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Original Article

Relationship between motor and cognitive learning abilities among primary school-aged children



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ABSTRACT

Background: The relationship between motor and cognitive development has already been proven in young children. However, in relation to the academic achievement the association between motor and cognitive performance still not well established. Therefore, the aim of this study was to examine the levels of motor and cognitive learning abilities and their independent and combined associations among German primary school-children.

Methods: Participants were (n = 197) between the ages of six to eight. The German motor test (DMT), the cognitive abilities test (KFT), height, weight, and body mass index (BMI) were measured.

Results: ANOVA testing found that boys perform better in long jumping and in the six minutes running test while girls perform better in balancing backwards and in deductive thinking test ($p < 0.05$). With maturation from ages six to eight the achievement level of both populations showed a higher performance in motor and cognitive learning abilities ($p < 0.001$). Concerning the combined and independent associations between the tested abilities, a significant correlation was shown between total motor and total cognitive learning abilities ($p < 0.001$, $r = 0.60$) with higher contribution of balancing backwards, six minutes running and push-up levels ($r = 0.63$, $r = 0.62$, $r = 0.60$, respectively) in the performance of the cognitive learning abilities (i.e. mathematical thinking, $r = 0.62$ and language understanding, $r = 0.59$).

Conclusions: In conclusion, fostering the childrens' physical fitness during the primary school age could enhance both motor and cognitive learning abilities related to the academic achievement.

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1. Introduction

Currently, it is well established that both cognitive and motor abilities followed similar developmental time tables with an accelerated progression in the kindergarten and elementary school years.^{1,2} Indeed, Bushnell and Boudreau³ suggest that motor development may play a central role for further parameter development (i.e., prerequisite for cognitive development and academic learning). This suggestion has been supported by recent results which

show a positive relationship between (i) intelligence quotient (IQ) and the movement speed during a sequencing task,⁴ (ii) motor proficiency and fluid crystallized intelligence⁵ and (iii) motor performance and working memory.⁶ In the same context, Thelen⁷ and Wrobel⁸ supported the role of improving motor abilities in the development of cognitive functions.

With regard to the specificity of academic achievement, previous studies have examined the association of physical fitness with cognitive development and found a positive association between children's academic achievement and their physical fitness.^{9–13} In this context, Dwyer et al.¹⁴ found that physically active students were more likely to be academically motivated, alert, and successful. Iverson¹⁵ and Preston et al.¹⁶ show an association between infant motor development and language development which predicts school-age reading skills. Furthermore, among children a significant association was found between (i) poor

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motor performance and poor academic achievement.¹⁷ (ii) poor gross motor performance and larger learning deficits.¹⁸ However, few studies found no relation between physical activity and academic performance.^{19,20}

In addition, based on previous result of Adkins et al.²¹, who showed that the cardiorespiratory capacity (1st component of physical fitness) was related to angiogenesis (i.e., development of blood vessels), whereas muscular strength and motor ability (2nd and 3rd component of physical fitness) were associated with synaptogenesis (i.e., formation of neuronal synapses), it was suggested that physical fitness improves inhibition, working memory, and cognitive flexibility^{22–24} (i.e., the three aspects involved in the cognitive control and provided the foundation for academic ability.^{23,25} These findings support the results of Etner et al.²⁶ and Pontifex et al.²² which also suggest that physical fitness may play a key role in brain health and academic performance in youths.

Therefore, it is reasonable to assert, from the preponderance of available research, that there is a line of evidence supporting the theoretical assumption of a relationship existing between motor and cognitive development in young children. However, it should be noted that, neither approach has examined the association between motor and cognitive performance related to the academic achievement. Thus, the present study investigated, (i) the levels of motor and cognitive learning abilities in German children ages sex to eight (i.e. assessing differences by gender and age) and (ii) the combined and independent contribution of each motor ability component in the performance of the cognitive learning abilities (i.e., related to the academic achievement).

Differentiate which motor components are more related to the cognitive learning performance could ultimately aid in the development of targeted interventions to enhance this performance.

2. Methods

2.1. Participants and setting

Participants were primary school aged-children ($n = 197$; 101 boys and 96 girls ranging in age from six to eight (age = 7.01 ± 0.76 years old; grades 1–3). The data were collected between 2012 and 2013 in five public primary schools in the city of Magdeburg in Germany. The selection of schools was based on age, socioeconomic status, demographic characteristics and the number of students in each school. Participation was voluntary and informed written consent was obtained from the school directors, participants, and their parents or guardians before the children entered into the study. The study was conducted according to the Declaration of Helsinki. The protocol and the consent form were fully approved by the institutional ethics committee before the commencement of the assessments.

The measurement of motor abilities was carefully supervised inside the school gym by observers trained in anthropometric and motor techniques with respect to the World Health Organization (WHO) recommendations for the anthropometric tests and to the German Health Interview and Examination Survey (KiGGS) for the motor tests. A well-tested design and frequently calibrated equipment was used.

Height, weight, and Body Mass Index (BMI) were assessed for all participants. Height was measured in a standing position, without shoes, to the nearest 0.1 cm using portable gauges (Seca, Germany). The weight was performed with minimal clothing and recorded to the nearest 0.1 kg using electronic scales (Teraillon, France). BMI was defined as the ratio of body weight to body height squared, expressed in kg/m^2 : $\text{weight (kg)}/\text{height}^2 (\text{m}^2)$. The DMT was administered in a group setting during regular classes. The

measurements were conducted in sessions lasting about 90 min. Five assistants helped the researchers during the realization of the test.

The cognitive learning ability test (KFT) used in the study is designed for use with children during their first three years in primary schools (i.e., six to eight years old). The test is based on guidance from the teachers and test instructors. The measurement of cognitive learning abilities was executed in a group setting, and carefully supervised in the classroom. Participating children were tested over a 60 min time interval KFT 1–3.²⁷

2.2. Test description

The German motor test DMT²⁸ is targeted for the children ages of 6–18. This test is used to assess motor abilities, including endurance, strength, speed, coordination, flexibility and indicate general motor performance ability (MPA).²⁹ Assessing the motor abilities is achieved through structured motor skills like running, jumping, and balancing. Sport-specific skills are excluded in this testing. In the current study the test items measuring the sprint (i.e., 20 m sprint), coordination (i.e., balancing backwards (BB), jumping sideways (JS)), strength (i.e., push-ups (PU), sit-ups (SU), standing long jump (SLJ)), endurance (i.e., 6 min running) were used.²⁸

The KFT test for cognitive learning ability is based on similarly conceptualized intelligence tests such as intelligence IQ tests. It is composed of four tests measuring cognitive learning abilities of the primary school children; grades 1–3 (KFT 1–3).²⁷ This test battery was developed to assess abstract intelligence and is used primarily for research in context with educational counseling, teaching differentiation and educational research. The KFT test includes items for measuring language understanding, relationship recognition, deductive and mathematical thinking. Together, these cognitive assessments indicate potential cognitive and intellectual learning of children during their first three years at school.

2.3. Validity and reliability

The validation of the motor test was based on an international expert questionnaire involving 40 selected fitness experts in 25 European countries. These experts were asked about the relevance of the test contents and the requirements in the motor performance tests with regard to the documentation of MPA.³⁰ All tests were checked for validity and reliability by experts in the field. The content-related validity of all tests were evaluated to be reliable. The cognitive test was validated by Heller and Geisler.²⁷ The authors found a good test-retest reliability coefficients for the motor and cognitive tests ($r_{\min} = 0.68$ to $r_{\max} = 0.94$ and $r_{\min} = 0.76$ to $r_{\max} = 0.84$, respectively).

2.4. Statistical analyses

All statistical tests were processed using STATISTICA Software (StatSoft, France). Values were expressed as mean \pm SD. Normality was confirmed using the Shapiro-Wilks W -test. The effect of gender was analyzed using an independent t -test and the effect of age was analyzed using a 1-way ANOVA (3 levels [6, 7, 8 years old]) with repeated measures. Significant differences between means were assessed using Fisher's post-hoc tests. Effect sizes were calculated as partial eta-squared (η_p^2) for the ANOVA analysis and as Cohen's d for the paired sample t -test to assess the practical significance of our findings. The correlations between anthropometric, motor, and cognitive data were assessed by Pearson product-moment correlation. Significance was set as $p < 0.05$.

3. Results

Regarding the gender effect, statistical analysis (Fig. 1) showed no significant difference between girls and boys in the anthropometric parameters ($p > 0.05$). However, for the motor and cognitive abilities (Table 1) a significant difference was found for balancing backwards (BB), standing long jump (SLJ), the 6 min running test, and the deductive thinking test with $p < 0.05$, ($t(195) = -2.14$, $d = 0.02$; $t(195) = 2.57$, $d = 0.04$; $t(195) = 2.36$, $d = 0.03$ and $t(191) = 2.18$, $d = 0.024$, respectively). These results indicated a better performance for girls in the BB and deductive thinking test (33.02 ± 1.1 vs 30.02 ± 1.2 pts; 9.56 ± 0.3 vs 8.62 ± 0.3 pts, respectively) and better performance for boys in the SLJ and 6 min running test (119.25 ± 2.2 vs 111.98 ± 1.2 cm; 897.72 ± 15.8 vs 849.44 ± 12.8 m, respectively). Going deeper and searching for gender effect in different age (6, 7 and 8 years old), a significant difference was found between boys and girls in the BB test at age of seven ($p < 0.05$) and for deductive thinking ability at the age of six ($p < 0.05$). However, no significant difference between genders was found for the age of eight years slot nor in the anthropometric parameters, in either motor and cognitive learning abilities.

Concerning the age effect, the results showed that the mean values of the anthropometric parameters (Fig. 1), as well as the motor and cognitive abilities (Table 1) among tested children, are affected by age ($F(2,194) = 32.37$, $p < 0.01$, $\eta_p^2 = 0.053$; $F(2,190) = 11.46$, $p < 0.001$, $\eta_p^2 = 0.088$ and $F(2,190) = 19.91$, $p < 0.001$, $\eta_p^2 = 0.165$, respectively).

Indeed, with age growing higher performance were noted at eight compared with six years old in the majority of MPA test (i.e., 20 m sprint, BB, JS, PU, SU, SLJ and 6 min running) with $p < 0.001$, and in the majority of cognitive test with $p < 0.001$ for the language understanding, relation recognition and mathematic thinking, and $p < 0.01$ for the deductive thinking. As expected, weight, height and BMI values were also higher for eight year olds than six year olds with $p < 0.01$ for height and weight and $p < 0.001$

for the BMI. From age six to eight the rate of increase for the total cognitive ability was higher ($p < 0.01$) than the rate of increase for the total motor ability with $12.41 \pm 0.91\%$ for the motor ability (i.e., 12.37 ± 1.35 for boys and 12.55 ± 0.47 for girls, $p > 0.05$) and $45.46 \pm 3.09\%$ for the cognitive ability (i.e., 57.93 ± 3.9 for boys and 34.05 ± 2.28 for girls, $p < 0.05$).

Additionally, for both genders, statistical analysis (Table 1) found that the highest level of significant improvement from six to eight years old occurred between the age of six and seven as we showed a significant increase in the BMI values and in the motor and cognitive performance with $p < 0.001$. However, in the period between seven and eight years old no significant improvement were registered for the majority of the tested abilities (i.e. motor and cognitive) and BMI parameters ($p > 0.05$) expect sprint and SU ($p < 0.05$). It should be noted, that inverse to boys, the deductive ability for girls (Table 1) did not show improvement for the age period between six and eight years old which can explain the suppression of the better performance (already registered for girls compared to boys at six years old) in the age of seven and eight years old ($p < 0.05$). For boys, during the age period of six to seven years old, no improvements were found (Table 1) for PU and the SLJ ($p > 0.05$) tests.

Table 2 shows the relationship of the tested abilities with the age and the anthropometric parameters. As this table indicate, the total MPA was significantly correlated with the age with $p < 0.05$ and $r = 0.51$. Likewise, a significant correlations were found between the majority of the motor tests and the age with $p < 0.001$ for the sprint, JS and PU tests (i.e., $r = -0.69$, $r = 0.67$ and $r = 0.62$, respectively) and $p < 0.01$ for the BB and the SU tests (i.e., $r = 0.59$ and $r = 0.54$ respectively). However, the majority of these test were not correlated with body height or weight ($p > 0.05$) with the exception of the JS ($p < 0.01$, $r = 0.5$) and the PU ($p < 0.01$, $r = 0.48$ and $p < 0.05$, $r = 0.44$, respectively) tests. The BMI was not correlated with the results of the motor tests. With regard to the cognitive learning abilities, significant

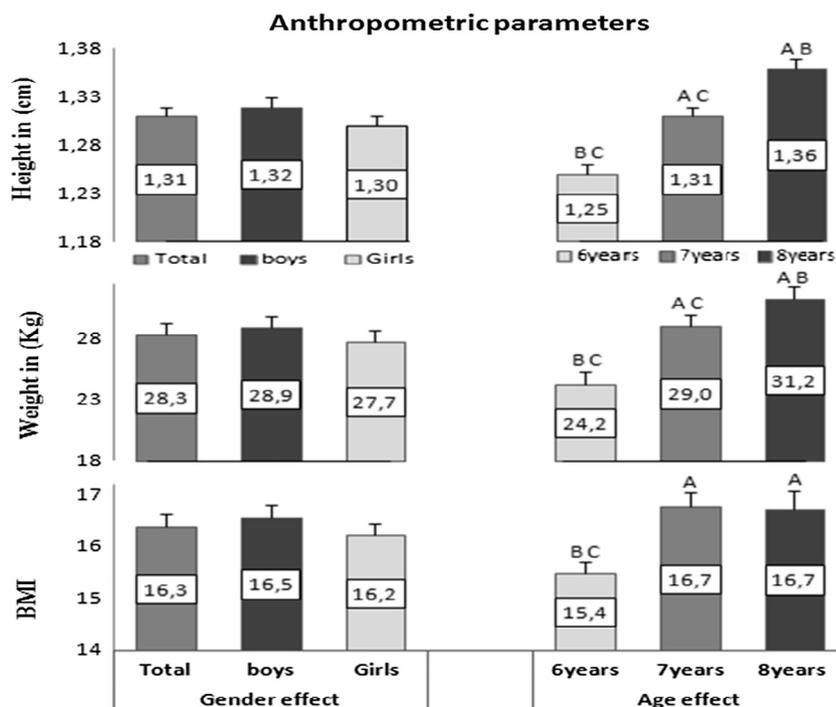


Figure 1. Anthropometric children's parameters (i.e. Height in (cm), Weight in (kg) and BMI). Analyses were adjusted by sex (i.e. total, boys and girls) and age (i.e. 6, 7 and 8 years old). A, B and C represents significant difference between different ages (i.e. compared to 6, 7 and 8 years old respectively) with $p < 0.05$. Values are represented as mean \pm SD.

Table 1
Motor and cognitive children's abilities.

	Motor Abilities					Cognitive Abilities					Total		
	Sprint	BB	JS	PU	Sit UP	LJ	6 min	Total	Lang	Relat		Deduc	Math
Boys	4.60 ± 0.05	30.02 ± 1.16*	22.30 ± 0.72	14.53 ± 0.76	18.77 ± 0.74	119.25 ± 2.15*	897.72 ± 15.8*	26.16 ± 15.8	8.85 ± 0.32	8.46 ± 0.36	8.62 ± 0.32*	7.69 ± 0.45	33.66 ± 1.26
Girls	4.72 ± 0.05	33.45 ± 1.09*	22.53 ± 0.78	13.59 ± 0.63	17.83 ± 0.68	111.98 ± 1.82*	849.44 ± 12.7	26.65 ± 0.72	8.05 ± 0.30	8.13 ± 0.32	9.56 ± 0.29*	7.26 ± 0.42	32.97 ± 1.10
6 Years	4.97 ± 0.06BC	25.09 ± 1.48BC	16.85 ± 0.79BC	10.00 ± 0.79BC	14.29 ± 0.81BC	107.18 ± 2.20BC	810.54 ± 19.98C	23.11 ± 1.01BC	6.96 ± 0.40BC	6.69 ± 0.43BC	8.03 ± 0.4 BC*	4.13 ± 0.52BC	25.81 ± 1.4BC
7 Years	4.60 ± 0.04AC	35.08 ± 1.3A*	23.78 ± 0.73A	15.53 ± 0.74A	18.90 ± 0.74C	117.53 ± 2.25A	915.71 ± 14.5A	28.90 ± 0.80AC	8.89 ± 0.34A	8.79 ± 0.38A	9.10 ± 0.40A	8.56 ± 0.41A	35.45 ± 1.26A
8 Years	4.44 ± 0.05A B	33.21 ± 1.37A	25.82 ± 0.91A	15.93 ± 0.91A	21.36 ± 0.96AB	121.33 ± 2.68A	876.24 ± 18.1A	25.98 ± 0.80AB	9.32 ± 0.39A	9.16 ± 0.40A	10.05 ± 0.33A	9.20 ± 0.49A	37.59 ± 1.27A
Boy 6Y	4.83 ± 0.09BC	22.48 ± 2.29BC	16.52 ± 1.13BC	10.11 ± 1.26C	14.41 ± 1.19BC	112.07 ± 3.22C	833.07 ± 31.30B	23.11 ± 1.58B	7.12 ± 0.55BC	6.65 ± 0.60BC	7.15 ± 0.53C	3.96 ± 0.74BC	24.89 ± 1.9BC
Boy 7Y	4.58 ± 0.06A	32.80 ± 1.62A*	23.28 ± 0.91A	15.96 ± 1.11	19.07 ± 0.98A	119.74 ± 3.31	935.59 ± 22.6A	28.11 ± 1.12A	9.15 ± 0.48A	8.72 ± 0.55A	8.59 ± 0.50AB	8.57 ± 0.57A	35.11 ± 1.84A
Boy 8Y	4.42 ± 0.09A	32.76 ± 1.71A	25.76 ± 1.34A	16.17 ± 1.37A	22.07 ± 1.49A	124.79 ± 4.22A	896.07 ± 27.1	25.97 ± 1.27	10.00 ± 0.54A	9.59 ± 0.60A	10.10 ± 0.49AC	9.62 ± 0.74A	39.31 ± 1.97A
Girl 6Y	5.10 ± 0.07BC	27.52 ± 1.84BC	17.16 ± 1.12BC	9.90 ± 0.89BC	14.17 ± 1.11BC	102.62 ± 2.81 BC	789.55 ± 25.0B	23.10 ± 1.31 B	6.83 ± 0.60BC	6.72 ± 0.61BC	8.83 ± 0.58*	4.28 ± 0.74BC	26.66 ± 2.1BC
Girl 7Y	4.62 ± 0.06A	37.92 ± 1.41A*	24.41 ± 1.18A	15.00 ± 0.92A	18.70 ± 1.01A	114.78 ± 2.90 A	891.00 ± 16.05A	29.89 ± 1.13AC	8.56 ± 0.45A	8.89 ± 0.50A	9.75 ± 0.49	8.56 ± 0.58A	35.89 ± 1.67A
Girl 8Y	4.46 ± 0.06A	33.66 ± 2.16A	25.88 ± 1.25A	15.69 ± 1.23A	20.66 ± 1.20A	117.86 ± 3.26 A	856.41 ± 24.01	26.00 ± 0.10B	8.59 ± 0.47A	8.70 ± 0.51A	10.00 ± 0.44	8.74 ± 0.64A	35.74 ± 1.54A

The tested abilities were (Sprint in "s", LJ in "cm", 6 min in "m" and BB, JS, PU, Sit UP in "pts") for motor abilities and (language, relation, deductive and mathematic in "pts") for cognitive abilities. Analyses were adjusted by sex, age and sex-age.

* Significant difference between gender; A, B and C represents significant difference between different ages (i.e. compared to 6, 7 and 8 years old respectively) with $p < 0.05$. Values are represented as mean ± SD.

correlations were found between the age and (i) the total cognitive performance with $p < 0.001$ ($r = 0.73$) and (ii) the majority of the tested abilities with $p < 0.001$, $r = 0.80$ for mathematical thinking; $p < 0.01$, $r = 0.59$ and $r = 0.53$ respectively for the language understanding and the relation recognition and $p < 0.05$, $r = 0.44$ for the deductive thinking. The body weight and BMI were correlated to the relation recognition ($p < 0.05$, $r = 0.40$) and to the mathematical thinking ($p < 0.01$, $r = 0.51$ and $p < 0.05$, $r = 0.39$, respectively). However, the body height was only correlated to the mathematical thinking with $p < 0.05$ and $r = 0.41$.

Regarding the relationship between the motor and cognitive learning abilities (Table 3), Pearson correlation found that the total performance of the motor and the cognitive learning abilities were significantly correlated with $p < 0.001$ and $r = 0.60$. The highest correlations were registered (i) between cognitive abilities and BB test with $p < 0.001$ and $r = 63$ (i.e., $p < 0.001$, $r = 0.75$ and $r = 0.63$ respectively for mathematical thinking and language understanding; $p < 0.05$ and $r = 0.36$ for deductive thinking) (ii) between cognitive abilities and six min running test with $p < 0.001$ and $r = 0.62$ (i.e., $p < 0.001$, $r = 0.64$ for mathematical thinking, $p < 0.01$, $r = 0.57$ for language understanding and $p < 0.05$, $r = 0.44$ for relation recognition) and (iii) between cognitive abilities and PU test with $p < 0.001$ and $r = 0.60$ (i.e., $p < 0.001$, $r = 61$ for mathematical thinking; $p < 0.01$, $r = 0.01$ for language understanding and $p < 0.05$, $r = 0.46$ for relation recognition). For total motor abilities the highest correlation was linked to mathematical thinking, language understanding ($p < 0.001$) and relation recognition ($p < 0.01$) with $r = 0.62$, $r = 0.59$ and $r = 0.52$, respectively.

4. Discussion

The present study investigated the levels of motor and cognitive learning abilities and their independent and combined associations among primary school-children aged six to eight. The current findings replicate and extend previous studies demonstrating: (i) a positive development of motor and cognitive abilities with respect to aging (30) and (ii) an association between children's physical fitness (e.g., motor abilities) and academic achievement.^{12–14,31,32}

4.1. Gender and age effect

Looking at the differences between boys and girls in the achievement level of motor and cognitive abilities, statistical analysis found better performances for girls in the BB and deductive test and better performances for boys in the SLJ and 6 min running test. Current results were in line with those of Karim et al.³⁰ who showed that German girls perform better on the coordination and flexibility test while boys performed better on the SLJ test.

According to the age effect, current results demonstrate that all performance abilities (i.e., motor and cognitive) were improved with aging. Similar results were reported by Karim et al.³⁰ who found that coordination abilities and strength performance were improved during the span from six to ten years of age (i.e., 6–8 and 8–10 years old). Taking seven years as middle age (i.e., 6–8) in the present study, statistical analysis found the most improvement for children coming between the ages of six to seven years old. These findings can be explained by the higher effect of the first year of schooling (i.e., that can be reduced in the second year due to the adaptation process). In fact, Nickel and Schmidt-Denter³³ show that adequate information processes and knowledge structures (i.e., including perception, attention, memory, analysis and deductive reasoning) are increasingly improved, reorganized and expanded especially in the beginning of schooling.

Table 2

Associations of motor and cognitive abilities with the age and the anthropometric children's parameters.

	Age		Height		Weight		BMI	
	p	r	p	r	p	r	p	r
<i>Motor abilities</i>								
Sprint	p < 0.001	r = -0.69	P > 0.05	–	p > 0.05	–	p > 0.05	–
BB	p < 0.01	r = 0.59	p > 0.05	–	p > 0.05	–	p > 0.05	–
JS	p < 0.001	r = 0.67	p < 0.01	r = 0.51	p < 0.01	r = 0.50	p > 0.05	–
PU	p < 0.001	r = 0.62	p < 0.01	r = 0.48	p < 0.05	r = 0.44	p > 0.05	–
Sit up	p < 0.01	r = 0.54	P > 0.05	–	p > 0.05	–	p > 0.05	–
LJ	p > 0.05	–	P > 0.05	–	p > 0.05	–	p > 0.05	–
6 min	p > 0.05	–	P > 0.05	–	p > 0.05	–	p > 0.05	–
Total	p < 0.05	r = 0.51	P > 0.05	–	p > 0.05	–	p > 0.05	–
<i>Cognitive abilities</i>								
Language	P < 0.01	r = 0.59	P > 0.05	–	P > 0.05	–	P > 0.05	–
Relation	p < 0.01	r = 0.53	P > 0.05	–	p < 0.05	r = 0.41	p < 0.05	r = 0.40
Deductive	p > 0.05	r = 0.44	P > 0.05	–	P > 0.05	–	p > 0.05	–
Math	p < 0.001	r = 0.80	p < 0.05	r = 0.41	p < 0.01	r = 0.51	p < 0.05	r = 0.37
Total	p < 0.001	r = 0.73	p < 0.05	r = 0.37	p < 0.01	r = 0.51	p < 0.05	r = 0.39

The tested abilities were (Sprint in "s", LJ in "cm", 6 min in "m" and BB, JS, PU, Sit UP in "pts") for motor abilities and (language understanding, relation recognizing, deductive thinking and mathematical thinking in "pts") for cognitive abilities.

Table 3

Associations between motor and cognitive children's abilities.

Cognitive abilities	Language		Relation		Deductive		Math		Total	
	p	r	p	r	p	r	p	r	p	r
<i>Motor abilities</i>										
Sprint	p > 0.05	–	p > 0.05	–	p > 0.05	–	p > 0.05	–	p > 0.05	–
BB	p < 0.001	r = 0.63	P > 0.05	–	p < 0.05	r = 0.36	p < 0.001	r = 0.75	p < 0.001	r = 0.63
JS	p > 0.05	–	p < 0.05	r = 0.41	p > 0.05	–	p < 0.05	r = 0.45	p < 0.05	r = 0.44
PU	p < 0.01	r = 0.58	P < 0.05	r = 0.46	p > 0.05	–	p < 0.001	r = 0.61	p < 0.001	r = 0.60
Sit up	p > 0.05	–	p > 0.05	–	p > 0.05	–	p < 0.01	r = 0.53	p < 0.01	r = 0.49
LJ	p < 0.05	r = 0.44	p > 0.05	–	p > 0.05	–	p > 0.05	–	p > 0.05	–
6 min	p < 0.01	r = 0.57	p < 0.05	r = 0.44	p > 0.05	–	p < 0.001	r = 0.64	p < 0.001	r = 0.62
Total	p < 0.001	r = 0.59	p < 0.01	r = 0.52	p > 0.05	–	p < 0.001	r = 0.62	p < 0.001	r = 0.60

The tested abilities were (Sprint in "s", LJ in "cm", 6 min in "m" and BB, JS, PU, Sit UP in "pts") for motor abilities and (language understanding, relation recognizing, deductive thinking and mathematical thinking in "pts") for cognitive abilities.

Concerning the relationship of the tested abilities with the age and the anthropometric parameters, the current results indicate that both motor and cognitive learning abilities were highly correlated with age and showed a low to moderate correlation in regards to the anthropometric parameters. These results were in line with those of Ahnert et al.¹ who showed that all participants' motor skill improved continuously over the years of the study (i.e., from 4 to 9 years old). These results affirm the solid relationship between motor abilities and age. Furthermore, there was only a low to moderate association between motor abilities and physical attributes (height, weight and BMI).

4.2. Inter-relation between tested abilities

For the combined contribution of the MPA, the results showed a significant correlation for the level of the motor abilities on the cognitive learning abilities performance (p < 0.001, r = 0.60). These findings confirm the previous results of Diamond³¹, Rosenbaum et al.³² and Davis et al.⁵ who showed a growing evidence that these two domains (motor and cognitive abilities) are fundamentally interrelated across age development. Current results also had similar outcomes to those of Voelcker-Rehage³⁴ who examined 85 German kindergarten children between the ages of four and six and found that children who posted better results in the motor test also showed better results in the cognitive test (i.e., the correlation between motor abilities determined by the central nervous system and the accuracy of optical differentiation were significant with r = 0.30–0.40 and p > 0.05). Similarly, the present study is in line with previous studies of Dwyer et al.,¹⁴ who showed that physi-

cally active students are more likely to be academically motivated, alert and successful. This strong relationship may be explained by the fact that promoting physical activity (i.e., positively effect the motor development^{35,36} can enhance gene expression associated with brain plasticity, neurogenesis (i.e., increases in gray matter density), blood flow and neuronal resistance to injury),³⁷ which are crucial for learning and memory storage and thus for the development of cognitive learning abilities. Moreover, human studies in neuro-imaging techniques showed changes in brain structure and functions with regular exercise (i.e., increases in cerebral blood volume in the dentate gyrus of the hippocampus) which are directly associated with verbal learning and memory improvements.²⁰

Concerning the independent contribution of the different motor abilities, it was further found that the levels of BB, six minute run and PU tests have the highest correlations with the performance of the cognitive learning abilities (p < 0.001).

Contribution of BB test: the highest correlation between total cognitive abilities and the different motor abilities, was present registering on the BB test at p < 0.001 and r = 0.63 (i.e. r = 0.75 BB-math and r = 0.63 BB-language). These results were in line with those of Ahnert et al.¹ and Dordel and Breithecker² who showed that difficulties in concentration and language development skills were related to the overweight and to deficiency in the coordinative tasks. It was also found that the development of coordination disorders (DCD) are often (40–90%) accompanied with the cognitive development disorder.³⁸ Furthermore, current results support two previous suggestions: First, that the intellectual ability to learn (i.e., both within and outside the school),³⁹ requires the acquisition

and improvement of certain performance conditions relating to coordination and motivation. Second, that with age growing the maturation of the Central Nerves System (CNS) (i.e. improved with coordination abilities development)²² provides suitable learning opportunities. Thus, motor coordination abilities could play a key role in brain health and academic performance in children.²²

Contribution of 6 min running: a high correlation was demonstrated between the endurance ability (i.e., 6 min test) and the global cognitive performance with $p < 0.001$ and $r = 0.62$ (i.e. $p < 0.001$, $r = 0.64$ and $p < 0.01$, $r = 0.57$ for math and language respectively). Results were in line with recent studies in children that focused on the P3b -an event related potential (ERP) component that played a key role in cognitive psychology research on information processing- that successfully demonstrated an association between aerobic fitness and specific, core aspects of cognition.^{20,22,40} The findings seemed also to confirm recent assertions of Scudder et al.⁴¹ who suggest that greater aerobic fitness levels in children had important implications for cognitive benefits associated with learning and academic performance. This relationship could be explained by the fact that higher cardio-respiratory capacity induces angiogenesis in the motor cortex, increases blood flow (i.e., improve brain vascularization), and increases levels of the brain-derived neurotrophic factor. In turn, these factors should promote neuronal survival and differentiation which ultimately could affect cognitive performance.²¹ Furthermore, it was found that cardio-respiratory capacity was related to higher P3 event-related brain potential amplitude and lower P3 latency which reflects a better ability to modulate neuroelectric indices of cognitive control.²² These processes are involved in cognitive control (specific inhibition), cognitive flexibility and working memory. All these components specifically provide the basis for academic performance.^{22,24}

Contribution of PU test: the results of PU test were also correlated to the total cognitive learning abilities with $p < 0.001$ and $r = 60$ (i.e., $p < 0.001$, $r = 0.61$ and $p < 0.01$, $r = 0.58$, respectively with mathematical thinking and language understanding). These findings were similar to those of Winter et al.⁴² who assessed the ability of 27 healthy subjects to be able to learn a novel vocabulary after varying levels of exercise. The participants were placed into one of three groups: (a) high intensity anaerobic exercise (e.g., strength training), (b) low intensity aerobic exercise, and (c) sedentary or no activity. Results revealed that vocabulary learning was 20% faster when it took place after the high intensity exercise compared to the low intensity and sedentary conditions.

Similar to the independent result of BB, PU and 6 min running tests, the result of total motor abilities show that the higher correlations were especially with mathematical thinking and language understanding with ($p < 0.001$; $r = 0.62$, $r = 0.59$ respectively). These findings go in line with previous research. Indeed, Ishigawara and Ishizuka⁴³ showed that a task conducted 3 min after exercise was efficient both in the promotion of learning English sentences as well as completing arithmetic calculations. Grisoom⁴⁴ examined data of 5th, 7th, and 9th graders in California and found a consistent positive relationship between physical fitness and academic achievement. Likewise, Schmidt-Kassow et al.⁴⁵ found that simultaneous physical activity during vocabulary learning facilitates memorization of new items. Consequently, as mentioned earlier, it may be reasonable to argue that exercise increases the blood stream of the hippocampus, which could thus improve memorization.

The significant contribution (i.e., global and independent) of motor levels in the performance of cognitive learning abilities (i.e., related to the academic achievement) can be explained by the findings of Taras⁴⁶ who found that students who are physically active demonstrate greater attention during class than sedentary students, and concluded that physically active subjects report

higher levels of self-esteem and lower levels of anxiety, which have both been associated with improved academic achievement.⁴⁷

5. Conclusions

The current study suggests that the higher motor and cognitive performances which is demonstrated by age growing, indicate an appropriate age-related development of nervous system and brain, to ensure adequate cognitive and motivational development of children as well as the expression of reasonable social behaviors.

Additionally, the present findings seem to underline the results from previous research that shows the association between promoting physical activity³⁶ and developing cognitive control involving inhibition, working memory, and cognitive flexibility^{22,31} where these 3 aspects provide the foundation for academic ability.^{23,25} It can be asserted that fostering physical activity, in both kindergarten and early primary school (i.e., 6–7 years) is recommended to enhance motor and cognitive development. Indeed, previous results found that students participating in extracurricular physical activities,^{48–50} had an improvement in executive function, Mathematics and English test scores (+20%). These results support the idea of an integrated curriculum in order to maximize the benefit from the study of comprehensive topics (i.e., focuses on all domains of learning: social-emotional, physical, cognitive (intellectual), and communication (language and literacy)) during the primary school age and its impact on the overall child development.

Declaration of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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