

Modeling relationships between physical fitness, executive functioning, and academic achievement in primary school children



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ABSTRACT

Objectives: The relationship between physical fitness and academic achievement in children has received much attention, however, whether executive functioning plays a mediating role in this relationship is unclear. The aim of this study therefore was to investigate the relationships between physical fitness, executive functioning, and academic achievement, more specifically to test whether the relationship between physical fitness and academic achievement is direct or indirect, via executive functioning.

Design: Cross-sectional.

Method: This study examined 263 children (145 boys, 118 girls), aged 7–12 years, who performed tests on physical fitness, executive functioning, and academic achievement.

Results: In a structural equation model linking physical fitness to executive functioning and academic achievement there was a significant relationship between physical fitness and executive functioning ($r = .43$, $R^2 = .19$) and academic achievement ($r = .33$, $R^2 = .11$). Adding a relationship from executive functioning to academic achievement resulted in a non-significant direct link between physical fitness and academic achievement ($r = -.08$, $R^2 = .006$). However, a significant indirect relation through executive functioning persisted. The indirect relation between fitness and academic achievement ($r = .41$), was stronger than both the direct and total relation ($r = .33$).

Conclusion: Executive functioning thus served as a mediator in the relation between physical fitness and academic achievement. This highlights the importance of including executive functioning when studying the relationship between physical fitness and academic achievement in children.

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Introduction

While researchers and health professionals notice that children are increasingly less fit, teachers are observing that there is a growing concentration deficit and reduced attention in children (Budde, Voelcker-Rehage, Pietrażyk-Kendziorra, Ribeiro, & Tidow, 2008). In this context it is interesting to look at the relation between physical fitness and performance in the classroom. Physical fitness (fitness) is a set of attributes associated with the capacity to perform physical activities (Ortega, Ruiz, Castillo, & Sjöström, 2008). It refers to the full range of physical qualities and can be subdivided into various aspects like aerobic endurance, muscle strength and body composition (Ruiz et al., 2006). In children, fitness has not only been related to performance on academic

achievement, but also to other cognitive functions. Some studies have found a positive relationship between aerobic endurance and academic achievement (Castelli, Hillman, Buck, & Erwin, 2007; Chomitz et al., 2009; Eveland-Sayers, Farley, Fuller, Morgan, & Caputo, 2009), or between aerobic endurance and aspects of higher order cognitive functions, e.g. executive functioning (Buck, Hillman, & Castelli, 2008; Hillman, Buck, Themanson, Pontifex, & Castelli, 2009; Pontifex et al., 2011). Executive functioning encompasses a subset of cognitive operations used to effortfully guide behavior towards a goal (Banich, 2009), and includes abilities such as inhibition, filtering interference, flexibility of action and strategy development. Executive functioning develops throughout childhood and adolescence and has been linked to academic achievement (Bull & Scerif, 2001).

Neuropsychological research shows that performance in executive functioning is mediated by the development of the prefrontal cortex (Stuss, 1992). Children show substantial improvements in executive functioning when the frontal brain regions mature, with rapid development between ages 7 and 9 (Anderson, 2002; Best, Miller, & Jones, 2009). A foundational component of executive

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functioning is cognitive flexibility (also called set-shifting). Cognitive flexibility is the ability to alternate attention between two simultaneous goals (Arbuthnott & Frank, 2000). The ability to shift between two tasks starts in infancy but develops into more complex switching capacity throughout childhood and into adulthood (Diamond, 2002). It is usually tested in set-switching tasks, in which the participant is asked to switch between two stimuli or to sort cards according to rules that change along the way (Best et al., 2009). Successful task switching requires inhibitory control of the currently irrelevant task set (Arbuthnott & Frank, 2000), and is found to be of importance in environments in which attentional demands are constantly changing.

Another important executive function is response planning or problem solving, which refers to the processes that facilitate the selection of task appropriate responses (Asato, Sweeney, & Luna, 2006). The ability to plan is a critical part of goal-oriented behavior and enables a child to direct and evaluate his or her behavior when confronted with a novel situation (Best et al., 2009). Tasks testing this ability require the child to plan multiple steps in advance and evaluate this plan while performing the actions (Best et al., 2009). Response planning involves multiple cognitive processes like response inhibition and working memory, and therefore reflects essential elements of executive functioning (Asato et al., 2006).

Both cognitive flexibility and response planning are frequently linked to the development of academic achievement in children, especially mathematics and reading (Best, Miller, & Naglieri, 2011). It is thought that improvements in executive functioning facilitate improvements in academic achievement (Best et al., 2009), or that adequate executive functioning develops prior to behaviors affecting academic achievement (Blair & Razza, 2007). Indeed, the ability to shift attention is likely to be important for moving between tasks and has been found to be involved in mathematics (Bull, Espy, & Wiebe, 2008) and reading performance (Van der Sluis, De Jong, & Van der Leij, 2007). Likewise, the ability to plan in order to solve a problem seems to be fundamental for mathematic skills (Sikora, Haley, Edwards, & Butler, 2002).

The link between fitness and executive functioning or academic achievement in children seems to be most valid for the aerobic fitness component of physical fitness. Aerobic fitness refers to the overall capacity of the cardiovascular and respiratory system to use oxygen, and the ability to carry out prolonged strenuous exercise (Ortega et al., 2008). Castelli et al. (2007) examined the relation between academic achievement and various aspects of fitness, including aerobic fitness, muscle fitness, flexibility and body composition. They found that only aerobic fitness and BMI were related to performance on reading and mathematics. Other studies also found that more fit children, based on performance on aerobic fitness tests, had better scores on academic achievement tests (Chomitz et al., 2009) and executive functioning tasks (Buck et al., 2008) than their lower fit peers. Research on neuro-electric activation patterns of cognition in children showed that more fit children, with greater aerobic fitness based on directly measured maximal oxygen consumption, were more accurate on executive functioning tasks compared to their lower fit peers (Hillman et al., 2009; Pontifex et al., 2011). In addition to the aerobic fitness component, studies in older adults also showed a positive relation between muscle strength and performance on executive functioning tasks (Cassilhas et al., 2007; Liu-Ambrose et al., 2010), but in children this possible relation is still unclear. Castelli et al. (2007) did not find a relation between muscle strength and academic achievement, however, in a study by Eveland-Sayers et al. (2009) a positive relationship was found between muscular fitness and mathematics scores. Also, Dwyer, Sallis, Blizzard, Lazarus, and Dean (2001) found an association between muscle force, muscle power

and academic achievement, specifically with sit-ups and standing long jump, measuring trunk strength and explosive leg power respectively.

One possible theory explaining the relationship between aerobic fitness and executive functioning or academic achievement is the physiological fitness hypothesis, also called the cardiovascular fitness hypothesis. It states that regular exercise (either aerobic or non-aerobic exercise like muscular resistance or games without an aerobic component) will induce short and long term changes in brain regions critical to learning and memory, as a result of increased cerebral blood flow (Etnier et al., 1997). Acute bouts of exercise will result in an increase in the release of neurotransmitters responsible for synaptic transmission and plasticity like growth factors and neurotrophins (Best, 2010). In the long term, chronic exercise not only results in increased brain neurotransmitters, it may also result in permanent structural changes in the brain like new neuronal and vascular architecture (Hillman, Erickson, & Kramer, 2008). While most support for the physical fitness hypothesis comes from non-human studies, more and more research on humans show similar results (Pereira et al., 2007).

Taken together, several studies have described the relationships between fitness, executive functioning, and academic achievement separately. However, it remains unclear how these factors relate when investigated together. The goal of this study was therefore to simultaneously examine the relations between fitness (including both aerobic fitness and strength components), executive functioning, and academic achievement. Prior to the main analysis of the relationships between the three latent factors fitness, executive functioning, and academic achievement, confirmatory factor analysis (CFA) was used to test whether the observed measures served as good indicators of each factor. Once the three factors fitness, executive functioning, and academic achievement were clearly defined by their respective indicators, the relationships between the three factors were analyzed by putting them together in a model using structural equation modeling (SEM). To confirm relations found in previous studies, it was first tested whether fitness was related to executive functioning and academic achievement. It was hypothesized that fitness would be positively related to both executive functioning and academic achievement. Next, to address the main question, it was tested whether executive functioning plays a mediating role within the relation between fitness and academic achievement. That is, whether the relationship between fitness and academic achievement is direct or indirect. We hypothesized that executive functioning would serve as a mediator in the relation between fitness and academic achievement.

Method

Participants

Children from four primary schools in the northern Netherlands were recruited to participate in the study. In total, 263 typically developing children (145 boys, 118 girls) between the ages of 7 and 12 years old were included. Most of the children came from similar socioeconomic backgrounds; 12% of the children had a low or middle low socioeconomic status (SES) based on the education of the parents.¹ No statistical differences were found between boys and girls with respect to age, height, weight, Body Mass Index (BMI) and the percentage of children with normal weight and

¹ Low SES: One of the parents has finished primary school at most, the other parent finished a maximum of two years of other education in addition to primary school. Middle low SES: One or both of the parents have at least finished primary school and a maximum of two years of other education.

overweight/obese, as depicted in Table 1. In all instances, informed consent was obtained from the children's parents/guardians prior to participation. Student consent rate was 94%. All procedures were in accordance with and approved by the ethical committee of the Center for Human Movement Sciences of the University Medical Center Groningen, University of Groningen.

Measures

Physical fitness

Participants' fitness was measured with four tests from the European physical fitness test battery (EUROFIT) (Adam, Klissouras, Ravazzolo, Renson, & Tuxworth, 1988). These tests were the standing broad jump (SBJ, in cm), sit-ups (SUP, number in 30 s), the 10 × 5 m shuttle run (10 × 5 m SR, in seconds) and the 20-meter shuttle run (20 m SR, in stages). All tests were administered by trained examiners. The shuttle run test was measured during a normal physical education lesson, while the remaining three tests were completed in circuit form in a random order during another physical education lesson. For a subsample of the data ($n = 83$) an analysis of covariance (ANCOVA) was performed, to evaluate if there would be a testing order effect. Three ANCOVA's were performed, one for the standing broad jump, one for the 10 × 5 m shuttle run, and one for the sit-ups, with testing order (1, 2 or 3) as independent variable, and age and gender as control variables. Examination of the results showed that there was no effect of testing order on the performances ($p > .05$).

It was hypothesized that the four measures reflect both a strength and aerobic component of fitness. In the SBJ test children were asked to jump as far as possible with two feet from a standing position, as a measure of explosive leg strength. Trunk strength was measured with the SUP test, in which children have to perform as many sit-ups as possible within 30 s. In the 10 × 5 m SR test children were asked to run 5 m 10 times, covering a distance of 50 m in total, to measure their running speed and agility. In the 20 m SR test children run back and forth between two lines 20 m apart, pacing their run to audio signals that progressively increase in difficulty. Results are expressed as the last completed stage. The test measures cardiorespiratory endurance. The test–retest reliability, ranging from .62 to .97, and construct validity of the four tests for children are adequate (Léger, Mercier, Gadoury, & Lambert, 1988; Mechelen, Lier, Hlobil, Crolla, & Kemper, 1991).

Executive functioning

All children were tested individually on their problem solving skills using the Tower of London test, and cognitive flexibility was measured using the Trailmaking test. Both tests were administered by trained examiners. The Tower of London (ToL, Shallice, 1982) is thought to examine the ability to plan and sequence a behavior towards a goal (Banich, 2009; Unterrainer et al., 2004). In the ToL task a child is presented with three colored balls that need to be

moved between three pegs of differing heights in order to reproduce a depicted target pattern in a prescribed number of moves (Baker, Segalowitz, & Ferlisi, 2001). The child must create a strategy and keep in mind the target pattern while evaluating their progress after each move. A total of 12 problems has to be solved that vary in difficulty by the number of required moves. Points are assigned when a child solves the problem, with a maximum of three points for each problem. The ToL has been tested and validated for use with children (Anderson, Anderson, & Lajoie, 1996). The Trailmaking test (TMT) is a visual task in which children are asked to connect circles in numerical order (trail A), and in alternating between both numerical and alphabetical order (trail B), by drawing a line from one point to the next as quickly as possible (Reitan, 1971; Reitan & Wolfson, 2004). To obtain an accurate measure of cognitive flexibility, the time to complete trail A is subtracted from the time to complete trail B (Strauss, Sherman, & Spreen, 2006). The TMT has been used and validated in children from age 7 (Anderson, 1998; Strauss et al., 2006).

Academic achievement

To assess the children's academic achievement, the child academic monitoring system was used (Cito). This system is used by Dutch schools to measure and monitor the progress in academic achievement at least twice a year. Standardized test scores on mathematics, reading and spelling were used. The math test consists of different parts measuring number sense and computation, algebraic, and measurement skills (Janssen, Verhelst, Engelen, & Schelkens, 2010). The test intends to measure whether the child is able to execute math and to use strategies to solve math problems. Reading abilities are assessed by having children read a text for themselves on which they have to answer several questions. In this case not only reading skills are measured, but also understanding, interpretation and reflection skills (Feenstra, Kamphuis, Kleintjes, & Krom, 2010; Weekers, Groenen, Kleintjes, & Feenstra, 2011). To assess spelling skills the child has to write down words that are read out aloud by the teacher and pick the wrongly spelled word out of a list of four words (De Wijs, Kamphuis, Kleintjes, & Tomesen, 2010). The reliability of all tests ranges from .87 to .96, the content validity and construct validity were good (De Wijs et al., 2010; Feenstra et al., 2010; Janssen et al., 2010; Weekers et al., 2011).

Statistical analysis and modeling

Initial data analyses were performed using SPSS 20.0 for Windows (statistical significance was set at .05). Descriptive statistics were used to describe participants' characteristics and performance on fitness, executive functioning, and academic achievement measures. An independent Student's *t*-test was used to test the effect of gender on the measured variables. A multivariate analysis of covariance (MANCOVA) was performed on a subsample of the data ($n = 61$) to find out if there were differences on the scores on the fitness, executive functioning and academic achievement measures between children with a low or middle low SES ($n = 28$) and children with a regular SES. Three MANCOVA's were performed on 1) four fitness measures, 2) two executive functioning measures, and 3) three academic achievement measures. To examine the relations between fitness, executive functioning, and academic achievement, models were constructed in LISREL modeling (Jöreskog & Sörbom, 2007), using PRELIS.

Confirmatory factor analysis was performed to test whether the observed measures served as good indicators for the latent factors fitness, executive functioning, and academic achievement. Next, two models were designed using structural equation modeling, in which it was investigated if the complete model fitted the empirical data. In the first model, fitness loaded directly to both executive

Table 1
Descriptive statistics.

	All ($n = 263$)		Boys ($n = 145$)		Girls ($n = 118$)		<i>p</i> -value
	Mean	SD	Mean	SD	Mean	SD	
Age (year)	9.5	1.2	9.5	1.2	9.5	1.3	.99 ^b
Height (cm)	142.8	10.0	142.8	9.1	142.8	11.0	.99 ^b
Weight (kg)	35.2	9.4	34.9	9.0	35.7	9.8	.51 ^b
BMI (kg/m ²)	17.1	2.9	16.9	2.9	17.4	3.0	.25 ^b
% Normal weight ^a	80		84		75		.06 ^c
% Overweight/obese ^a	20		16		25		

^a Calculated from cut-off criteria of Cole, Bellizzi, Flegal, and Dietz (2000).

^b Student's *t*-test.

^c Non parametric Chi square test.

functioning and academic achievement, with a covariance between executive functioning and academic achievement. In the second model a path was added from executive functioning to academic achievement. In this model, academic achievement was both directly and indirectly linked to fitness. In addition to this, age and gender were added as a factor to both models, loading directly on the three factors fitness, executive functioning, and academic achievement, to see whether the models would change when taking these confounding factors into account. Maximum Likelihood estimation was used in all models to calculate the covariance matrix from the raw data. To investigate the mediating role of executive functioning in the second model, the total and indirect effects were obtained from the LISREL output, using raw correlations to give a measure of the effect size. The indirect effect of physical fitness on academic achievement via executive functioning is the product of the direct relations, while the total effect is the sum of all direct and indirect relations.

Goodness of fit

For all CFA and SEM models, standardized solutions were used that reflect correlations (r) between indicators and latent variables. R^2 values indicate how well the latent variable explains the variance in the observed variable, or in the case of structural relations the variance in another latent variable. A stepwise approach was used to drop relationships that were not significant (t -value smaller than -1.96) from the model. Several goodness of fit measures were used to describe the final model; χ^2 statistic, the root mean square error of approximation (RMSEA), and the non-normed fit index (NNFI). The χ^2 statistic is a measure of overall fit of the model to the data. A small χ^2 corresponds to a good fit and a large χ^2 to a bad fit between the sample correlation matrix and the fitted correlation matrix (Jöreskog, 1993). In addition, a good model fit will result in a non-significant p -value ($p > .05$). The RMSEA is a measure of the error of approximation and shows how well the model, with unknown, but optimally chosen parameter values fit the population matrix. Values below .08 are indicative of acceptable fit (Hooper, Coughlan, & Mullen, 2008). The NNFI value is based on the χ^2 distribution and ranges between 0 to values greater than 1, with values greater than .95 indicating a good fit (Hooper et al., 2008).

Results

Descriptive statistics

Only children with measures on all variables were included in the analysis, and cases with extreme outliers ($n = 1$) were excluded, resulting in 243 cases (134 boys, 109 girls). Table 2 shows the

correlations between the variables and participants' performance on fitness, executive functioning, and academic achievement measures. A Student's t -test revealed that boys performed significantly better on all fitness tests: 20-meter shuttle run test, 10×5 m shuttle run, standing broad jump, and sit-ups ($p < .05$). No differences between boys and girls were found on measures of executive functioning and academic achievement. Results of the MANCOVA indicated that there were no differences on fitness, executive functioning and academic achievement scores between children with a low or middle low SES and children with a regular SES ($p > .05$).

Confirmatory factor analysis

One model was constructed to test if the four measured variables, 20 m SR, 10×5 m SR, SUP and SBJ provided good measures of fitness. The model provided a good fit with the data, as reflected in the fit indices ($\chi^2 (2) = 5.17$, $p = 0.075$, RMSEA = 0.077, NNFI = 0.97). The latent factors executive functioning and academic achievement were specified according to their described indicators ToL and TMT (executive functioning), and mathematics, reading and spelling (academic achievement). This model also provided a good fit with the data ($\chi^2 (4) = 2.05$, $p = 0.730$, RMSEA = 0.000, NNFI = 1.01). Table 3 shows the standardized parameter estimates for the CFA models. All correlations explained a small to large amount of the item variance (R^2 ranged from 0.09 to 0.81).

Structural equation modeling

In all models, fitness was defined as the exogenous latent variable related to the endogenous variables executive functioning and academic achievement. For all models, executive functioning was scaled to 1 to compensate for the high difference in scale between the ToL and TMT. Furthermore, as the CFA revealed the covariance between executive functioning and academic achievement was high, in Model 1 we set the error covariance between these factors free.

Model 1, in which fitness was related to both executive functioning and academic achievement, provided a good fit with the data ($\chi^2 (24) = 34.86$, $p = 0.071$, RMSEA = 0.040, NNFI = 0.98).

Adding age to the first model did not provide a good fit with the data on all fit indices ($\chi^2 (30) = 75.39$, $p = 0.00$, RMSEA = 0.076, NNFI = 0.95). Adding gender to the first model did not provide a good fit with the data on all fit indices either ($\chi^2 (30) = 49.91$, $p = 0.013$, RMSEA = 0.046, NNFI = 0.98). We thus continued interpreting Model 1 without these confounding factors.

Table 2
Correlations between the variables used in the analysis with mean and SD for each variable.

	20 m SR ^a	10 × 5 m SR ^b	SUP ^a	SBJ ^a	ToL ^a	TMT ^b	Maths ^a	Read ^a	Spell ^a
20 m SR	1.0								
10 × 5 m SR	-.55**	1.0							
SUP	.41**	-.33**	1.0						
SBJ	.46**	-.52**	.39**	1.0					
ToL	.06	-.09	.00	.2	1.0				
TMT	-.15*	.20**	-.13*	-.21**	-.16**	1.0			
Maths	.28**	-.22**	.15*	.32**	.25**	-.46**	1.0		
Reading	.15*	-.12	.08	.18**	.25**	-.39**	.76**	1.0	
Spelling	.16*	-.19**	.06	.24**	.21**	-.44**	.78**	.74**	1.0
Mean	4.5	23.3	16	134.4	27.7	79.4	83.3	29.9	131.4
(SD)	(1.9)	(2.4)	(5.0)	(20.7)	(3.2)	(40.6)	(22.1)	(20.2)	(11.4)

Note. 20 m SR = 20-meter shuttle run. 10×5 m SR = 10×5 m shuttle run. SUP = sit-ups. SBJ = standing broad jump. ToL = Tower of London. TMT = Trailmaking test. Maths = mathematics. Read = reading. Spell = spelling. * $p < .05$. ** $p < .01$.

^a A higher score indicates a better performance.

^b A lower score indicates a better performance.

Table 3

Standardized parameter estimates for the CFA models fitness and executive functioning (EF)/academic achievement (AA).

Item	Physical fitness	R ²	Executive functioning	Academic achievement	R ²
<i>Fitness</i>					
20 m SR	0.72	0.52			
10 × 5 m SR	−0.74	0.55			
SUP	0.52	0.27			
SBJ	0.68	0.46			
<i>EF/AA</i>					
ToL			−0.29		0.09
TMT			0.53		0.28
Mathematics				0.90	0.81
Spelling				0.87	0.75
Reading				0.84	0.71

Note. 20 m SR = 20-meter shuttle run. 10 × 5 m SR = 10 × 5 m shuttle run. SUP = sit-ups, SBJ = standing broad jump. ToL = Tower of London. TMT = Trailmaking test.

Model 1 showed there is a stronger relationship between fitness and executive functioning ($r = .43$, $R^2 = .19$) than fitness and academic achievement ($r = .33$, $R^2 = .11$). This means fitness explains 19% of the variance in executive functioning, and 11% of the variance in academic achievement.

To test the main question whether the relation between fitness and academic achievement was a direct or indirect path, thus indicating if executive functioning serves as a mediator in this relationship, a second model was tested. In Model 2 fitness was related to both academic achievement and executive functioning, and an extra relation was added from executive functioning to academic achievement (Fig. 1). The goodness of fit indices were the same as Model 1, indicating that Model 2 has a good fit with the data ($\chi^2(24) = 34.86$, $p = 0.071$, RMSEA = 0.040, NNFI = 0.98).

Adding age to Model 2 did not provide a good fit with the data ($\chi^2(30) = 75.39$, $p = 0.00$, RMSEA = 0.076, NNFI = 0.95). Adding gender to Model 2 did not provide a good fit with the data either ($\chi^2(30) = 49.91$, $p = 0.013$, RMSEA = 0.046, NNFI = 0.98). We thus continued interpreting Model 2 without these confounding factors.

Model 2 showed that the (direct) link between fitness and academic achievement was not significant ($t = -.38$, $r = -.08$, which is an explained variance of only 0.64%), indicating that this relation does not exist in the population. The relationship between fitness and executive functioning persisted ($r = .43$, $R^2 = .19$), and executive functioning was strongly related to academic achievement ($r = .95$, $R^2 = .90$).

To investigate the mediating role of executive functioning in the relation between physical fitness and academic achievement, the total and indirect effects of the model were obtained from the LISREL output. The total effect was .33 ($p < .01$), while the indirect effect was .41 ($p < .05$). The indirect effect ($r = .41$) is thus stronger

than the total effect ($r = .33$), as well as the direct effect found in Model 1 ($r = .33$), confirming the mediating role of executive functioning in Model 2.

Finally, as we found statistically significant differences between boys and girls on all physical fitness measures, multi-group moderation analysis was conducted to determine whether the structural relations would change as a result of these differences in fitness. Results showed that the structural relations between fitness, executive functioning and academic achievement did not significantly differ between boys and girls when gender differences in fitness were taken into account.

Discussion

The relationship between fitness and academic achievement in children have been increasingly studied over the last decades, resulting in evidence of a relationship between fitness and academic achievement (Castelli et al., 2007). Also, there is increasing evidence of a relation between fitness and executive functioning (Buck et al., 2008). However, to our knowledge this is the first study to examine the associations between fitness, executive functioning, and academic achievement simultaneously in a sample of primary school children. We hypothesized that fitness would be positively related to both executive functioning and academic achievement, and attempted to investigate whether executive functioning was a mediator in the relation between fitness and academic achievement. CFA showed that the four measured fitness variables used in this study (20 m SR, 10 × 5 m SR, SUP and SBJ) were good indicators of the latent variable fitness. CFA also showed that the ToL and TMT significantly loaded on the latent variable executive functioning, and that mathematics, reading, and spelling loaded significantly on the latent variable academic achievement. SEM showed that fitness was significantly related to both executive functioning and academic achievement, and more strongly related to executive functioning than academic achievement (Model 1). Furthermore, SEM showed that the direct link between fitness and academic achievement disappeared when a relationship was added from executive functioning to academic achievement (Model 2), confirming the hypothesis that executive functioning serves as a mediator in the relationship between fitness and academic achievement.

Findings from the SEM confirm the strong relations between fitness and executive functioning or fitness and academic achievement found in other studies (e.g. Castelli et al., 2007; Chomitz et al., 2009), and extends our current knowledge on these relations by showing that fitness was more strongly related to executive functioning ($r = .43$, $R^2 = .19$) than academic achievement ($r = .33$, $R^2 = .11$). The significant relationship between fitness and

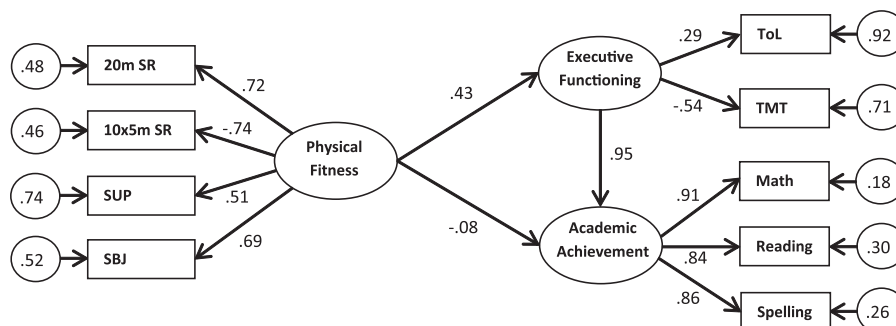


Fig. 1. The estimated structural Model 2 (the direct and indirect effect of physical fitness on academic achievement). 20 m SR = 20-meter shuttle run, 10 × 5 m SR = 10 × 5 m shuttle run, SUP = sit-ups, SBJ = standing broad jump, ToL = Tower of London, TMT = Trailmaking test, Math = mathematics.

executive functioning is in agreement with the existing evidence of the physical fitness hypothesis, which states that executive functioning can be improved by gains in aerobic fitness by means of increased blood flow and brain neurotransmitters. However, this might not only be the case for aerobic fitness; gains in muscle strength may have an effect as well, suggesting that more mechanisms could be involved in explaining the potential benefit of fitness on executive functioning. In a study by Cassilhas et al. (2007) the benefits of strength training on executive functioning in the elderly are explained by increased concentrations of insulin-like growth factor I, which promotes neuronal growth and survival and improves executive functioning. Whether this same mechanism applies to executive functioning benefits of strength gains in children is not yet known.

Physical fitness is thus related to both executive functioning and academic achievement, however, as previous studies suggest a relation between executive functioning and academic achievement (e.g. Best et al., 2011), this relation was added in Model 2. Findings from this model showed that executive functioning was a mediator in the relationship between fitness and academic achievement. The direct link in Model 2 was non-significant, meaning that the direct relationship between fitness and academic achievement is negligible when a mediating relation between executive functioning and academic achievement is taken into account. Moreover, the indirect relation between fitness and academic achievement ($r = .41$), was stronger than the direct and total relation ($r = .33$). This raises the question whether adequate executive functioning might be a prerequisite for using fitness to improve academic achievement. The cognitive capacities involved in executive functioning might be foundational for academic achievement. As Bull et al. (2008) suggest, executive functioning skills provide children with building blocks for the development of mathematics and reading. To improve school performance, targeting executive functioning can then be crucial (Best et al., 2011), as some studies on preschoolers have already shown (Blair & Razza, 2007; Welsh, Nix, Blair, Bierman, & Nelson, 2010). Research aiming to improve academic achievement by increasing fitness must therefore not forget to include executive functioning, as it might be that executive functioning will improve prior to improvements in academic achievement.

Despite the contribution of the current study to extend the knowledge on the relationships between fitness, executive functioning, and academic achievement, it is worth mentioning several points to consider in future studies. We used a cross-sectional design, which did not allow us to draw firm conclusions about the causality of the relationships we found. It would be interesting to explore whether the findings can be replicated in longitudinal studies. For example, the addition of age and gender in the models in this cross-sectional study did not provide a good fit with the data. Therefore, the role of age and gender in the relations between fitness, executive functioning, and academic achievement requires further explanation, as this might be different when looking at the development of these relations in a longitudinal design. Also, it would be interesting to explore the relations in children from a low socioeconomic status or in children from special populations. For example, there is evidence of a relationship between motor performance and executive functioning (Hartman, Houwen, Scherder, & Visscher, 2010) and motor performance and academic achievement (Vuijk, Hartman, Mombarg, Scherder, & Visscher, 2011) in children with learning or intellectual disabilities. However, whether fitness is also related to executive functioning and academic achievement in these cognitively vulnerable populations requires further investigation. Finally, the positive relations between fitness and both executive functioning and academic achievement highlight the importance of children being physically

active, which can be achieved during the school day, in physical education classes or recess, free play time after school or involvement in organized sports. Moreover, special fitness programs could be developed for children to stimulate academic achievement. Interventions focusing on increasing fitness in children should include activities targeting aerobic fitness and strength, and research focusing on the effects of these interventions should incorporate both academic achievement and executive function measurements.

In conclusion, the present study confirms the associations between physical fitness, executive functioning, and academic achievement in primary school children. In the sample of primary school children, physical fitness was represented by four measured variables reflecting both a strength and aerobic component of fitness. Moreover, the study shows that executive functioning is a mediator in the relationship between physical fitness and academic achievement, thus making executive functioning an important aspect to examine in future research.

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