

# Associations of Physical Fitness and Motor Competence With Reading Skills in 9- and 12-Year-Old Children: A Longitudinal Study

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## Abstract

This longitudinal study explores the association of motor competence and physical fitness with reading skills in children aged 9 and 12 years. Sixty-seven children aged 9 years completed an assessment of motor competence (measured using the Movement Assessment battery for Children), physical fitness (assessed using the Test of Physical Fitness), and reading (measured using the Wordchain test). The testing procedures were repeated after 32 months. For the 9-year-old group, there was a low, negative correlation between motor competence and reading overall,  $r = -.031$  (girls:  $r = -.207$ ; boys:  $r = .180$ ). Correlation between fitness and reading was also low ( $r = .064$ ). Girls had a higher correlation between fitness and reading than boys ( $r = .404$ ; 17.7% shared variance, vs.  $r = -.138$ ). When the children were 12 years old, there was still a low association of motor competence and fitness with reading. These low associations can be used to support the task specificity principles of learning.

## Keywords

longitudinal, movement skills, physical activity, academic performance, children

## Introduction

The possible associations of physical activity and exercise with cognitive functioning and academic performance in children and adolescents has been increasingly investigated in recent years (Donnelly et al., 2016; Haapala et al., 2016; Hillman, Erickson, & Hatfield, 2017; Van der Niet, Hartman, Smith, & Visscher, 2014). Although there has been research performed on this topic for many years (see, for example, Ayres, 1965), the renewed interest may be caused by concern that today's children do not maintain appropriate levels of physical activity and physical fitness (Tremblay et al., 2011), and there have also been reports of declining motor competence (Bardid, Rudd, Lenoir, Polman, & Barnett, 2015; Kambas et al., 2012). Despite the known benefits to health outcomes (Janssen & LeBlanc, 2010; Timmons et al., 2012), evidence suggests that many children do not meet the recommended amount of daily physical activity (Kolle, Steene-Johannessen, Andersen, & Anderssen, 2010; Verloigne et al., 2012). In addition, evaluation of education systems worldwide by testing children's skills and knowledge in important key subjects may have increased the focus on academic results and efforts to improve the educational systems (The Programme for International Student Assessment [PISA]).

Several mechanisms related to changes in brain structure and cognitive function have been discussed when explaining the possible effects of physical activity on brain health in children (for a complete overview, see reviews by Donnelly et al., 2016; Hillman et al., 2017; Voelcker-Rehage & Niemann, 2013). The constructs of physical activity, physical fitness, cardiovascular fitness, and motor competence are interrelated, but the results indicate that these different aspects of exercise and activity are differently associated with the brain structure, cognition, and function (Haapala, 2013; Voelcker-Rehage & Niemann, 2013). Higher physical fitness and higher cardiovascular fitness in children has been related to a larger volume of the subcortical structures such

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as the basal ganglia and hippocampus (Chaddock et al., 2010, 2012); additional evidence suggests that children who are more fit have a higher integrity of white matter microstructure and cortical thickness (see Hillman et al., 2017). These structures are related to the modulation of executive control such as inhibition, memory, cognitive flexibility, and attention, which are cognitive operations that often are referred to as “gate keepers” to learning and academic achievement (Voelcker-Rehage & Niemann, 2013).

More recently, studies on the association between motor coordination and cognitive function in children have emerged (Haapala et al., 2015; Van der Fels et al., 2014), but the link between this kind of research and specific brain structures and functions is unclear. According to Koutsandr eou, Wegner, Niemann, and Budde (2016), improvement of the working memory is significantly better for children undergoing motor exercise compared with a cardiovascular exercise training group and a control group. It is suggested that coordination and motor skill learning taps into the neurophysiological motor system to a greater extent than the metabolic processes involved in fitness and physical activity, and that this has specific mechanistic effects on the brain structure and function via influence of the neural synapses and network (Koutsandr eou et al., 2016; Voelcker-Rehage & Niemann, 2013). The underlying mechanisms that are different between types of physical activity and brain structure/function are diverse and complex, and they are beyond the scope of the present study.

Reading is a skill that, in many societies, will determine success because decoding of written text to attain meaning is a prerequisite to gain knowledge from books. The reading process presupposes the graphemic encoding of visually presented words that in turn is recoded into speech and meaning is activated in semantic memory corresponding to comprehension (Revlin, 2013). At some point in the reading process, there is a need to recognize individual words. Word decoding can be defined as “the accurate and fast retrieval of the phonological code for written word forms” (Verhoeven, 2011, p. 38) and has a central role in children’s reading development (Stanovich, 2000). Age differences are intuitively present in reading, but sex differences are also found; girls display better general reading comprehension compared with boys (Mullis, Martin, Kennedy, & Foy, 2007). Sex differences are also observed in word processing because physiological evidence reveals differences in event-related field patterns during word recognition, that is, more strength of activation and involvement of different neural structures in women (see, for overview, Walla, Hufnagl, Lindinger, Deecke, & Lang, 2001). Walla et al. (2001) suggested that in females, both hemispheres are equally involved in word processing compared with males where the left hemisphere is more involved, that is, hemispheric asymmetry. However, researchers have also suggested that there is a strong influence of sex hormones on cognitive functions (Kimura, 1996) and cerebral lateralization (Geschwind & Galaburda, 1985). In this

respect, Geschwind and Galaburda (1985) argued that testosterone slows down the development of the left hemisphere during prenatal period. This causes difference in abilities between the genders, girls being superior in verbal abilities.

Caspersen, Powell, and Christenson (1985, p. 128) defined physical fitness as a set of inherent or achieved personal attributes that relate to the ability to perform physical activity. Physical fitness is a multifaceted concept, and some fitness components included in this term seem to be especially important markers of various health outcomes in young people, namely cardiorespiratory fitness, flexibility, muscular fitness, and speed/agility (Ortega, Ruiz, Castillo, & Sj ost om, 2008). Muscular fitness is the capacity to perform work against resistance, while speed and agility is the ability to move quickly and change direction of the body rapidly and in a controlled way (Gallahue & Ozmun, 2006). Cardiorespiratory fitness is the overall capacity of the cardiovascular, respiratory, and skeletal muscle system to use oxygen for energy production, and it has been positively associated with cognition and brain health. Castelli, Hillman, Buck, and Erwin (2007) found that a higher aerobic fitness performance (measured by Pacer, 20-m shuttle run) was positively related to reading achievement ( $p < .001$ ) among children in the third and fifth grades. Children with a higher cardiovascular fitness are also found to perform better compared with their less-fit peers in executive function processes (e.g., memory, attention, and inhibitory control; Chaddock et al., 2010; Hillman, Erickson, & Kramer, 2008), supporting the findings that executive functioning is a mediator of the relationship between physical fitness and academic achievement (Van der Niet et al., 2014). Moreover, a higher fitness level in children affects the speed of the neuroelectric responses associated with specific language processing abilities (Scudder et al., 2014). In contrast, Haapala et al. (2015) found no association between cardiovascular performance (assessed by a maximal exercise test with cycle ergometer) and academic skills. Similarly, Kantomaa et al. (2013) did not find any association between cardiovascular fitness and grade-point average in adolescents. Moreover, van der Niet et al. (2014) showed that the different measures included in physical fitness (including 20-m shuttle run, 10 × 5-m shuttle run, sit-ups, and standing broad jump) correlated differently with the academic outcomes of interest (mathematics, reading, and spelling). For example, standing broad jump had highest correlations to academic performance, then 20-m shuttle run, 10 × 5-m shuttle run, while sit-ups had the lowest correlation. Other fitness components, such as muscle fitness and flexibility, did not relate to academic achievement (general academic achievement, reading, and mathematics; Castelli et al., 2007). In addition, an intervention study by Bassin and Breihan (1978) found no significant improvements ( $p > .05$ ) in reading achievement after a period of exposure (3 times a week, in ½-hr sessions during a 20-week period) to different motor activities (including coordination and rhythm, agility, speed, strength, flexibility, balance, and

endurance) among children in the second grade compared with a control group and an experimental group.

Motor competence can be defined as an individual's level of performance when executing different motor acts (Burton & Rodgerson, 2001; Henderson & Sugden, 1992; Sigmundsson & Haga, 2016), and the term encompasses both fine and gross motor skills/activities. When measuring motor competence, typical aspects in focus are balance/postural control, speed, sureness, and accuracy of movement coordination. Compared with the health-related components found in physical fitness, test items on motor competence tests demand little muscular strength or endurance, and aerobic performance (Fjørtoft, Pedersen, Sigmundsson, & Vereijken, 2003; Haga, 2009). Motor competence was shown to influence several aspects in a child's development, including psychosocial factors (e.g., self-esteem; Vedul-Kjesås, Sigmundsson, Stensdotter, & Haga, 2012), probability of participation in a physical activity (Holfelder & Schott, 2014), overall performance on different fitness components (Haga, 2008; Rivilis et al., 2011), and the degree of excessive weight and obesity (D'Hondt et al., 2013; Hendrix, Prins, & Dekkers, 2014). More recently, motor competence has been studied in relation to cognitive function and academic performance in children. Haapala et al. (2015) highlighted how different measures of motor performance are not equally linked to cognition in children, because better cognition (measured by Raven Colored Progressive Matrices) was significantly associated with better overall motor performance (calculated as the sum of shuttle run, balance, and manual dexterity) and better performance in the shuttle run test and balance test (modified flamingo balance test), but not with standing long jump, 15-m sprint, and manual dexterity in the entire sample. Similar findings were also reported by Haapala et al. (2014), because children with a lower performance, that is, results in the lowest third, in overall motor performance, shuttle run, and manual dexterity in Grade 1 had significantly worse reading fluency and arithmetic skills compared with children with higher performance in motor competence, while no such association was found between balance and academic performance.

Intervention studies that investigated the effects of motor skills and physical activity (measured by Motor Skills Development as Ground for Learning (MUGI) that specially focused on balance and coordination) on school performance for a period of 9 years revealed better marks (Swedish, English, and mathematics) in the intervention group than the control group ( $p < .05$ ), and a larger proportion from the intervention group qualified for upper secondary school. However, both these associations were found for boys but not for girls (Ericsson & Karlsson, 2012). Results also indicate that participating in an exercise program focusing on bimanual coordination activities can contribute to improved reading comprehension ( $p < .05$ ), but not decoding ( $p > .05$ ; measured using the Gates-MacGinitie Reading Test) in children from 10 to 11 years of age (Uhrich & Swalm, 2007).

Although the evidence is still vague and insufficient, there might be some indications of a reduction in the strength of the association between motor skills and cognitive skills in pubertal children (greater than 13 years of age) compared with prepubertal children, and that this might be explained by a more separate development in these two domains as they get older (Van der Fels et al., 2014).

Thus, exploring the relative contribution of the different components included in these two different constructs (e.g., aerobic and muscular fitness and manual dexterity, hand-eye coordination, and balance) on cognitive skills could therefore contribute to a more comprehensive picture of the possible mechanisms (Castelli et al., 2007). A longitudinal design could also provide a better understanding of these possible processes during development (Hillman et al., 2017; Hillman et al., 2008). The purpose of this study was therefore to explore the possible associations of physical fitness and motor competence with reading skills in children aged 9 and 12 years.

## Method

### Study Design and Participants

Sixty-seven school children aged 9 to 10 years (the total population in that age group in the school selected) completed assessments of motor competence (Movement Assessment Battery for Children [MABC]; Henderson & Sugden, 1992), physical fitness (Test of Physical Fitness [TPF]; Fjørtoft, Pedersen, Sigmundsson, & Vereijken, 2011), and reading (Word Recognition Test [WCT]; Høien & Tønnesen, 1997). The entire sample ( $N = 67$ , 31 girls and 36 boys) was obtained from a local mainstream primary school in an urban area. The sample included children from a wide range of socioeconomic backgrounds and reflected the population of children attending schools in this area. The mean chronological age for the entire group was 9.7 ( $SD = 0.3$ ) years; the overall range was 9.3 to 10.2 years. No participant had any behavioral or medical condition that would qualify as an exclusion criterion for this study.

The testing procedures were repeated for the entire sample after 32 months. From the initial sample, data from 9 children were missing. The mean age was 12.1 years ( $SD = 0.2$ ) for the whole group ( $N = 58$ ) at the second sampling, and the group consisted of 28 girls and 30 boys.

### Measurements

**Reading.** Reading was tested using the Wordchain Test (WCT) in Norwegian, the *ordkjeder* (Wordchains; Høien & Tønnesen, 1997). In the WCT, the participants were given a booklet containing rows presented in the form of 90 chains similar to the following:

Peghousefishone sandcoffeebbluehome lambglassbootcat mudswanbrightrocket

Subjects were given 4 min in which to divide as many chains as possible into their component words by drawing a

line where the gap should be. Both speed and accuracy of word recognition is measured (Miller-Guron & Lundberg, 2000). Higher scores on WCT indicate better performance. The WCT measures speed and accuracy of word recognition, and has proved to be a reliable and valid test to assess isolated word decoding proficiency (Jacobson, 1993; Miller-Guron, 1999).

**Physical fitness.** The TPF is a measure that aims to provide reliable and objective quantification of children's physical fitness (Fjørtoft et al., 2003, 2011). The TPF consists of nine different test items: three items based on jumping, two on throwing, one on climbing, and three on running. The test items are described in more detail elsewhere (see Fjørtoft et al., 2011; Haga, 2009). Higher TPF scores indicate better performance. Test-retest correlation of total TPF scores is high (0.90,  $p < .0001$ ; Fjørtoft et al., 2011). The construct validity of the test was 0.93 for girls and 0.89 for boys ( $p < .0001$  for both, Spearman's correlation; Fjørtoft et al., 2011).

**Motor competence.** The MABC (Henderson & Sugden, 1992) was used to measure motor performance. The MABC is an extended version of Test of Motor Impairment (TOMI; Stott, Moyes, & Henderson, 1984). The MABC provides a global test of motor competence and is designed for children in the 4- to 12-year age group. The test is standardized and requires the participant to perform a motor task in a specified way. The test provides a quantitative evaluation of the child's or adolescent's motor competence. Each age group is tested on eight items in three subcategories: manual dexterity, ball skills, and static and dynamic balance. The test contains different tasks for different ages. A child's performance is referenced to a standardized sample value from individuals of same age. Lower MABC scores indicate better motor competence. The MABC has a minimum test-retest reliability at any age of 0.75 and an interrater reliability of 0.70 (Henderson & Sugden, 1992; Tan, Parker, & Larkin, 2001).

## Procedure

All participants and parents provided informed consent before participation in the study, and all procedures were performed in accordance with the Declaration of Helsinki. The participants were tested using the MABC and WCT on the same day, and then using the TPF 1 week later. The assessment of motor performance took place in a quiet room during normal school hours. The assessment of physical fitness took place in a sport hall. All participants were tested individually by assistants who had been trained in the test protocols. Each test item was explained and demonstrated to the participant before testing. During the testing, participants were given verbal encouragement and support. If the participants made a procedural error, instructions and demonstrations were repeated and the participant made a new attempt. The participant wore clothing and trainers suitable for physical activity during both tests.

## Data Reduction and Analysis

For the statistical analysis, SPSS Version 19 for Windows was used (SPSS Inc., Chicago, IL, USA). A total TPF score was calculated by transforming test item scores into standardized scores ( $z$  scores) using the overall sample mean. Higher  $z$  scores indicate higher performance on the tasks. The total test score for each child was calculated as the average  $z$  score. Pearson product-moment correlation was used to investigate the possible associations between the MABC, TPF, and WCT. To analyze the significance of the difference between the correlation coefficient between genders, Fischer  $r$ -to- $z$  transformation was used. Statistical significance was set at  $p < .05$ .

## Results

Descriptive statistics of the overall MABC score and the subcategory scores were calculated for the following: manual dexterity, ball skills, and balance; the nine TPF test items; and the WCT for the age groups 9- and 12-year-old girls and boys. The results are shown in Table 1. Higher scores on the TPF and WCT indicate better performance (better physical fitness and reading skills), while lower scores on MABC indicate better motor competence. Table 1 shows the performance on all test items using the TPF test and the WCT, and results improved from 9 years of age to 12 years of age. It is difficult to determine the changes in the MABC because the test items at age 9 years are different than those used at age 12 years (the test battery contains of different tasks in the age span 9 to 10 years and 11 to 12 years).

The correlation (Pearson's, two-tailed) between total MABC, TPF, and WCT scores for the 9- and 12-year-old children are presented in Table 2. When the children were 9 years old, there was a low correlation between motor competence and reading for the entire group ( $r = -.031$ ), and for both girls ( $r = -.207$ ) and boys ( $r = .180$ ). For boys, there was a positive correlation, indicating that higher motor competence is related to lower reading performance (lower WCT score), or the reverse. The correlation between physical fitness and reading skills for the entire group was also low ( $r = .064$ ). However, there was a significant correlation between physical fitness and reading in girls ( $r = .404$ ,  $p < .05$ ; 95% confidence interval [CI]: [0.055, 0.662]). For boys, the correlation was negative and low ( $r = -.138$ ). In addition, there was no significant association between the cardiovascular fitness component (measured using the reduced Cooper test) and reading when they were analyzed separately from the total TPF score.

When the children were 12 years old, a low correlation was found between motor competence and reading skills for the entire group ( $r = -.134$ ), which is similar for both girls ( $r = -.074$ ) and boys ( $r = .028$ ). There was a low correlation between physical fitness and reading skills for the entire group ( $r = -.022$ ), which is similar for girls ( $r = -.041$ ) and boys ( $r = -.017$ ).

**Table 1.** Descriptive Statistics of the Overall MABC Score, Including the Score the Subcategories Manual Dexterity, Ball Skills and Balance; the Nine TPF Subcategories; and the WCT for 9- and 12-Year-Old Girls and Boys.

Test item	Age group	Girls		Boys	
		M	SD	M	SD
<b>MABC</b>					
MABC Total score	9	8.54	6.50	9.71	5.76
	12	6.10	3.69	9.70	6.24
Manual dexterity	9	5.88	3.62	6.12	3.81
	12	1.58	1.54	2.70	2.08
Ball skills	9	1.61	2.09	1.52	2.10
	12	0.78	1.18	1.80	1.94
Balance	9	1.05	2.15	2.08	2.39
	12	3.81	2.74	5.19	4.14
<b>TPF</b>					
Standing broad jump	9	1.32	0.19	1.37	0.21
	12	1.48	0.178	1.58	0.23
Jumping on 2 feet	9	3.53	0.60	4.08	1.18
	12	3.16	0.43	3.32	0.75
Jumping on 1 foot	9	2.92	0.52	2.98	0.45
	12	2.53	0.30	2.56	0.35
Throwing tennis ball	9	12.99	2.82	15.17	2.77
	12	15.79	2.15	16.74	0.93
Putting medicine ball	9	4.24	0.60	4.41	0.74
	12	5.86	0.86	6.15	0.80
Climbing wall bars	9	6.54	1.80	6.49	1.70
	12	3.67	0.67	3.73	1.12
Shuttle run	9	23.08	2.55	23.34	2.68
	12	20.44	3.51	20.56	4.08
Running 20 m	9	4.40	0.40	4.49	0.35
	12	4.18	0.29	4.17	0.37
Reduced Cooper test	9	937.61	123.00	957.33	151.98
	12	1190	98.38	1180	164.26
<b>WCT</b>					
	9	24.45	6.57	19.67	7.38
	12	41.20	8.67	33.32	10.66

Note. MABC = Movement Assessment Battery of Children; TPF = Test of Physical Fitness; WCT = Wordchain Test.

**Table 2.** Correlation (Pearson's, Two-Tailed) Between the Overall MABC, TPF, RCT and WCT Scores for the 9- and 12-Year-Old Groups Overall, and For Girls and Boys.

	WCT		
	Whole sample ( <i>n</i> = 67)	Girls ( <i>n</i> = 31)	Boys ( <i>n</i> = 36)
<b>9 years old</b>			
MABC	-0.031	-0.207	0.180
TPF	0.064	0.404 <sup>ab</sup>	-0.138 <sup>a</sup>
RCT	0.129	0.280	0.089
<b>12 years old</b>			
MABC	-0.134	-0.074	0.028
TPF	-0.022	-0.041	-0.017
RCT	0.044	-0.105	0.091

Note. MABC = Movement Assessment Battery of Children; TPF = Test of Physical Fitness; RCT = reduced Cooper test; WCT = Wordchain Test.

<sup>a</sup>Fischer *r*-to-*z* transformation indicates a significant difference between the correlation coefficient in girls and boys (*p* = 0.027, two-tailed).

\*Correlation is significant at the .05 level (*p* < .05, two-tailed); 95% confidence interval: [0.055, 0.662].

The Fischer  $r$ -to- $z$  transformation shows no significant difference between the correlation coefficient for girls and boys, except for the relationship between TPF and WCT which showed a significant difference ( $p = .027$ , two-tailed) for 9 years old.

## Discussion

These results suggest that the relationship between motor competence and reading skills in children who are 9 and 12 years of age are low both for girls and boys, but at 9 years of age, there was a significant correlation between physical fitness and reading for girls ( $r = .404$ ,  $p < .05$ ). The correlation is negative for the entire group (9 and 12 years) and for girls, but positive for the boys at 9 and 12 years (i.e., better performance in MABC correlates with a lower performance on the WCT or vice versa). These results are partly supported by earlier findings that showed no strong association between motor competence and academic achievement (Haapala et al., 2014; Urich & Swalm, 2007), as well as between fitness and academic performance (Haapala et al., 2015; Kantomaa et al., 2013; Resaland, Aadland, Moe, Aadland, & Skrede, 2016). It is challenging, however, to compare across studies because of the diverse measurement used to assess the different variables.

In the 1960s, there were attempts to explore and explain how perceptual-motor functioning could increase educational effectiveness, and perceptual-motor training was a primary intervention method in special education (Kephart, 2004). Behind such a hypothesis, there was an assumption about the existence of underlying general abilities in both the motor and cognitive domains, and that they shared common underlying processes. However, a meta-analysis concluded that interventions based on perceptual-motor training were not effective for the improvement of academic or cognitive variables (Kavale & Mattson, 1983). More recently, similar findings have emerged in intervention studies that showed no effect of increased physical activity on academic performance in numeracy, reading, and English (Resaland et al., 2016). Empirical evidence to support the construct of such general abilities is also lacking; for example, correlation between the eight test items and also within each of the MABC subgroups (manual dexterity, balance, and ball skills) is low (Haga, Pedersen, & Sigmundsson, 2008). In addition, very low correlations are reported between six test items of static and dynamic balance (Drowatsky & Zuccato, 1967) as well as between three fine motor tasks in adults (Lorås & Sigmundsson, 2012). For cognitive skills, intercorrelations between mathematics tasks are found to be relatively low-to-moderate, indicating that the nine test items shared less than 25% of the variance (Sigmundsson, Polman, & Lorås, 2013). Therefore, because of the low correlations *within* separate domains (i.e., the motor and cognitive domains), the low correlation *between* skills in different domains (motor competence and reading) is not surprising.

Except for a significant and moderate correlation between physical fitness and reading in 9-year-old girls ( $r = .404$ ; 17.7% shared variance), no significant associations between fitness and reading skills were found in either age group. These results are in accordance with the relatively low relationships between motor competence and reading, and may confirm the lack of spillover from the physical modality to the cognitive modality. There is no consensus about this association in children, but the associations between physical fitness and cognitive skills seems to be stronger when comparing children with high and low fitness levels, with the latter having worse academic or cognitive achievement (Chaddock et al., 2010; Hillman, Castelli, & Buck, 2005; Scudder et al., 2014). Thus, a possible association could be exaggerated by comparing groups at the extremes of the distribution.

The significant differences between girls and boys in the 9-year-old age group (see Table 2) and the significant correlation between fitness and reading in girls may be explained by earlier maturation of the neural network that is more important for executive function in girls than in boys (Giedd, Raznahan, Mills, & Lenroot, 2012). However, this association is not found when the children are 12 years old. This could be linked to the suggestion by Hillmann et al. (2017) that variability is a hallmark of cognitive performance because both maturation and experience influence structure and function.

Physical activity and fitness are reported to have effects on executive functions (Davis et al., 2011; Kamijo et al., 2011) and they may provide some benefits for learning. However, research indicates that to develop skills such as reading, specific training is needed. Dehaene et al. (2010) suggested that learning to read means reorganizing neural circuits in the brain; the changes that reading makes to our brain result mainly from the effect of our experience with reading. These findings can be used as an argument for task specificity principles of learning across cognitive and motor skills, because the processes associated with learning may seem relatively independent and specific (Hadders-Algra, 2000; Sigmundsson et al., 2013). As mentioned in the introduction, coordination and motor skill learning taps into the neurophysiological motor system, which is characterized by its plasticity (Kleim & Jones, 2008). A perspective that has been translated into the domain of human motor behavior is the “neuronal group selection theory” (NGST; Blauw-Hospers, Dirks, Hulshof, Bos, & Hadders-Algra, 2011; Edelman, 1987, 1992; Hadders-Algra, 2000; Thelen & Smith, 1994). Within this theory, experience and stimuli serve as the basis for motor development and learning, emphasizing that development is a process of selection within the central nervous system. This means that behavioral experience increases connections within specific areas of the brain and strengthens the neural network involved in the generation of successful movement. Under this perspective, the gradual learning and performance of an efficient

movement solution for a given task is experience-dependent, because it builds on self-produced instances of trial and error (Gottlieb, 1998; Hadders-Algra, 2000; Thelen & Smith, 1994). Training/executing specific tasks will reinforce the neural networks that are involved in a particular task, thus making this behavior more plausible to be performed the next time (Sporns & Edelman, 1993). NGST may support the task-specificity hypothesis of learning (Edelman, 1987, 1992) and the low association of motor competence and physical fitness with reading in this study can be generally interpreted as support for specificity in learning skills.

A challenge in this field is also how the different constructs are conceptualized and measured (Donnelly et al., 2016). It is difficult to obtain a pure measure of the basic components of physical fitness in children. Even in test and laboratory settings, only an indirect indication of the different basic components is likely. Because physical fitness is measured by performing movements, elements of motor behavior will always be included (Fjørtoft et al., 2003, 2011). Fjørtoft et al. (2011) suggested that the constituent components of a skill are not known, nor is it known how they combine to make up the complex skill, making it hard to find an isolated measure of the basic components. Movement tests do not always discriminate well between motor competence and physical fitness (Vandendriessche et al., 2011), and therefore, finding the independent contributions of each phenomenon to the outcomes of interest is impeded. Thus, the association between these variables and cognitive function may depend on the specific content of the specific fitness test and the tasks used to measure motor competence.

Stronger associations are found between cardiovascular fitness and academic achievement when field-based running test were used as a measure compared with ergometer cycle tests (Haapala et al., 2015). Haapala also suggests that, in children, motor competence may have a greater effect on executions of such fitness tasks, as the running technique is not as well developed; this suggests that motor performance is more important for academic achievement compared with cardiovascular fitness.

It is also unclear whether fitness is related to better performance in cognitive outcomes because of indirect factors, such as motivation and attention to tasks, or if fitness has a more direct effect on specific subprocesses related to reading (Scudder et al., 2014). It might be that physical fitness is more related to executive functions (Tomprowski, Davis, Miller, & Naglieri, 2008; Van der Niet et al., 2014), which can be regarded as premises for the learning process and academic achievement (Diamond, 2013.)

This study has some limitations. First, the statistical power of the relative small sample must be taken into account. Second, possible sex differences are not sufficiently discussed in this article. Furthermore, the data are not adjusted for socioeconomic status, which is an important confounder that could both predict academic performance and moderate the association between physical fitness and academic skills.

## Conclusion

Different types of physical activity may have the potential to enhance the metabolic mechanism and improve executive function and academic performance. A challenge to target is how to conceptualize and measure the different constructs included in motor competence and physical fitness. However, to learn and improve academic skills, it is possible that practice should be specific to the particular cognitive skill that is being performed. The results from this study may support the principle of specificity in learning, because the results for boys (9 and 12 years old) and girls (12 years old) in this study showed very low associations of physical fitness and motor competence with reading skills. However, there was a significant correlation between physical fitness and reading in girls at the age of 9 years. Further research related to sex differences and the life span perspective is required.

## Authors' Note

All procedures performed in studies involving human participants were in accordance with the ethical standards of the national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study

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