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Original Article

Physical fitness and executive functions in adolescents: cross-sectional associations with academic achievement

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Abstract. [Purpose] This study analyzed the relationship between fitness and executive functions in adolescents and its influence on academic achievement. [Participants and Methods] The design was cross-sectional. The sample included 713 adolescents (14.2 ± 1.5 years old). Physical fitness was evaluated using flexibility test, strength test, balance test and aerobic test. Executive function was evaluated with the tests (Stroop, Symbol digit, Trail making, Wechsler memory, and MESSY scale). Academic performance was evaluated through the school records. A partial correlational analysis of physical fitness and executive functions with respect to academic achievement was carried out. A multivariate linear regression was performed to identify the physical component model that best defined each of the executive functions. [Results] The analysis showed how academic achievement is significantly influenced, from a physical point of view, by resistance strength (r=0.21), aerobic endurance (r=0.188), and flexibility (r=0.17), whereas from a cognitive point of view it is significantly influenced by inhibition/interference (r=0.25), working memory (r=0.10) and processing speed (r=0.18). [Conclusion] The results indicate that the physical fitness and executive function are closely related and both have a significant influence on academic achievement.

Key words: Cognition, Physical activity, Education

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INTRODUCTION

The benefits of physical activity (PA) practice in humans have been shown in numerous investigations[1)]. One of the privileged spaces to practice PA is the physical education classroom in schools, since it allows all students to participate under the supervision of a qualified professional in the area of Sports Science[2)]. Systematic and regular PA practice improves physical fitness (PF), especially in adolescents[3)].

Several studies have shown the relationship between PA and cognitive functions (CFs) in adolescents, indicating that the latter can be positively influenced by PA practice[4)]. Improvement in CFs positively influences students' academic achievement (AA), since CFs are the foundation of human learning processes[5, 6)].

CFs are the mental processes that allow us to play an active role in the processes of attention and concentration, perception and recognition, orientation, memory, language, calculation and executive functions (EFs). EFs are covert, internally self-directed cognitive skills at the service of a goal, therefore they direct our behavior and our cognitive and emotional activity[4, 6)].

The relationship between the practice of PA and EFs, despite being an object of interest for many years, has only recently started to be evaluated systematically. Among other reasons, technological advancements and the improvement of techniques such as neuroimaging have contributed to answering questions that had been difficult to resolve[7)].

In short, after analyzing the existing literature, owing to which the relationship between the practice of PA and the PF of the

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population has become clearer and in view of the scarcity of research work linking PF with EFs in adolescents[3, 8], it would seem necessary to conduct new research projects aimed at identifying the relationship between the physical components that define PF and EFs, and how they influence adolescent's academic performance.

PARTICIPANTS AND METHODS

The design was a cross-sectional, with randomized selection of the sample. It was carried out from September 2016 to January 2017. The study protocol was performed in accordance with the ethical standards laid down in the 1961 Declaration of Helsinki (as revised in 2000). The research protocol was submitted for approval to the Local Ethics Committee (12-2205-17) and eventually included in EudraCT with registration number 2017-001837-24.

The population consisted of 147,000 students between the ages of 12 and 16. Sample size was estimated with the statistical power analysis program G * Power 3.1[9] that allows for this type of analysis in cross-sectional studies. The total population was n=147,000 students, the level of confidence 95% (1-alpha), proportion of 5% (which maximizes the sample size) and precision of 98.4% (d). Based on these parameters, the resulting sample size was 709 participants; however, with an expected sample loss of 35%, n increased to 1,026 students.

A sample of 1,026 students was randomly selected among all the educational centers of the Galician Autonomous Community in which the Compulsory Secondary Education (CSE) levels are taught: 12.1% did not complete the questionnaires correctly, 7.9% did not perform any of the physical tests, and 8.7% could not provide a signed consent. The final sample consisted of 713 students enrolled in five Secondary Education centers of the Galician Autonomous Community: 336 were males (age: 14.1 ± 1.6 years old) and 374 females (age: 14.2 ± 1.5 years old).

Data were collected with objective measurements and questionnaires. Five professionals from the field of education, who had received specific training on the protocols of physical and cognitive tests, completed the data collection process over a 5-month period in the five randomly selected centers with the statistical program SPSS (Data-Select cases →Random sample of cases →% of all cases). Each of the educational centers was considered a case.

To evaluate the adolescents' physical condition levels, nine physical tests were administered, which allowed for the evaluation of physical components that define the physical condition: resistance strength with the 30-second Chair Stand Test[6]; explosive strength with Standing broad jump[10]; agility and speed with 10 × 5 m shuttle run[11] and the quadrant jump test[12]; aerobic endurance with 20 m shuttle run[13] and 6 min endurance run[14]; balance with BOT 2-Balance[15]; and flexibility with the Sit and Reach[16] and Back Scratch[17] tests. To measure the level of physical activity, a Physical Activity Questionnaire PAQ-A was administered, as well as a one-week retrospective questionnaire consisting of 9 questions that assess the different aspects of adolescent physical activity using a 5-point Likert scale, although only 8 questions were used to calculate the final score[18].

The evaluation of EF parameters was carried out as follows: inhibition/interference with the Stroop Golden Test, which examines the effects of interference on reading ability[19]; working memory with the Visual Memory-Weschsler Memory Scale, which evaluates the short or long term visual memory by reproducing four line drawings the participant sees for 10–15 seconds each and must then reproduce after they are shown and 30 minutes later[20]; processing speed with the Symbol Digit Modalities Test, a neuropsychological test that assesses certain neurocognitive functions, such as working memory, speed of information processing, sustained, focused and selective attention, visual-spatial function as well as constructive praxis[21]; cognitive flexibility with the Trail Making Test, another neuropsychological test that provides information about motor skills, visual-spatial search, sustained and divided attention, and cognitive flexibility[22] and social skills with the MESSY Scale, which allows for the evaluation of social group skills[23].

Academic achievement (AA) was assessed through school records at the end of the second trimester of the academic year. Six indicators were used to define academic performance: Language, Mathematics, Sciences, Social Sciences, Physical Education and Arts (music, arts and crafts and technology). The AA score was obtained by calculating the arithmetic mean of the values obtained in the six indicators, worst to best, from 0 to 10.

A descriptive analysis was performed using central tendency measures (mean and standard deviation) of the physical (PF and PA) and cognitive (AA and EFs) parameters, both globally and stratified by gender. The normality of the variables under study was verified through the Kolmogorov-Smirnov test ($p>0.05$), and Student's t-test for independent data was applied to analyze the existence of significant differences in the main variables according to gender. The relationship between the components of PF, the domains of EFs and AA was studied through a partial correlation analysis, adjusting by age, gender and school. A multivariate regression analysis was conducted to identify which components of PF defined the EF domains better. Statistical analyses were carried out using the statistical package IBM-SPSS v. 21 for Windows, setting significance at $p<0.05$.

RESULTS

Table 1 show the physical and cognitive descriptive characteristics of the sample. With respect to the physical parameters, the level of physical activity presented by males is higher than females (2.7 vs. 2.4, $p=0.001$). As for the components that define the physical condition in adolescents, it should be noted that a comparison between the levels of resistance strength

Table 1. Descriptive analysis of the sample. Physical and cognitive parameters

	All (n=713)	Males (n=336)	Females (n=374)
Physical characteristics			
Age (years)	14.2 ± 1.5	14.1 ± 1.6	14.2 ± 1.5
Weight (kg)	55.8 ± 2.1	56.1 ± 2.4	55.6 ± 1.9
Height (cm)	160.1 ± 1.0	160.6 ± 1.1	159.6 ± 0.9
BMI (kg/m^2)	21.8 ± 0.6	21.7 ± 0.5	21.8 ± 1.7
Level of physical activity			
Physical Activity Questionnaire PAQ-A	2.6 ± 0.7	2.7 ± 0.7	2.4 ± 0.7**
Physical fitness			
Resistance strength			
30-second chair stand test (n)	26.6 ± 7.2	26.7 ± 7.2	26.1 ± 7.2
Explosive strength			
Standing broad jump (cm)	159.9 ± 28.8	172.5 ± 29.6	148.8 ± 23.1**
Agility and speed			
10 × 5 shuttle run (s)	20.0 ± 3.1	19.2 ± 3.1	20.7 ± 2.8**
Quadrant jump test (n)	25.4 ± 4.8	25.9 ± 5.0	24.9 ± 4.6*
Aerobic endurance			
20 m shuttle run (n levels)	11.3 ± 3.2	12.6 ± 3.4	10.1 ± 2.5**
Speed	11.6 ± 1.6	12.3 ± 1.7	11.0 ± 1.3**
VO_2max (ml/kg/min)	48.0 ± 9.1	51.8 ± 9.3	44.5 ± 7.5**
6 min endurance run (m)	1,033.1 ± 260.1	1,149.7 ± 265.6	928.4 ± 204.9**
HR (10s)	22.1 ± 4.4	22.2 ± 4.6	21.9 ± 4.2
VO_2max (ml/kg/min)	35.9 ± 10.4	40.6 ± 10.6	31.7 ± 8.2**
Balance			
BOT-2: Stand with open eyes on the 10s-line, one foot in front of the other	3.9 ± 0.2	3.9 ± 0.2	3.9 ± 0.1
BOT-2: Walk 6 steps from the line	4.0 ± 0.1	3.9 ± 0.1	4.0 ± 0.1
BOT-2: Stay in flamingo balance with open eyes on the 10s-line	3.9 ± 0.3	3.9 ± 0.3	3.9 ± 0.3
BOT-2: Stand with closed eyes on the 10s-line, one foot in front of the other	3.9 ± 0.4	3.8 ± 0.4	3.9 ± 0.4
BOT-2: Walk 6 steps from the line hitting heels	3.9 ± 0.2	3.9 ± 0.2	3.9 ± 0.2
BOT-2: Stay in flamingo balance with closed eyes on the 10s-line	3.4 ± 0.8	3.5 ± 0.8	3.4 ± 0.9
BOT-2: Stay in flamingo balance on the base with open eyes on the 10s-line	3.8 ± 0.6	3.8 ± 0.5	3.8 ± 0.6*
BOT-2: Stay in balance on the base with one foot in front of the other	3.8 ± 0.5	3.9 ± 0.4	3.8 ± 0.5
BOT-2: Stay in flamingo balance on the base with closed eyes on the 10s-line	3.7 ± 1.2	3.8 ± 1.2	3.7 ± 1.2
BOT-2: Balance score	34.6 ± 2.2	34.8 ± 2.2	34.5 ± 2.3
Flexibility			
Sit and reach test (cm)	9.1 ± 10.6	6.1 ± 10.7	11.8 ± 9.7**
Back scratch test (cm)	5.9 ± 6.2	5.7 ± 7.1	6.3 ± 5.3*
Academic achievement	6.9 ± 1.4	6.8 ± 1.5	7.1 ± 1.3*
Inhibition/Interference			
Stroop test, P (n)	104.9 ± 14.3	105.3 ± 14.9	104.6 ± 13.9
Stroop test, C (n)	84.9 ± 12.9	84.6 ± 12.9	85.1 ± 13.1
Stroop test, PC (n)	60.2 ± 14.9	60.2 ± 15.7	60.3 ± 14.3
Interference index	13.5 ± 12.3	13.5 ± 12.6	13.6 ± 12.1
Working memory			
Wechsler memory scale 1	2.6 ± 0.9	2.5 ± 0.9	2.7 ± 0.8*
Wechsler memory scale 2	2.3 ± 1.0	2.2 ± 1.1	2.5 ± 0.9**
Wechsler memory scale 3	2.3 ± 0.9	2.2 ± 1.0	2.3 ± 0.9
Wechsler memory scale score	7.3 ± 2.3	6.9 ± 2.5	7.5 ± 2.1*
Wechsler memory scale 1 retard	2.5 ± 0.9	2.4 ± 1.0	2.5 ± 0.8
Wechsler memory scale 2 retard	2.1 ± 1.1	2.0 ± 1.1	2.3 ± 1.0**
Wechsler memory scale 3 retard	2.1 ± 1.1	2.1 ± 1.1	2.1 ± 1.1
Wechsler memory scale retard score	6.8 ± 2.5	6.5 ± 2.7	7.0 ± 2.4*
Processing speed			
Symbol digit modality test, hits (n)	53.8 ± 11.4	52.2 ± 11.3	55.2 ± 11.4**
Symbol digit modality test, misses (n)	0.9 ± 1.7	0.8 ± 1.3	1.1 ± 1.9*
Cognitive flexibility			
Trail making test-A (s)	30.5 ± 13.3	31.6 ± 15.6	29.5 ± 10.6*
Trail making test-B (s)	83.5 ± 38.1	84.9 ± 36.0	82.2 ± 39.9
Social skills			
MESSY scale	138.8 ± 13.4	138.8 ± 13.8	138.8 ± 13.1

Obs.: *p<0.05; **p<0.001; BOT-2: Bruininks-Oseretsky Test of Motor Proficiency, 2nd ed.

did not lead to significant differences according to gender (26.7 vs. 26.1, p=0.257). This same principle applied in the balance component (34.8 vs. 34.5, p=0.132). In the remaining physical components analyzed, gender was a significantly influential variable. The descriptive analysis of the cognitive parameters show that gender had a significant influence on AA (p=0.002), working memory (p=0.003; p=0.013), processing speed (p=0.001) and cognitive flexibility (p=0.042), no significant differences being observed in the social skills (p=0.960) or in inhibition/interference (p=0.925).

Table 2 shows the partial correlations between PF and AA, adjusting by gender, age and school level. Resistance strength (r=0.41, p<0.001), explosive strength (r=0.32, p<0.05), agility and speed (r= −0.30, p<0.05, r=0.33, p<0.001), aerobic endurance (r=0.49, p<0.001, r=0.49, p<0.001) and flexibility (r=0.37, p<0.001, r=0.35, p<0.001) have a positive influence on students' AA, while balance (r=0.21; p>0.05) does not. The partial correlations between EFs and AA, adjusting by gender, age and level school show association with students' academic achievement in Inhibition/interference (r=0.25, p<0.001), working memory (r=0.10, p<0.05, r=0.19, p<0.05), and processing speed (r= −0.180, p<0.05). However, cognitive flexibility (r= −0.17, p>0.05) and social skills (r=0.13, p>0.05) seem to show no significant correlation with AA.

Table 3 shows the association of PF components with EF parameters. Inhibition/Interference has shown an association with resistance strength (30-second chair stand test, β=0.22, p=0.039) and balance (BOT-2 balance Score, β= −0.87, p=0.035). Working memory has shown association with balance (Sit and reach test, β=0.04, p=0.004, Back Scratch Test, β= −0.05, p=0.014). Delayed working memory has shown an association with explosive strength (Standing broad jump, β= −0.01, p=0.045) and with the flexibility (Sit and reach test, β=0.04, p=0.018, Back Scratch Test, β= −0.03, p=0.019). Cognitive flexibility showed association with resistance strength (30-second chair stand test, β= −0.39, p=0.001) as well as agility and speed (Quadrant Jump Test, β= −0.31, p=0.042). Social skills are only related to resistance strength (30-second chair stand test, β=0.36, p=0.002).

DISCUSSION

The current study aimed at identifying the relationship between the physical components that define PF and EFs, and how they influence adolescent's academic performance. Previous studies have analyzed the association between PF and AA[4, 24)]. However, when PF components are considered, the degree of association varies, which highlights how the physical components of strength and aerobic endurance have greater influence on the AA of adolescents[25)]. The present study supports the idea that each component has an independent influence on AA, with resistance strength and aerobic endurance being the most influential and balance the least.

Different researchers have justified the relationship between the aerobic component and academic performance. Such relationship may be justified by the increased blood flow in the brain, which causes an improvement of vascularization leading to greater cognitive performance, angiogenesis in the motor cortex, and the relationship between aerobic capacity and the potentials related to amplitude and latency in the brain (P3), which would improve cognitive control indexes[26)].

The evidence justifying the relationship between academic performance and muscle strength seems not to be as solid: there are studies that confirm this association[27, 28)], while others have not found such relationship[25)]. This disparity of results may be due to the type of manifestation of the force under study, or to the interference caused by other physical components. In the present study, the relationship between academic performance and the manifestations of force were analyzed—strength resistance and explosive force—with correlations of 0.41 and 0.42 respectively.

The relationship between EFs and AA has been thoroughly studied over the years, ratifying the degree of association between both parameters not only in adolescents[29)], but also in other age groups[27)]. The degree of association is determined by the domain of the executive function under analysis (inhibition/interference, working memory, processing speed, cognitive flexibility, social skills) and the educational content being assessed (mathematics, language, reading). Working memory[29)], processing speed and inhibition/interference[4)] are the three domains that seem to influence academic performance more strongly. Within the relationship between executive function and academic performance, it is worth highlighting the association between working memory and reading and mathematics[30)]; the relationship between inhibition/interference, mathematics[30)], reading and language. The results obtained in the present study are in agreement with those previously stated and the domains of executive function which have the greatest influence on academic performance are inhibition/interference (r=0.25), working memory (r=0.10; r=0.19) and processing speed (r=0.18).

Few studies have analyzed the relationship between the different components of physical condition and the domains of executive function[4, 7, 24)]. Research has focused on defining the effect of a physical activity program, mainly with a cardiovascular objective, on the domains of executive function[24)]. They indicate that the influence of a cardiovascular program on executive function domains depend on the duration of the program (acute, longitudinal) and the executive domain analyzed, which highlights that the development of programs of acute physical activity may lead to significant benefits in inhibition, while longitudinal physical activity programs may cause significant benefits in working memory and cognitive flexibility[24)]. The results obtained in the present study reflect a disparate relationship between the executive domains and defining components of the physical condition, observing how inhibition/interference is influenced by resistance strength and balance, working memory is influenced by explosive strength and flexibility, cognitive flexibility by resistance strength and agility/velocity, and lastly social skills by resistance strength.

The limitations of the present study include its cross-sectional design, which does not facilitate the determination of cause-

Table 2. Partial correlations between physical fitness and academic achievement (n=713)

		Resistance strength	Explosive strength	Agility and speed		Aerobic endurance		Balance score	Flexibility	
		30-second chair stand test (n)	Standing broad jump (cm)	10 × 5 shuttle run (s)	Quadrant jump test (n)	20 m shuttle run (n)	6 min endurance run	BOT-2: Balance score	Sit and reach test (cm)	Back scratch test (cm)
Academic achievement	-	0.41*	0.32**	−0.30**	0.33*	0.49*	0.49*	0.21	0.37*	0.35**
Resistance strength	30-second chair stand test (n)	-	0.14*	−0.05	0.23*	0.21*	0.21*	0.07	0.41*	0.10**
Explosive strength	Standing broad jump (cm)		-	−0.42*	−0.42*	0.38*	0.38*	0.01	0.22*	0.09**
Agility and speed	10 × 5 shuttle run (s)			-	−0.21*	−0.34*	−0.35*	0.19*	−0.15*	0.19**
	Quadrant jump test (n)				-	0.25*	0.23*	0.07	0.23*	0.05*
Aerobic endurance	20 m shuttle run (n)					-	0.99*	0.18*	0.18*	0.15*
	6 min endurance run						-	0.20*	0.19*	0.14*
Balance score	BOT-2: Balance score							-	−0.06	−0.29
Flexibility	Sit and reach test (cm)								-	0.11**
	Back scratch test (cm)									-

Analysis adjusted for age, gender and school.
**p<0.001; *p<0.05.

Table 3. Association of physical fitness with executive function in adolescents (n=713)

		Inhibition/Interference	Working memory		Processing speed	Cognitive flexibility	Social skills
		Stroop test	Wechsler memory scale	Wechsler memory scale retard	Symbol digit modality test	Trail making test-A	Messy scale
Predictor variables		β	β	β	β	β	β
Resistance strength	30-second chair stand test (n)	0.22*	−0.02	−0.03	−0.07	−0.38**	0.36*
Explosive strength	Standing broad jump (cm)	0.01	−0.01	−0.01*	0.01	−0.03	0.01
Agility and speed	10 × 5 shuttle run (s)	−0.07	−0.03	−0.06	0.22	−0.21	0.35
	Quadrant jump test (n)	0.09	0.02	−0.01	0.19	−0.31*	0.06
Aerobic endurance	20 m shuttle run (n levels)	−1.44	0.39	0.01	1.79	−0.21	2.08
	6 min endurance run (m)	0.02	−0.01	0.01	−0.02	0.01	−0.02
Balance score	BOT-2 balance score	−0.87*	−0.07	−0.02	0.43	0.19	−0.25
Flexibility	Sit and reach test (cm)	0.09	0.04*	0.04*	0.05	−0.11	0.01
	Back scratch test (cm)	0.04	−0.05*	−0.03*	−0.04	0.09	−0.01

**p<0.001; *p<0.05.

effect directionality and, due to the scarcity of investigations that relate the components of physical condition with executive functions, these data should be interpreted with caution. The strengths of the study, however, are linked to its sample size and sample randomization, which make it possible to adequately generalize the data, as well as to obtain a standardized assessment of data linked to physical condition and executive functions in adolescents.

The main findings of this study indicate that the AA of secondary school students is influenced by force (resistance and explosive), agility and speed, aerobic endurance, and flexibility, but not by balance. From a cognitive point of view, AA is influenced by inhibition/interference, working memory and processing speed. In contrast, cognitive flexibility and social skills have not attested any correlation with AA.

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Conflict of interest

None.

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