Erschienen in: Alexandria Journal of Medicine ; 53 (2017), 4. - S. 325-331
https://dx.doi.org/10.1016/j.ajme.2016.12.004

Alexandria Journal of Medicine 53 (2017) 325–331

HOSTED BY

Contents lists available at ScienceDirect

Alexandria Journal of Medicine

journal homepage: http://www.elsevier.com/locate/ajme

Original Article

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

Osama Abdelkarim [a,b,*], Achraf Ammar [a,c], Hamdi Chtourou [c], Matthias Wagner [d], Elke Knisel [a], Anita Hökelmann [a], Klaus Bös [e]

[a] *Institute of Sport Science, Otto-von-Guericke-University, Magdeburg, Germany*
[b] *Faculty of Physical Education, University of Assiut, Assiut, Egypt*
[c] *Research Unit (EM2S), High Institute of Sport and Physical Education, Sfax University, Tunisia*
[d] *Institute of Sports Science, University of Konstanz, Konstanz, Germany*
[e] *Institute of Sport and Sports Science, University of Karlsruhe, Karlsruhe, Germany*

ARTICLE INFO

Article history:
Received 15 November 2016
Revised 22 December 2016
Accepted 22 December 2016
Available online 11 January 2017

Keywords:
Physical fitness
Intellectual performance
Child development

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.

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 Boudreau[3] 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 intelligence[5] and (iii) motor performance and working memory.[6] In the same context, Thelen[7] and Wrobel[8] 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. Iverson[15] 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

---

Peer review under responsibility of Alexandria University Faculty of Medicine.

* Corresponding author at: Otto-von-Guericke-University Magdeburg, Institute of Sport Science, Building 40, Zschokkestr. 32, 39104 Magdeburg, Germany.

E-mail addresses: osamahalim@ymail.com (O. Abdelkarim), ammar.achraf@ymail.com (A. Ammar), H_chtourou@yahoo.fr (H. Chtourou), matthias.wagner@uni-konstanz.de (M. Wagner), elke.knisel@ovgu.de (E. Knisel), anita.hoekelmann@ovgu.de (A. Hökelmann), boes@sport.uka.de (K. Bös).

http://dx.doi.org/10.1016/j.ajme.2016.12.004
2090-5068/

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 Etnier 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:weight (kg)/height^2 (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 DMT[28] 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 ± 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 ± 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 ± 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

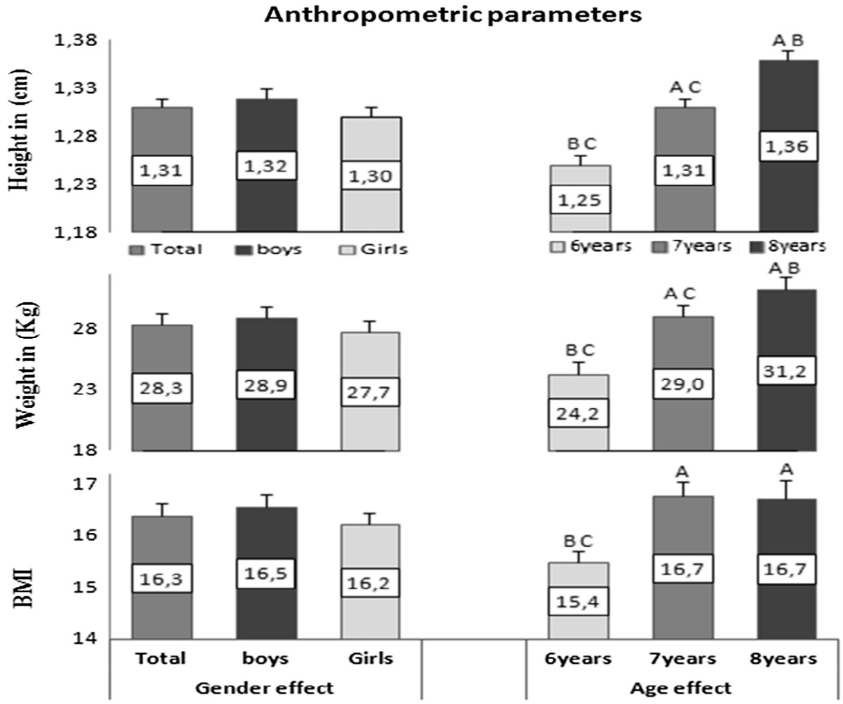

Figure 1. Anthropometric children's parameters (i.e. Height in (cm), Weight in (kg) and BMI). Analyses were adjusted by sex (i.e. total, boys and girls) and age (i.e. 6, 7 and 8 years old). A, B and C represents significant difference between different ages (i.e. compared to 6, 7 and 8 years old respectively)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

Table 1
Motor and cognitive children's abilities.

	Motor Abilities								Cognitive Abilities				
	Sprint	BB	JS	PU	Sit UP	LJ	6 min	Total	Lang	Relat	Deduc	Math	Total
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 ± 0.06*BC*	25.09 ± 1.48*BC*	16.85 ± 0.79*BC*	10.00 ± 0.79*BC*	14.29 ± 0.81*BC*	107.18 ± 2.20*BC*	810.54 ± 19.9*BC*	23.11 ± 1.01*BC*	6.96 ± 0.40*BC*	6.69 ± 0.43*BC*	8.03 ± 0.4 *BC*[*]	4.13 ± 0.52*BC*	25.81 ± 1.4*BC*
7 Years	4.60 ± 0.04*AC*	35.08 ± 1.3*A*[*]	23.78 ± 0.73*A*	15.53 ± 0.74*A*	18.90 ± 0.7*AC*	117.53 ± 2.25*A*	915.71 ± 14.5*A*	28.90 ± 0.80*AC*	8.89 ± 0.34*A*	8.79 ± 0.38*A*	9.10 ± 3.40*A*	8.56 ± 0.41*A*	35.45 ± 1.26*A*
8 Years	4.44 ± 0.05*A B*	33.21 ± 1.37*A*	25.82 ± 0.91*A*	15.93 ± 0.91*A*	21.36 ± 0.96*AB*	121.33 ± 2.68*A*	876.24 ± 18.1*A*	25.98 ± 0.80*AB*	9.32 ± 0.39*A*	9.16 ± 0.40*A*	10.05 ± 0.33*A*	9.20 ± 0.49*A*	37.59 ± 1.27*A*
Boy 6Y	4.83 ± 0.09*BC*	22.48 ± 2.29*BC*	16.52 ± 1.13*BC*	10.11 ± 1.26*C*	14.41 ± 1.19*BC*	112.07 ± 3.22*C*	833.07 ± 31.30*B*	23.11 ± 1.58*B*	7.12 ± 0.55*BC*	6.65 ± 0.60*BC*	7.15 ± 0.5*BC*[*]	3.96 ± 0.74*BC*	24.89 ± 1.9*BC*
Boy 7Y	4.58 ± 0.06*A*	32.80 ± 1.62*A*[*]	23.28 ± 0.91*A*	15.96 ± 1.11	19.07 ± 0.98*A*	119.74 ± 3.31	935.59 ± 22.6*A*	28.11 ± 1.12*A*	9.15 ± 0.48*A*	8.72 ± 0.55*A*	8.59 ± 0.50*AB*	8.57 ± 0.57*A*	35.11 ± 1.84*A*
Boy 8Y	4.42 ± 0.09*A*	32.76 ± 1.71*A*	25.76 ± 1.34*A*	16.17 ± 1.37*A*	22.07 ± 1.49*A*	124.79 ± 4.22*A*	896.07 ± 27.1	25.97 ± 1.27	10.00 ± 0.54*A*	9.59 ± 0.60*A*	10.10 ± 0.49*AC*	9.62 ± 0.74*A*	39.31 ± 1.97*A*
Girl 6Y	5.10 ± 0.07*BC*	27.52 ± 1.84*BC*	17.16 ± 1.12*BC*	9.90 ± 0.89*BC*	14.17 ± 1.11*BC*	102.62 ± 2.81 *BC*	789.55 ± 25.0*B*	23.10 ± 1.31 *B*	6.83 ± 0.60*BC*	6.72 ± 0.61*BC*	8.83 ± 0.58[*]	4.28 ± 0.74*BC*	26.66 ± 2.1*BC*
Girl 7Y	4.62 ± 0.06*A*	37.92 ± 1.41*A*[*]	24.41 ± 1.18*A*	15.00 ± 0.92*A*	18.70 ± 1.01*A*	114.78 ± 2.90 *A*	891.00 ± 16.05*A*	29.89 ± 1.13*AC*	8.56 ± 0.45*A*	8.89 ± 0.50*A*	9.75 ± 0.49	8.56 ± 0.58*A*	35.89 ± 1.67*A*
Girl 8Y	4.46 ± 0.06*A*	33.66 ± 2.16*A*	25.88 ± 1.25*A*	15.69 ± 1.23*A*	20.66 ± 1.20*A*	117.86 ± 3.26 *A*	856.41 ± 24.01	26.00 ± 0.10*B*	8.59 ± 0.47*A*	8.70 ± 0.51*A*	10.00 ± 0.44	8.74 ± 0.64*A*	35.74 ± 1.54*A*

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-Denter[33] 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
Motor abilities								
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	–
Cognitive abilities								
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
Motor abilities										
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 < 0.0 01	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 Diamond[31], 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-Rehage[34] 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 physically 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 Breithecker[2] 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 Ishizuka[43] 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. Grisoom[44] 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 Taras[46] 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 activity[36] 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.

References

1. Ahnert J, Schneider W, Bös K. Developmental changes and individual stability of motor abilities from the preschool period to young adulthood. In: Schneider W, ed. *Human Development from Early Childhood to Early Adulthood: Findings from a 20 Year Longitudinal Study*. New York, NY: Psychology Press; 2009:35–62.
2. Dordel S, Breithecker D. Bewegte Schule als Chance einer Förderung der Lern- und Leistungsfähigkeit. *Haltung und Bewegung*. 2003;23:5–15.
3. Bushnell EW, Boudreau JP. Motor development and the mind: the potential role of motor abilities as a determinant of aspects of perceptual development. *Child Dev*. 1993;64:1005–1021.
4. Martin R, Tigera C, Denckla MB, Mahone EM. Factor structure of pediatric timed motor examination and its relationship with IQ. *Dev Med Child Neurol*. 2010;2010:188–194.
5. Davis E, Pitchford N, Jaspan T, Macarthur D, Walker D. Development of cognitive and motor function following cerebellar tumour injury sustained in early childhood. *Cortex*. 2010;46:919–932.
6. Wassenberg R, Feron FJM, Kessels AGH, Hendriksen JGM, Kalff AC, Kroes M. Relation between cognitive and motor performance in 5- to 6-year-old children: results from a large-scale cross-sectional study. *Child Dev*. 2005;76:1092–1103.
7. Thelen E. Motor development as foundation and future of developmental psychology. *Int J Behav Dev*. 2000;24:385–397.
8. Wrobel J. "Vom Kopf auf die Füße stellenEllipsis" Die Bedeutung von Bewegung für das Lernen. *Praxis der Psychomotorik*. 2004;29:204–208.
9. Fields T, Diego M, Sanders CE. Exercise is positively related to adolescents' relationships and academics. *Adolescence*. 2001;36:105–110.
10. Kim EY, Iwaki N, Imashioya H, Uno H, Fujita T. Error-related negativity in children: effect of an observer. *Dev Neuropsychol*. 2005;28:871–883.
11. Lindner KJ. The physical activity participation-academic performance relationship revisited: perceived and actual performance and the effect of banding (academic tracking). *Pediatr Exerc Sci*. 2002;14:155–169.
12. Castelli DM, Hillman CH, Buck SM, Erwin HE. Physical fitness and academic achievement in 3rd and 5th grade students. *J Sport Exerc Psychol*. 2007;29:239–252.
13. Roberts CK, Freed B, McCarthy WJ. Low aerobic fitness and obesity are associated with lower standardized test scores in children. *J Pediatr*. 2010;156:711–718.
14. Dwyer T, Sallis JF, Blizzard L, Lazarus R, Dean K. Relation of academic performance to physical activity and fitness in children. *Pediatr Exerc Sci*. 2001;13:225–237.

15. Iverson JM. Developing language in a developing body: the relationship between motor development and language development. *J Child Lang.* 2010;37:1–25.
16. Preston JL, Frost SJ, Mencl WE. Early and late talkers: school-age language, literacy and neurolinguistic differences. *Brain*. 2010;133:2185–2195.
17. Haapala EA. Cardiorespiratory fitness and motor skills in relation to cognition and academic performance in children-a review. *J Hum Kinet*. 2013;36:55–68.
18. Westendorp M, Hartman E, Houwen S, Smith J, Visscher C. The relationship between gross motor skills and academic achievement in children with learning disabilities. *Res Dev Disabil.* 2011;32:2773–2779.
19. Tomporowski PD, Davis CL, Miller PH, Naglieri JA. Exercise and children's intelligence, cognition, and academic achievement. *Educ Psych Rev*. 2008;20:111–131.
20. Hillman CH, Erickson KI, Kramer AF. Be smart, exercise your heart: exercise effects on brain and cognition. *Nat Rev Neurosci*. 2008;9:58–65.
21. Adkins DL, Boychuk J, Remple MS, Kleim JA. Motor training induces experience-specific patterns of plasticity across motor cortex and spinal cord. *J Appl Physiol.* 2006;101:1776–1782.
22. Pontifex MB, Raine LB, Johnson CR, et al.. Cardiorespiratory fitness and the flexible modulation of cognitive control in preadolescent children. *J Cogn Neurosci*. 2011;23:1332–1345.
23. Chaddock L, Hillman CH, Pontifex MB, Johnson CR, Raine LB, Kramer AF. Childhood aerobic fitness predicts cognitive performance one year later. *J Sports Sci*. 2012;30:421–430.
24. Diamond A. Executive functions. *Annu Rev Psychol*. 2013;64:135–168.
25. Agostino A, Johnson J, Pascual-Leone J. Executive functions underlying multiplicative reasoning: problem type matters. *J Exp Child Psychol.* 2010;105:286–305.
26. Etnier JL, Salazar W, Landers DM, Petruzzello SJ, Han M, Nowell P. The influence of physical fitness and exercise upon cognitive functioning: a meta-analysis. *J Sport Exerc Psychol*. 1997;19:249–277.
27. Heller K, Geisler H. *Kognitiver Fähigkeit Test (Grundschuleform). KFT 1–3.* Weinheim: Beltz test GmbH; 1983.
28. Bös K. Deuscher Motorik Test (DMT 6-18), Deusche Vereinigung Für Sportwissenschaft, ad-hoc-Ausschuss (Motorische Test Für Kinder und Jugendliche) 2009; 17.
29. Lämmle L, Tittelbach S, Oberger J, Worth A, Bös K. A two-level model of motor performance ability. *J Exerc Sci Fit*. 2010;8:41–49.
30. Karim OA, Ammar A, Chtourou H, et al.. A comparative study of physical fitness among egyptian and German children aged between 6 and 10 years. *Adv Phys Ed*. 2015;5:7–17.
31. Diamond A. Close interrelation of motor development and cognitive development and of the cerebellum and prefrontal cortex. *Child Dev*. 2000;71:44–56.
32. Rosenbaum DA, Carlson RA, Gilmore RO. Acquisition of intellectual and perceptual-motor skills. *Annu Rev Psychol*. 2001;52:453–470.
33. Nickel H, Schmidt-Denter U. *Vom Kleinkind zum Schulkind. Eine Entwicklungs-psychologische Einfuhrung für Erzieher, Lehrer und Eltern*. Ernst-Reinhardt Verlag; 1991.
34. Voelcker-Rehage C. Der Zusammenhang zwischen motorischer und kognitiver Entwicklung im frühen Kindesalter – Ein Teilergebnis der MODALIS-Studie [Association of motor and cognitive development in young children – Apartial result of the MODALIS-study]. *Deutsche zeitschrift für sportmedizin*. 2005;56:358–363.
35. Kambas A, Antoniou P, Xanthi G, Heikenfeld R, Taxildaris K, Godolias G. Unfallverhütung durch Schulung der Bewegungskoordination bei Kindergartenkindern. *Deutsche Zeitschrift für Sportmedizin*. 2004;55:44–47.
36. Rethorst S. Kinder in Bewegung. Welche Chancen bieten bewegungsfreundliche indergärten für die motorische Entwicklung im Kindesalter? *Sportunterricht*. 2004;53:72–78.
37. Cotman C, Berchtold N. Exercise: a behavioural intervention to enhance brain health and plasticity. *Trends Neurosci*. 2002;25:295–301.
38. Hill E. Non-specific nature of specific language impairment: a review of the literature with regard to concomitant motor impairment. *Int J Lang Commun Disord*. 2001;36:149–171.
39. Nüske F. Kognitive Aspekte der Bewegungssteuerung bei jungeren Schulkindern. In: Kaul P, Zimmermann KW, editors. *Psychomotorik in Forschung und Praxis*, Bd. 15. Kassel: Universitatsbuchhandlung Greifswald; 1993.
40. Hillman CH, Motl RW, Pontifex MB, et al.. Physical activity and cognitive function in a cross-section of younger and older community-dwelling individuals. *Health Psychol*. 2006;25:678–687.
41. Scudder MR, Federmeier KD, Raine LB, Direito A, Boyd JK, Hillman CH. The association between aerobic fitness and language processing in children: Implications for academic achievement. *Brain Cogn*. 2014;87:140–152.
42. Winter B, Breitenstein C, Mooren FC, et al.. High impact running improves learning. *Neurobiol Learn Mem*. 2007;87:597–609.
43. Ishigawara K, Ishizuka H. Effects of Brain Activation through Physical Exercise on Language Learning (presentation manuscript). Hokkaido University of Education Asahikawa. The Third Pacific Rim Conference of Education 2012.
44. Grisoom JB. Physical fitness and academic achievement. *J Exerc Physiol*. 2005;8:11–25.
45. Schmidt-Kassow M, Kulka A, Gunter TC, Rothermich K, Kotz SA. Exercising during learning improves vocabulary acquisition: behavioral and ERP evidence. *Neurosci Lett*. 2010;482:40–44.
46. Taras H. Physical activity and student performance at school. *J Sch Health*. 2005;75:214–218.
47. Flook L, Repetti RL, Ullman JB. Classroom social experiences as predictors of academic performance. *Dev Psychol*. 2005;41:319–327.
48. Nelson MC, Gordon-Larsen P. Physical activity and sedentary behavior patterns are associated with selected adolescent health risk behaviors. *Pediatr*. 2006;117:1281–1290.
49. Donczik J. Brain exercise improves reading and memory. *Brain Gym Journal*. 2001;1–15.
50. Best JR. Effects of physical activity on children's executive function: contributions of experimental research on aerobic exercise. *Dev Rev*. 2010;30:331–351.