Physical activity and obesity mediate the association between childhood motor function and adolescents' academic achievement

Marko T. Kantomaa[a,b,1], Emmanuel Stamatakis[c,d], Anna Kankaanpää[a], Marika Kaakinen[e,f], Alina Rodriguez[b,g,h], Anja Taanila[e,i], Timo Ahonen[j], Marjo-Riitta Järvelin[b,e,f], and Tuija Tammelin[a]

[a]LIKES – Research Center for Sport and Health Sciences, FI-40720 Jyväskylä, Finland; [b]Department of Epidemiology and Biostatistics, MRC–HPA Centre for Environment and Health, Imperial College London, London W2 1PG, United Kingdom; [c]Department of Epidemiology and Public Health, University College London, London WC1E 6BT, United Kingdom; [d]Physical Activity Research Group, Population Health Division, University College London, London WC1E 6BT, United Kingdom; [e]Institute of Health Sciences, University of Oulu, FI-90014 Oulu, Finland; [f]Biocenter Oulu, University of Oulu, FI-90014 Oulu, Finland; [g]MRC Social, Genetic and Developmental Psychiatry Centre, King's College London, London SE5 8AF, United Kingdom; [h]Department of Social Sciences, Mid Sweden University, 831 25 Östersund, Sweden; [i]Primary Health Care Unit, Oulu University Hospital, FI-90014 Oulu, Finland; and [j]Department of Psychology, University of Jyväskylä, FI-40014 Jyväskylä, Finland

Edited by Amy Bastian, Johns Hopkins University, Baltimore, MD, and accepted by the Editorial Board November 22, 2012 (received for review August 24, 2012)

The global epidemic of obesity and physical inactivity may have detrimental implications for young people's cognitive function and academic achievement. This prospective study investigated whether childhood motor function predicts later academic achievement via physical activity, fitness, and obesity. The study sample included 8,061 children from the Northern Finland Birth Cohort 1986, which contains data about parent-reported motor function at age 8 y and self-reported physical activity, predicted cardiorespiratory fitness (cycle ergometer test), obesity (body weight and height), and academic achievement (grades) at age 16 y. Structural equation models with unstandardized (B) and standardized (β) coefficients were used to test whether, and to what extent, physical activity, cardiorespiratory fitness, and obesity at age 16 mediated the association between childhood motor function and adolescents' academic achievement. Physical activity was associated with a higher grade-point average, and obesity was associated with a lower grade-point average in adolescence. Furthermore, compromised motor function in childhood had a negative indirect effect on adolescents' academic achievement via physical inactivity (B = –0.023, 95% confidence interval = –0.031, –0.015) and obesity (B = –0.025, 95% confidence interval = –0.039, –0.011), but not via cardiorespiratory fitness. These results suggest that physical activity and obesity may mediate the association between childhood motor function and adolescents' academic achievement. Compromised motor function in childhood may represent an important factor driving the effects of obesity and physical inactivity on academic underachievement.

academic performance | exercise | motor skills | overweight

Ten percent of school-aged children and youths worldwide are estimated to be overweight or obese, with the rate escalating dramatically in many countries (1). At the same time, only one-third of children and adolescents are estimated to be sufficiently physically active (2). Recent literature shows that, besides the well-known physical health risks (3), physical inactivity (4–6) may have detrimental effects on young people's cognitive function and academic achievement, whereas adequate physical activity (4–6) and increased cardiorespiratory fitness (7–9) may benefit them. Obesity is one of the most common consequences of sedentary lifestyles (10), and has been shown to predict poor academic achievement and cognitive function in childhood (4). Such associations are potentially explained by lifestyle factors related to the energy–metabolic balance (e.g., physical activity and diet) and to changes in learning and memory that these two key health behaviors induce (11).

Because childhood motor function is closely related to growth and cognitive development (12, 13), it may represent an important underlying factor for later academic achievement. Adequate motor function is also a prerequisite for performing physical activity (14), and has been linked to cardiorespiratory fitness (15–17) and obesity (16) through increased capacity and competence to perform physical activities (e.g., increased strength and power) (14). In addition, childhood motor function is a developmental means for language acquisition (13, 18), and well-developed gross motor skills facilitate children's academic abilities in reading, language, and mathematics (18).

As the prevalence of physical inactivity and obesity continues to rise in youth around the world (4), it is important that we understand the interrelatedness of these key factors and their potential impact on academic achievement. The aim of this study was to examine whether childhood motor function predicts later academic achievement via physical activity, fitness, and obesity. Our main hypothesis is that compromised motor function in childhood would lead to adolescent obesity, physical inactivity, and low cardiorespiratory fitness, all of which are, in turn, associated with academic underachievement. We used data from a large, prospective birth cohort including 8,061 children. For the study design, see Fig. S1.

Results

The sex-specific distributions of parent-reported motor function, self-reported physical activity, predicted cardiorespiratory fitness, obesity, academic achievement, and all contextual variables from the original data are presented in Table S1. At age 8 y, boys were more likely to have compromised motor function compared with girls ($P < 0.001$). At age 16 y, girls (M = 8.1, SD 0.8) had higher academic achievement levels, as indicated by grade-point average (GPA), compared with boys (M = 7.5, SD 0.9) ($P < 0.001$). The mean metabolic equivalent of task (MET) hours per week were 32.8 (SD 17.9) for boys and 28.7 (SD 15.5) for girls ($P < 0.001$). The mean peak oxygen consumption (VO_{2peak} in $mL \cdot kg^{-1} \cdot min^{-1}$) was 49.1 (SD 9.7) among boys and 35.4 (SD 6.4) among girls ($P < 0.001$). Boys were more often overweight or obese compared with girls ($P = 0.001$). Correlations of the variables are presented in Table S2.

Author contributions: M.T.K., E.S., A.R., T.A., M.-R.J., and T.T. designed research; A.T., M.-R.J., and T.T. performed research; M.T.K., A.K., and M.K. analyzed data; and M.T.K., E.S., and A.R. wrote the paper.

The authors declare no conflict of interest.

This article is a PNAS Direct Submission. A.B. is a guest editor invited by the Editorial Board.

Freely available online through the PNAS open access option.

[1]To whom correspondence should be addressed. E-mail: marko.kantomaa@likes.fi.

This article contains supporting information online at www.pnas.org/lookup/suppl/doi:10.1073/pnas.1214574110/-/DCSupplemental.

The structural equation models (with standardized β-coefficients) that describe the mediating effects of physical activity, fitness, and obesity on the association between childhood motor function at age 8 y and adolescents' academic achievement at age 16 y are described in Fig. 1. The model fitted the data well in terms of root-mean-square error of approximation (0.045) and comparative-fit index (0.974). Unstandardized (B) and standardized (β) regression coefficients conditional on all of the variables in the structural equation modeling (SEM) analysis are shown in Table 1. Table 2 presents the indirect and total effects (unstandardized B coefficients) of childhood motor function and adolescents' physical activity, fitness, and obesity levels on academic achievement, calculated assuming that the relations depicted in Fig. 1 are correct. Initially, childhood motor function had a direct effect on adolescents' academic achievement, but it did not remain statistically significant after taking into account the mediating effects of physical inactivity and obesity.

The unstandardized B coefficients suggested that compromised motor function in childhood predicted lower levels of physical activity (B = –4.673), poor cardiorespiratory fitness (B = –1.460), and higher levels of obesity (B = 0.287) in adolescence (Table 1). Furthermore, higher levels of physical activity were associated with a higher GPA (B = 0.005) and obesity with a lower GPA (B = –0.086) in adolescence. Compromised motor function had a negative indirect effect on academic achievement via lower levels of physical activity (B = –0.023) and obesity (B = –0.025), but not via cardiorespiratory fitness (Table 2). The estimated total effect of compromised motor function on academic achievement (B = –0.042) corresponded to a decrease of 0.04 units in the GPA. The described model explained 31% of the variance in the GPA, as indicated by the R^2 value (0.31).

We also fitted structural equation models separately for boys (n = 4,126) and girls (n = 3,935), and compared the estimates with those obtained from an analysis including both sexes. In general, there were no significant differences in the estimates between boys and girls, except in the association between compromised motor function and cardiorespiratory fitness, which was attenuated among girls [B = –0.135, 95% confidence interval (CI) = –0.619, 0.349] compared with boys (B = –2.574, 95% CI = –4.275, –0.873). We further compared the distributions of all of the variables used in the present study between the sample with complete cases only (information available on all of the variables in the model) (n = 2,865) and the full study sample, including those participants who had missing values in at least one variable (n = 8,061). Participants in the full sample were more likely to have problems in learning to read (12% vs. 10%), write (17% vs. 14%), and do mathematics (9% vs. 6%), to have a mother with basic-level education (11% vs. 9%), to have a lower GPA (7.8 vs. 8.0), and to be less physically active (mean MET hours per week = 30.7 vs. 32.3) compared with participants with complete data. We then fitted the models for complete cases only, and compared the estimates with those obtained from an analysis including all cases. In general, all of the estimates pointed in the same direction and were approximately of the same magnitude as in the all-cases analyses. However, the association between compromised motor function and cardiorespiratory fitness was attenuated in the complete-case analyses (B = –0.442, 95% CI = –1.034, 0.151) compared with the all-cases analyses (B = –1.460, 95% CI = –2.426, –0.494). The variables with missing values were included in the model used for the all-cases analyses; therefore, imbalances between participation and nonparticipation at any given time were implicitly taken into account in the all-cases analyses.

Discussion

Our data provide evidence that physical activity and obesity mediate the association between childhood motor function and adolescents' academic achievement. Compromised motor function in childhood may serve as a significant underlying factor for the effects of obesity and physical inactivity on academic underachievement, which has recently attracted attention as a growing global education and public health concern (4). Poor motor activity in the early school years can contribute to setting the child on a negative developmental trajectory.

There is a growing body of literature demonstrating that lifestyle factors such as excess sedentary behavior and an unhealthy diet may

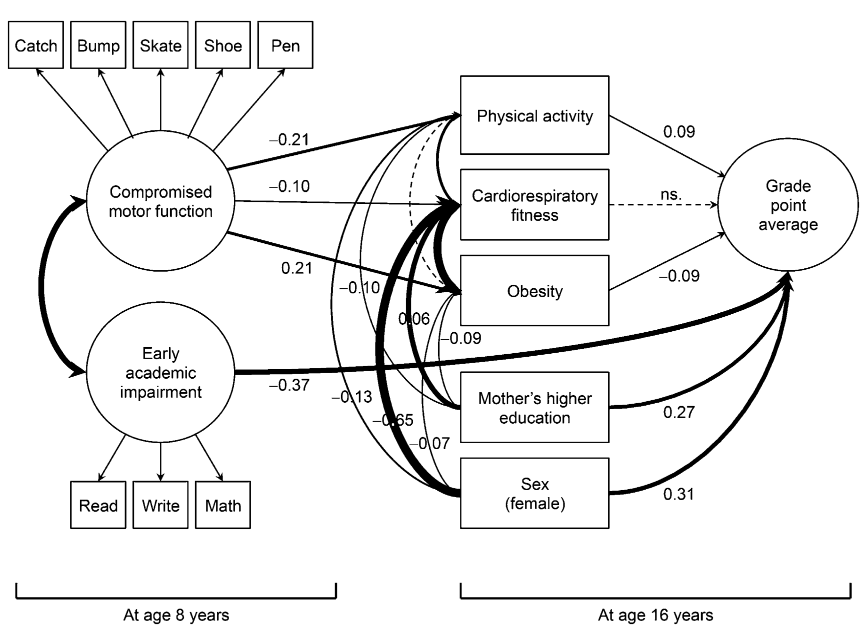

Fig. 1. Pathway model of the association between childhood motor function and adolescents' academic achievement (n = 8,061). Path coefficients are standardized β-estimates computed via structural equation modeling. The thickness of the causal path lines are proportional to the estimates; nonsignificant (ns.) (P > 0.05) paths are shown with dashed lines. Bump, bumps or falls often; Catch, succeeds in catching a ball in a game; Math, problems in mathematics; Pen, pencraft is awkward; Read, problems in reading; Shoe, can tie shoelaces; Skate, can skate; Write, problems in writing.

Table 1. Relations between childhood motor function and adolescents' physical activity, cardiorespiratory fitness, obesity level, and academic achievement ($n = 8{,}061$)

Model	B	SE	95% CI	P value	β
Grade-point average[a]					
Physical activity[b]	0.005	0.001	0.003, 0.007	<0.001	0.091
Cardiorespiratory fitness[c]	−0.003	0.002	−0.007, 0.001	0.225	−0.032
Obesity level[d]	−0.086	0.021	−0.127, −0.045	<0.001	−0.094
Early academic impairment	−0.341	0.015	−0.370, −0.312	<0.001	−0.365
Mother's higher education	0.721	0.048	0.627, 0.815	<0.001	0.266
Mother's upper secondary education	0.226	0.039	0.150, 0.302	<0.001	0.106
Sex (female vs. male)	0.565	0.038	0.491, 0.639	<0.001	0.308
Physical activity[b]					
Compromised motor function	−4.673	0.644	−5.935, −3.411	<0.001	−0.207
Cardiorespiratory fitness[c]	25.513	2.253	21.097, 29.929	<0.001	0.195
Obesity level[d]	−0.252	0.324	−0.887, 0.383	0.437	−0.016
Mother's higher education	5.055	0.802	3.483, 6.627	<0.001	0.102
Mother's upper secondary education	2.034	0.644	0.772, 3.296	0.002	0.052
Sex (female vs. male)	−4.248	0.450	−5.130, −3.366	<0.001	−0.126
Cardiorespiratory fitness[c]					
Compromised motor function	−1.460	0.493	−2.426, −0.494	0.003	−0.102
Physical activity[b]	25.513	2.253	21.097, 29.929	<0.001	0.195
Obesity level[d]	−4.587	0.349	−5.271, −3.903	<0.001	−0.571
Mother's higher education	1.770	0.565	0.663, 2.877	0.002	0.056
Mother's upper secondary education	1.132	0.419	0.311, 1.953	0.007	0.046
Sex (female vs. male)	−13.817	0.250	−14.307, −13.327	<0.001	−0.649
Obesity level[d]					
Compromised motor function	0.287	0.048	0.193, 0.381	<0.001	0.213
Physical activity[b]	−0.252	0.324	−0.887, 0.383	0.437	−0.016
Cardiorespiratory fitness[c]	−4.587	0.349	−5.271, −3.903	<0.001	−0.571
Mother's higher education	−0.266	0.075	−0.413, −0.119	<0.001	−0.090
Mother's upper secondary education	−0.165	0.056	−0.275, −0.055	0.003	−0.071
Sex (female vs. male)	−0.138	0.035	−0.207, −0.069	<0.001	−0.068
Compromised motor function					
Early academic impairment	0.309	0.032	0.246, 0.372	<0.001	0.420

[a]The grade-point average (scale 4–10) included mother tongue (in most cases Finnish or Swedish), first foreign language (started at grade 3), second foreign language (started at grade 7), mathematics, biology, geography, physics, chemistry, religion or ethics, history, music, visual arts, physical education, crafts, and home economics.
[b]Physical-activity level was defined as metabolic equivalent hours per week based on the intensity and volume of physical activity engaged in outside school hours, including commuting to and from school.
[c]Cardiorespiratory fitness was measured with a submaximal cycle ergometer test and expressed as peak oxygen uptake in $mL \cdot kg^{-1} \cdot min^{-1}$.
[d]Obesity level was defined using the IOTF age-specific cutoff points for BMI. The BMI was calculated as the weight divided by the square of the height (kg/m^2).

compromise children's cognitive and academic performance (4, 5). Our results partly support previous findings indicating that overweight and obesity (19, 20), especially overconsumption of energy (11, 21) and excess body fat content (22), are adversely linked to cognitive and academic performance in children and youths. On the other hand, physical activity may counteract the decrease in hippocampal brain-derived neurotrophic factor levels due to the consumption of a high-fat diet (23). Our results underscore the growing literature, expounding the beneficial effects of physical activity on academic performance (4–6). Some studies have suggested that involvement in physical activity influences engagement in learning, defined as improved self-concept and increased academic self-confidence (24). Physical activity may induce arousal and reduce boredom, leading to an increase in attention span and concentration (25). In addition, animal studies have suggested that molecular and cellular changes such as neurogenesis, synaptic plasticity, and neurotransmitters appear to underlie the effects of physical activity on cognition and learning (5). The positive effect of physical activity on the brain's health, structure, and function may be especially beneficial for memory and executive functions (26–28), which may partly explain the positive association between physical activity and academic achievement.

The present study contributes to the knowledge pool by demonstrating candidate causal pathways from childhood motor function to adolescents' academic achievement via obesity and physical activity. Our results are in line with previous studies in which compromised motor function in childhood predicted adolescent obesity (16, 29, 30), physical inactivity (17, 31), and poor cardiorespiratory fitness (14, 16). It has been suggested that there is a negative spiral of disengagement in physical activity with low motor competence, low perceptions of motor skill competence, physical inactivity, and poor fitness, leading to obesity, which, in turn, negatively influences the other factors (14). However, cardiorespiratory fitness did not mediate the association between childhood motor function and adolescents' academic achievement in the present study when the mediating effects of physical activity and obesity were taken into account. Evidence on this is mixed and inconclusive, with some studies indicating a positive association and some showing no association (4). Our results add to the current knowledge by indicating complex interrelations and shared, as well as independent, effects of physical activity and obesity on academic achievement. This emphasizes the need to better understand the mediators for the effects of physical activity and obesity on academic achievement. It is also possible that the

Table 2. Indirect and total effects of childhood motor function and adolescents' physical activity, fitness, and obesity level on academic achievement (n = 8,061)

Model	B	SE	95% CI	P value
Grade-point average[a]				
Total effect	−0.042	0.008	−0.058, −0.026	<0.001
Total indirect effect	−0.042	0.008	−0.058, −0.026	<0.001
MF–PA[b]–GPA[a]	−0.023	0.004	−0.031, −0.015	<0.001
MF–CRF–GPA[a]	0.004	0.004	−0.004, 0.012	0.314
MF–OL[c]–GPA[a]	−0.025	0.007	−0.039, −0.011	<0.001

CRF, cardiorespiratory fitness; MF, motor function; OL, obesity level; PA, physical activity.

[a]The grade-point average (scale 4–10) included mother tongue (in most cases Finnish or Swedish), first foreign language (started at grade 3), second foreign language (started at grade 7), mathematics, biology, geography, physics, chemistry, religion or ethics, history, music, visual arts, physical education, crafts, and home economics.

[b]Physical-activity level was defined as metabolic equivalent hours per week based on the intensity and volume of physical activity engaged in outside school hours, including commuting to and from school.

[c]Obesity level was defined using the IOTF age-specific cutoff points for BMI. The BMI was calculated as the weight divided by the square of the height (kg/m^2).

effects of physical activity and obesity on academic achievement are determined by different subcomponents of these factors, such as the intensity and type of physical activity. The shared effects of physical activity and obesity on academic achievement have been rarely recognized in previous studies and may, thus, partly explain inconsistencies in previous literature.

Although some previous studies have reported sex differences in obesity (20), physical activity (32, 33), and fitness (34) in association with academic achievement, in this study the direction and magnitude of the associations were similar for boys and girls. The use of a large, unselected population sample with the ability to use observations with missing values allowed us to exploit the data to their full potential, with a considerable increase in statistical power. Further studies of more-contemporary cohorts within different sociocultural settings and with objective measures of motor function and physical activity are needed to address causality and to confirm these results. However, the present results provide evidence that supports the establishment of educational and public health policies to identify children at risk for physical inactivity and obesity and to prevent their negative consequences on cognitive function and academic achievement. Considering the simplicity and the reasonable validity of the questions used to measure childhood motor function in the present study, they could be considered as a valuable and practical screening tool for parental evaluation at the societal level.

Our study was based on a large, unselected population sample, which allowed robust SEM using path analysis and latent variables. Furthermore, the prospective longitudinal study design supports some inferences about the direction of the association. Participation rates were high (80–90%). Information on academic achievement was based on nationally comparable grades of the final assessment of basic education, allowing a representative and comprehensive estimate of adolescents' academic achievement. Despite the benefits of the SEM as a statistical approach, the results must be interpreted in conjunction with a set of assumptions. First, in interpreting the direct and indirect effects obtained, we assume that the specified model was correct with no unmeasured confounders (35). Further, to be able to claim that the effects obtained are causal, the following assumptions need to be fulfilled: (*i*) no unmeasured confounding between the exposure–mediator relationship; (*ii*) no unmeasured confounding between the mediator–outcome relationship; (*iii*) no unmeasured confounding between the exposure–outcome relationship; and (*iv*) no unmeasured mediator–outcome confounders that are affected by treatment (36). We have used our subject-matter knowledge in selecting the confounders and covariates in our model and assume that most of the relevant confounders were included. However, the possibility of residual confounding always remains. In addition, any causal inference drawn should be treated with the appropriate caution.

The measures of motor function were based on parental reports rather than on more-accurate objective measurements and are, thus, susceptible to inaccuracy (37). It is possible that poor parental understanding of motor development contributes to the measures of parent-reported motor function. Furthermore, the criterion validity of the questions used to measure parent-reported motor function has not been established in Finnish children. However, the prevalence of compromised motor function in our study was comparable to the prevalence reported in previous studies. In addition, we have produced evidence supporting the convergent validity of these questions, including the previously reported associations of these measures of parent-reported motor function with physically active play in childhood and with physical activity and cardiorespiratory fitness in adolescence (17). Our study relied on adolescents' self-reported physical activity, which might contain relatively large measurement errors and social desirability bias (38, 39). Physical activity, fitness, obesity, and academic achievement were measured at 16 y, limiting the interpretation of causality in explaining academic achievement. It would have been useful and informative to have all these factors measured at several time points to enable the examination of how these variables change with respect to each other over time. However, one of the indications of successful selection and model fitting was, for example, the fact that the assumed models explained a high percentage (~31%) of the total variation in academic achievement, yet it is likely that a notable proportion of this variation was explained by sex and maternal education.

In summary, using a large European population-based cohort, we found evidence that physical activity and obesity mediate the association between childhood motor function and adolescents' academic achievement. Compromised motor function in childhood may represent an important factor driving the effects of obesity and physical inactivity on academic underachievement.

Materials and Methods

For a full description of all materials and methods, see *SI Materials and Methods*.

Participants. The study sample consisted of a prospective mother–child birth cohort, the Northern Finland Birth Cohort 1986, which at baseline was composed of 9,432 infants whose expected date of birth was between July 1, 1985, and June 30, 1986, in the two northernmost provinces of Finland, Oulu and Lapland (40). Data collection commenced during the mothers' pregnancy, and follow-up surveys were carried out when the children were 7–8 y old (1992–1994) (hereafter "8 y") and 15–16 y old (2001–2002) (hereafter "16 y"). The present analysis included those 8,061 children (4,126 boys and 3,935 girls) who had complete information on academic achievement at age 16. Informed consent was obtained from all participants and their parents, and the research protocol was approved by the Ethics Committee of Northern Ostrobotnia Hospital District.

Parent-Reported Motor Function. Gross motor skills at the age of 8 y were measured through the parents' questionnaire. The parents were asked the following questions: "Does your child bump into something or fall down often?" [response alternatives: (*i*) yes, (*ii*) no, and (*iii*) cannot say]; "Can your child usually catch a ball in a game?" (*i*) mostly, (*ii*) sometimes, and (*iii*) hardly ever; and "Can your child skate?" (*i*) yes, (*ii*) no, and (*iii*) not attempted. Fine motor skills were investigated with the following questions: "Is your child's pencil use awkward?" (*i*) yes, (*ii*) no, and (*iii*) cannot say; and "Can your child tie his or her shoelaces?" (*i*) yes, (*ii*) no, and (*iii*) not attempted. A latent variable "compromised motor function" was specified using these five variables measuring gross and fine motor skills to represent the underlying parent-reported motor function at age 8 y. The questions used to measure parent-reported motor function have been previously described in detail (17).

Self-Reported Physical Activity, Predicted Cardiorespiratory Fitness, and Obesity. Self-reported physical activity outside school hours was evaluated separately for moderate-to-vigorous physical activity and light physical activity at age 16 y by asking participants, "How many hours a week all together do you participate in (*a*) brisk and (*b*) light physical activity outside school hours?" In the questionnaire, the term "brisk" was defined as physical activity causing at least some sweating and shortness of breath (here referred to as moderate- to vigorous-intensity physical activity), whereas the term "light physical activity" was defined as causing no sweating or shortness of breath. In addition, the adolescents were asked about their daily time spent in physically active commutes to and from school. The response alternatives (not at all, less than 20 min, 20–39 min, 40–59 min, and at least 1 h per day) were multiplied by 5 (5 school days a week) to correspond to 0, 1, 2.5, 3.75, and 5 h/wk (41). The physical-activity level was converted into MET hours per week based on the intensity and the volume of physical activity engaged in outside school hours, including commuting to and from school (in this study, referred to as "physical activity"). A MET-intensity value of three METs was used for light physical activity, five METs for brisk physical activity, and four METs for commuting physical activity in the calculations (42). The test–retest reliability of these physical-activity questions among Finnish adolescents aged 15–16 y has been reported to be good (41). The intraclass correlation coefficient for physical-activity levels described in terms of quintile categories of MET hours per week was 0.70 (95% CI = 0.58–0.80), and the proportion of subjects who were classified in exactly the same category or next to the same category in two different tests was 86%.

Predicted cardiorespiratory fitness (in this study, referred to as "cardiorespiratory fitness") was measured during a health examination at age 16 (n = 5,375) with a submaximal cycle ergometer test and expressed as peak oxygen uptake in $mL \cdot kg^{-1} \cdot min^{-1}$. The exercise test protocol included two incremental work stages of 4 min each on a bicycle ergometer (model 818E; Monark). Peak oxygen uptake was calculated based on the heart-rate response during submaximal work stages. The method has been validated against directly measured VO_{2peak} during the maximal exercise test and has been previously described in detail (43). The cycle ergometer test is likely to be a relatively objective measure of physical fitness for young people, regardless of their motor development (17).

At the age of 16 y, the adolescents self-reported their body weight and height in the postal questionnaire, and these were measured in the health examination. Self-reported body weight and height were used for those who failed to attend the health examination. Body mass index (BMI) was calculated as the individual's weight divided by the square of the height (kg/m^2). Obesity was defined using the International Obesity Task Force (IOTF) age-specific cutoff points for BMI (44).

Learning and Education. Information on academic achievement was provided by the National Application Register for Upper Secondary Education, Finland, based on nationally comparable grades of the final assessment of basic education. The grades refer to numerical assessment on a scale of 4–10, where 4 denotes failure (US grade F) and 10 denotes excellent knowledge and skills (US grade A). They describe the level of performance in relation to the objectives of basic education at the end of grade 9 (age 16). The GPA was calculated as a measure of academic achievement based on the grades in the following school subjects: mother tongue (in most cases Finnish or Swedish), first foreign language (started at grade 3), second foreign language (started at grade 7), mathematics, biology, geography, physics, chemistry, religion or ethics, history, music, visual arts, physical education, crafts, and home economics. A Finnish GPA of 5.0–5.9 equals 1.0 (D) in US GPA, 6.0–6.9 equals 2.0 (C), 7.0–8.9 equals 3.0 (B), and 9.0–10.0 equals 4.0 (A).

Teachers assessed the children's academic impairment at the age of 8 y by answering the question, "Does the child have difficulties with learning (*i*) to read, (*ii*) to write, or (*iii*) to do mathematics?" [response alternatives: (*a*) yes and (*b*) no] (45). Previous studies have reported that single-item teacher ratings are accurate measures of impairment, concurring with results of achievement tests (46, 47). These three components of impairment in learning were combined into a single latent variable, "early academic impairment."

The mother's highest level of education when the adolescent was 16 y old was ascertained from the parents. The variable was categorized according to education-level categories used by the International Standard Classification of Education (48): (*i*) basic education, lasting 9 y or less, (*ii*) upper secondary education, lasting 10–12 y, and (*iii*) tertiary/higher education, lasting ≥13 y.

Statistical Analyses. We used structural equation modeling to explore and model the hypothesized underlying relations between the variables of interest. Four simultaneous equations were fitted, with academic achievement, physical activity, cardiorespiratory fitness, and obesity level at age 16 y as the outcome variables. Estimation of the parameters was carried out by the method of a robust weighted least-squares estimator. The multiple imputation by chained equations method (49) was used to generate multiple datasets of incomplete data, which were analyzed using a special feature of Mplus (50). For comparison, we also estimated the model's parameters separately for boys and girls and for complete cases only. Effect sizes of the predictors on the outcome variables were expressed as unstandardized (B) and standardized (β) estimates. The total effects of the predictors on the outcomes were computed by adding the indirect and direct effects together. The model was evaluated using the following goodness-of-fit indices: the comparative-fit index and the root-mean-square error of approximation. Modification indices (51) were used to detect misspecifications in the model. All of the analyses were conducted with SPSS software, version 19 (52), R, version 2.12.2 (53), and Mplus, version 6.11 (50). All P values reported are two-sided.

ACKNOWLEDGMENTS. We thank Prof. Esko Leskinen and Adjunct Prof. Asko Tolvanen for statistical help and advice. This study was supported by grants from the Ministry of Education and Culture, Finland. The Northern Finland Birth Cohort 1986 is supported by grants from the Academy of Finland, European Union, National Institutes of Health, Wellcome Trust, Nordic Academy for Advanced Study, and Ministry of Education and Culture, Finland.

1. Lobstein T, Baur L, Uauy R; IASO International Obesity TaskForce (2004) Obesity in children and young people: A crisis in public health. *Obes Rev* 5(Suppl 1): 4–104.
2. Ekelund U, et al.; International Children's Accelerometry Database (ICAD) Collaborators (2012) Moderate to vigorous physical activity and sedentary time and cardiometabolic risk factors in children and adolescents. *JAMA* 307(7):704–712.
3. US Department of Health and Human Services (2010) *The Surgeon General's Vision for a Healthy and Fit Nation* (Office of the Surgeon General, US Department of Health and Human Services, Rockville, MD).
4. Burkhalter TM, Hillman CH (2011) A narrative review of physical activity, nutrition, and obesity to cognition and scholastic performance across the human lifespan. *Adv Nutr* 2(2):201S–206S.
5. Hillman CH, Erickson KI, Kramer AF (2008) Be smart, exercise your heart: Exercise effects on brain and cognition. *Nat Rev Neurosci* 9(1):58–65.
6. Singh A, Uijtdewilligen L, Twisk JW, van Mechelen W, Chinapaw MJ (2012) Physical activity and performance at school: A systematic review of the literature including a methodological quality assessment. *Arch Pediatr Adolesc Med* 166(1):49–55.
7. Castelli DM, Hillman CH, Hirsch J, Hirsch A, Drollette E (2011) FIT Kids: Time in target heart zone and cognitive performance. *Prev Med* 52(Suppl 1):S55–S59.
8. Chomitz VR, et al. (2009) Is there a relationship between physical fitness and academic achievement? Positive results from public school children in the northeastern United States. *J Sch Health* 79(1):30–37.
9. Van Dusen DP, Kelder SH, Kohl HW III, Ranjit N, Perry CL (2011) Associations of physical fitness and academic performance among schoolchildren. *J Sch Health* 81(12):733–740.
10. Thorp AA, Owen N, Neuhaus M, Dunstan DW (2011) Sedentary behaviors and subsequent health outcomes in adults: A systematic review of longitudinal studies, 1996–2011. *Am J Prev Med* 41(2):207–215.
11. Vaynman S, Gomez-Pinilla F (2006) Revenge of the "sit": How lifestyle impacts neuronal and cognitive health through molecular systems that interface energy metabolism with neuronal plasticity. *J Neurosci Res* 84(4):699–715.
12. Thelen E (1995) Motor development. A new synthesis. *Am Psychol* 50(2):79–95.
13. Iverson JM (2010) Developing language in a developing body: The relationship between motor development and language development. *J Child Lang* 37(2):229–261.
14. Stodden D, et al. (2008) A developmental perspective on the role of motor skill competence in physical activity: An emergent relationship. *Quest* 60:290–306.
15. Barnett LM, Van Beurden E, Morgan PJ, Brooks LO, Beard JR (2008) Does childhood motor skill proficiency predict adolescent fitness? *Med Sci Sports Exerc* 40(12): 2137–2144.
16. Cantell M, Crawford SG, Doyle-Baker PK(Tish) (2008) Physical fitness and health indices in children, adolescents and adults with high or low motor competence. *Hum Mov Sci* 27(2):344–362.
17. Kantomaa MT, et al. (2011) Suspected motor problems and low preference for active play in childhood are associated with physical inactivity and low fitness in adolescence. *PLoS One* 6(1):e14554.
18. Westendorp M, Hartman E, Houwen S, Smith J, Visscher C (2011) The relationship between gross motor skills and academic achievement in children with learning disabilities. *Res Dev Disabil* 32(6):2773–2779.
19. Campos AL, Sigulem DM, Moraes DE, Escrivão AM, Fisberg M (1996) [Intelligent quotient of obese children and adolescents by the Weschler scale]. *Rev Saude Publica* 30(1):85–90, Portuguese.

20. Datar A, Sturm R (2006) Childhood overweight and elementary school outcomes. *Int J Obes (Lond)* 30(9):1449–1460.
21. Wu A, Ying Z, Gomez-Pinilla F (2004) The interplay between oxidative stress and brain-derived neurotrophic factor modulates the outcome of a saturated fat diet on synaptic plasticity and cognition. *Eur J Neurosci* 19(7):1699–1707.
22. Taras H, Potts-Datema W (2005) Obesity and student performance at school. *J Sch Health* 75(8):291–295.
23. Molteni R, et al. (2004) Exercise reverses the harmful effects of consumption of a high-fat diet on synaptic and behavioral plasticity associated to the action of brain-derived neurotrophic factor. *Neuroscience* 123(2):429–440.
24. Coatsworth JD, Conroy DE (2007) Youth sport as a component of organized after-school programs. *New Dir Youth Dev* 2007(115):57–74.
25. Coe DP, Pivarnik JM, Womack CJ, Reeves MJ, Malina RM (2006) Effect of physical education and activity levels on academic achievement in children. *Med Sci Sports Exerc* 38(8):1515–1519.
26. Rasberry CN, et al. (2011) The association between school-based physical activity, including physical education, and academic performance: A systematic review of the literature. *Prev Med* 52(Suppl 1):S10–S20.
27. Davis CL, et al. (2011) Exercise improves executive function and achievement and alters brain activation in overweight children: A randomized, controlled trial. *Health Psychol* 30(1):91–98.
28. Kamijo K, et al. (2011) The effects of an afterschool physical activity program on working memory in preadolescent children. *Dev Sci* 14(5):1046–1058.
29. McKenzie TL, et al. (2002) Childhood movement skills: Predictors of physical activity in Anglo American and Mexican American adolescents? *Res Q Exerc Sport* 73(3): 238–244.
30. Okely AD, Booth ML, Chey T (2004) Relationships between body composition and fundamental movement skills among children and adolescents. *Res Q Exerc Sport* 75(3):238–247.
31. Barnett LM, van Beurden E, Morgan PJ, Brooks LO, Beard JR (2009) Childhood motor skill proficiency as a predictor of adolescent physical activity. *J Adolesc Health* 44(3): 252–259.
32. Carlson SA, et al. (2008) Physical education and academic achievement in elementary school: Data from the Early Childhood Longitudinal Study. *Am J Public Health* 98(4): 721–727.
33. Fox CK, Barr-Anderson D, Neumark-Sztainer D, Wall M (2010) Physical activity and sports team participation: Associations with academic outcomes in middle school and high school students. *J Sch Health* 80(1):31–37.
34. Eveland-Sayers BM, Farley RS, Fuller DK, Morgan DW, Caputo JL (2009) Physical fitness and academic achievement in elementary school children. *J Phys Act Health* 6(1): 99–104.
35. Cole SR, Hernán MA (2002) Fallibility in estimating direct effects. *Int J Epidemiol* 31(1): 163–165.
36. VanderWeele TJ (2010) Bias formulas for sensitivity analysis for direct and indirect effects. *Epidemiology* 21(4):540–551.
37. Wilson BN, Kaplan BJ, Crawford SG, Campbell A, Dewey D (2000) Reliability and validity of a parent questionnaire on childhood motor skills. *Am J Occup Ther* 54(5): 484–493.
38. Sallis JF, Saelens BE (2000) Assessment of physical activity by self-report: Status, limitations, and future directions. *Res Q Exerc Sport* 71(2 Suppl):S1–S14.
39. Shephard RJ (2003) Limits to the measurement of habitual physical activity by questionnaires. *Br J Sports Med* 37(3):197–206, discussion 206.
40. Järvelin MR, Hartikainen-Sorri AL, Rantakallio P (1993) Labour induction policy in hospitals of different levels of specialisation. *Br J Obstet Gynaecol* 100(4):310–315.
41. Tammelin T, Ekelund U, Remes J, Näyhä S (2007) Physical activity and sedentary behaviors among Finnish youth. *Med Sci Sports Exerc* 39(7):1067–1074.
42. Ainsworth BE, et al. (1993) Compendium of physical activities: Classification of energy costs of human physical activities. *Med Sci Sports Exerc* 25(1):71–80.
43. Tammelin T, et al. (2007) Cardiorespiratory fitness of Finnish adolescents. *Int J Sports Med* 28(10):853–859.
44. Cole TJ, Bellizzi MC, Flegal KM, Dietz WH (2000) Establishing a standard definition for child overweight and obesity worldwide: International survey. *BMJ* 320(7244): 1240–1243.
45. Rodriguez A, et al. (2007) Do inattention and hyperactivity symptoms equal scholastic impairment? Evidence from three European cohorts. *BMC Public Health* 7:327.
46. Fabiano GA, et al. (2006) A practical measure of impairment: Psychometric properties of the impairment rating scale in samples of children with attention deficit hyperactivity disorder and two school-based samples. *J Clin Child Adolesc Psychol* 35(3): 369–385.
47. Gresham F, MacMillan D, Bocian K (1997) Teachers as "tests": Differential validity of teacher judgments in identifying students at-risk for learning difficulties. *School Psych Rev* 26(1):47–60.
48. Statistics Finland (2001) *UNESCO's International Standard Classification of Education ISCED 1997: Finnish Implementation Manual 2000: Appendix 1 to the Finnish Standard Classification of Education 2000* (Statistics Finland, Helsinki).
49. Van Buuren S, Groothuis-Oudshoorn K (2011) mice: Multivariate imputation by chained equations in R. *J Stat Softw* 45(3):1–67.
50. Muthen LK, Muthen BO (1998–2010) *Mplus User's Guide* (Muthen & Muthen, Los Angeles), 6th Ed.
51. Sorbom D (1989) Model modification. *Psychometrika* 54(3):371–384.
52. SPSS (2010) *IBM SPSS Statistics 19 Core System User's Guide* (SPSS, Chicago).
53. R Development Core Team (2011) *R: A Language and Environment for Statistical Computing* (R Found Stat Comput, Vienna).