>
<thead>
<tr>
<th>Background characteristics in Grade 1</th>
<th>All (n=174)</th>
<th>Boys (n=99)</th>
<th>Girls (n=75)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>7.7 (0.4)</td>
<td>7.7 (0.4)</td>
<td>7.6 (0.3)</td>
<td>0.080</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>129 (5.7)</td>
<td>130 (6.0)</td>
<td>128 (5.3)</td>
<td>0.056</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>27.4 (5.4)</td>
<td>27.7 (5.6)</td>
<td>27.0 (5.1)</td>
<td>0.407</td>
</tr>
<tr>
<td>Lean body mass (kg)</td>
<td>21.0 (2.4)</td>
<td>21.8 (2.3)</td>
<td>19.9 (2.1)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Body fat percentage</td>
<td>20.2 (8.9)</td>
<td>18.0 (8.6)</td>
<td>23.1 (8.6)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Prevalence of overweight (%)</td>
<td>16.1</td>
<td>14.1</td>
<td>18.7</td>
<td>0.421</td>
</tr>
<tr>
<td>Current height as a percentage of predicted adult height (%)</td>
<td>74.5 (3.5)</td>
<td>72.5 (2.7)</td>
<td>77.0 (2.8)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

| Pubertal status (%)                   |            |            |            |        |
| Prepubertal                           | 95.3       | 96.9       | 93.2       | 0.252  |
| Pubertal                              | 4.7        | 3.1        | 6.8        |        |
| Physical activity (min/d)             | 105 (39.7) | 115 (43.3) | 92.5 (29.8)| 0.001  |
| Children at the risk of reading disability (%) | 13.5       | 17.5       | 8.1        | 0.085  |
| Parental education (%)                |            |            |            |        |
| Vocational school or less             | 20.8       | 23.5       | 17.3       | 0.253  |
| Polytechnic                           | 41.0       | 35.7       | 48.0       |        |
| University degree                     | 38.2       | 40.8       | 34.7       |        |
| PANIC Study group                     |            |            |            |        |
| Intervention                          | 66.7       | 67.7       | 65.3       | 0.745  |
| Control                               | 33.3       | 32.3       | 34.7       |        |

| Motor and cardiovascular performance in Grade 1 |            |            |            |        |
| Shuttle run time (seconds)                | 24.1 (2.1) | 23.7 (2.1) | 24.7 (2.0) | 0.001  |
| Balance (errors)                         | 3.5 (2.6)  | 3.6 (2.7)  | 3.3 (2.4)  | 0.473  |
| Box and block (cubes moved in 2 min)      | 100 (14.5) | 98.8 (14.9)| 103 (13.7) | 0.132  |
| Overall motor performance^a               | 0.1 (1.9)  | 0.1 (1.9)  | 0.03 (1.9) | 0.859  |
| Maximal workload (W/kg of lean body mass) | 3.6 (14.5) | 3.7 (0.5)  | 3.4 (0.4)  | <0.001 |

| Academic skills in Grade 1               |            |            |            |        |
| Reading fluency (score)                  | 18.8 (9.0) | 17.8 (9.6) | 20.2 (8.0) | 0.035  |
| Reading comprehension (score)            | 5.0 (3.4)  | 4.7 (3.5)  | 5.3 (3.3)  | 0.233  |
| Arithmetic skills (score)                | 10.3 (4.1) | 10.7 (4.3) | 9.8 (3.9)  | 0.236  |

| Academic skills in Grade 2               |            |            |            |        |
| Reading fluency (score)                  | 25.1 (8.0) | 24.6 (8.7) | 25.7 (7.0) | 0.148  |
| Reading comprehension (score)            | 8.0 (2.9)  | 7.6 (3.0)  | 8.5 (2.6)  | 0.053  |
| Arithmetic skills (score)                | 15.5 (5.0) | 15.6 (5.4) | 15.4 (4.4) | 0.751  |

| Academic skills in Grade 3^a             |            |            |            |        |
| Reading fluency (score)                  | 36.6 (8.5) | 35.3 (8.7) | 38.3 (8.1) | 0.023  |
| Reading comprehension (score)            | 9.0 (2.0)  | 8.8 (2.2)  | 9.3 (1.6)  | 0.216  |
| Arithmetic skills (score)                | 19.6 (4.4) | 19.7 (4.2) | 19.5 (4.8) | 0.938  |

^a Maximal workload (W/kg of lean body mass)
Data are from the Student’s t-test or Mann-Whitney U-test for continuous variables and chi-square test for categorical variables and are displayed as means (SD) or percentages (%). P-values refer to statistical significance for differences between boys and girls with statistically significant differences being bolded.

aOverweight was defined according to the criteria of the International Obesity Task Force (IOTF) (8). bA continuous measure of overall motor performance was calculated by Z-score of reversed shuttle run, reversed balance and Box and block test performance. cThere were 167 children (96 boys, 71 girls) in Grade 3.
Table 2. The associations of measures of motor and cardiovascular performance in Grade 1 with academic skills in Grades 1–3

<table>
<thead>
<tr>
<th></th>
<th>Reading fluency</th>
<th>Reading comprehension</th>
<th>Arithmetic skills</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All (n=174)</td>
<td>Boys (n=99)</td>
<td>Girls (n=75)</td>
</tr>
<tr>
<td>Shuttle run</td>
<td>-0.21*</td>
<td>-0.35†</td>
<td>-0.01</td>
</tr>
<tr>
<td>Balance</td>
<td>-0.05</td>
<td>-0.01</td>
<td>-0.06</td>
</tr>
<tr>
<td>Box and block</td>
<td>0.18*</td>
<td>0.28**</td>
<td>0.14</td>
</tr>
<tr>
<td>Overall motor performance</td>
<td>0.28†</td>
<td>0.40†</td>
<td>0.11</td>
</tr>
<tr>
<td>Maximal workload</td>
<td>-0.01</td>
<td>0.04</td>
<td>0.06</td>
</tr>
</tbody>
</table>

Results of two step hierarchical linear regression analyses. Results are displayed as standardized regression coefficients and only the step 2 is presented. Background variables including age, sex, parental education and the PANIC study group were forced in a linear regression model in the step 1, and measures of motor and cardiovascular performance were entered into the model stepwise in the step 2.

a Seconds. b The number of floor touches with a free foot or eye openings during 30 seconds in flamingo balance test. c Cubes moved in two minutes. d A continuous measure of overall motor performance was calculated by Z-score of reversed shuttle run, reversed balance and Box and block test performance. Analyses of overall motor performance were conducted separately from other measures of motor performance. e Watts/kg of lean body mass in maximal exercise test with cycle ergometer. Overall motor performance was added stepwise together with maximal work load in the step 2. f Associations of maximal work load with academic skills were similar in analyses where maximal workload was added into the model together with three measures of motor performance or overall motor performance. g There were 167 children (96 boys, 71 girls) in Grade 3.

* P < 0.05, ** P < 0.01, † P < 0.001