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ATTENTION AND EXECUTIVE FUNCTION ARE PREDICTED BY ANTHROPOMETRIC INDICATORS, STRENGTH, MOTOR PERFORMANCE, AND AEROBIC FITNESS IN CHILDREN AGED 6–10 YEARS

original paper
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ABSTRACT
Purpose. To predict attention and executive function in children through anthropometric, physical, and motor indicators.
Methods. A cross-sectional study was carried out among 271 children aged 6–10 years. Aerobic fitness was measured by using the Yo-Yo Intermittent Recovery Test Level 1, adapted for children. Motor performance was assessed with the Körperkoordinationstest für Kinder. Attention and executive function were evaluated by the cancellation test and the trail making test, part A and B.
Results. The receiver operating characteristic curve pointed the following executive function predictors, with respective cut-off points: body mass index: 0.69 (0.62–0.76), 18.62 kg/m^2; waist circumference: 0.83 (0.77–0.88), 65.53 cm; sum of skinfolds: 0.69 (0.63–0.75), 32.51 mm; percentage of body fat: 0.67 (0.61–0.74), 27.36%; Yo-Yo Intermittent Recovery Test Level 1: 0.60 (0.52–0.67), 176 m; motor quotient score: 0.97 (0.95–0.98), 69.50; score of attention: 0.82 (0.77–0.87), 77.75.
Conclusions. Executive function seems to be influenced by the anthropometric and functional components.
Key words: attention, executive function, anthropometry, motor performance, strength, physical fitness

Introduction

Higher cognitive skills seem to depend on attention and executive function (EF), which are essential for control domain, responsibility, planning, organization, creativity, and self-control [1, 2]. However, the number of attention deficits in children and adolescents increased in the last decade [2], which could negatively affect school performance and the children's development. Notwithstanding, parents, teachers, and researches are focused on investigating what could be associated with higher cognition and what factors could interfere with the cognitive process.

EF is essential for the proper functioning and cognitive development of children and adolescents because it is responsible for controlling attention, thoughts, emotions, and actions. It is divided into 3 components: inhibitory control, working memory, and cognitive flexibility [3]. In this sense, inhibitory control regulates actions of self-control and discipline to perform and complete a task, working memory allows to maintain and work with recent information, used previously by learned elements associated with the behaviour, and cognitive flexibility is defined as the ability to change and alternate thoughts about concepts or ideas in order to adapt to new demands or priorities; these processes are fundamental to good social and school development [3–5].

One of the main factors that could influence EF is physical exercise, an extremely relevant tool to act beneficially on the capacities of EF components. Its advantages are directly linked to the development of cardio-

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respiratory fitness and motor skills performance [6, 7]. Another factor that could impact on EF is the anthropometric profile, which seems to be inversely associated with the performance and development of cognitive and executive functions [8, 9].

Anthropometric profile, aerobic fitness, and motor coordination seem to influence children's school performance [10–12] and are highlighted owing to their repercussions on attention and EF. Motor development is closely related to cognitive development because of the interrelationship between brain and synaptic regions responsible for motor coordination and those responsible for EF [5, 6]. Moreover, structural neural changes as higher vascularization and cerebral neurotransmitters concentration could explain the association of high aerobic capacity and complex motor skills with EF [13], an example being a negative impact of overweight and obesity.

Obese children have an elevated incidence of chronic degenerative diseases, added to poorer aerobic and motor capacities, as well as lower performance of EF components compared with eutrophic children [14–16], particularly in tasks that require greater self-control, organization, memory, processing of cognitive information [17, 18]. Recent research has observed the effects of anthropometric components and motor coordination as possible indicators of attention and EF [7, 19–21].

However, the exact role of body composition, aerobic fitness, motor coordination, and strength as related to attention and EF, such as cut-off points of predictive variables, has not been established yet. Thus, the objective of the present study was to analyse the association of the anthropometric indicators, strength, and motor and aerobic performances with attention and EF, as well as their predictive validity. We hypothesized that children with lower motor and physical performance would have lower EF and attention values, and that overweight and obese children would present a similar response.

Material and methods

Sample

A cross-sectional study was performed among 271 school children aged 6–10 (7.53 ± 1.52) years, selected by convenience for the study; 45.75% of the group were boys. The volunteers were free from a diagnosis of neurological or psychiatric diseases, osteoarticular problems, and medication use. Participants who did not complete all the tests were excluded.

General procedures

The anamnesis was carried out by an interview with the children and with their parents separately; it was used to ensure the inclusion criteria of the study, such as schooling, history of school disapproval, applied medication, and neurological disorders. All the tests were executed in 3 days, randomly selected by the researchers. All the professionals that applied the test were previously trained and the children were previously familiarized with all instruments 1 week before the tests. The following tests were performed randomly on 3 different days: (1) the attention cancellation test and the trail making test, part A and B (applied collectively); (2) jumping tests and the Yo-Yo Intermittent Recovery Test Level 1 (Yo-Yo); (3) body composition and the Körperkoordinationstest für Kinder (KTK).

Anthropometric and body composition variables

The anthropometric and body composition variables were derived from waist and hip circumference, body mass, height, and skinfold equations and were described as follows: body mass index (BMI) = body mass (kg) / height (m)^2; conicity index = waist circumference (m) / $0.109\sqrt{\text{body mass (kg) / height (m)}}$; waist-to-hip ratio = waist circumference / hip circumference; and the sum of skinfolds ΣSF). The equation proposed by Slaughter et al. [22] was used to determine body fat percentage (%BF). The techniques adopted for the measurement of the anthropometric variables followed the procedures described by Petroski [23].

Cardiorespiratory fitness

For cardiorespiratory fitness assessment, the Yo-Yo test was used, characterized by sequences of runs with rhythm controlled by sounds of a CD player. The run distances were 16 and 20 meters, respectively, for children aged 6–9 years and for those above 9 years of age [24, 25], with the track width of 1.3 meters. The rhythm was increased progressively, with rest intervals of 10 seconds. The finish was determined when the volunteer failed to reach 16 or 20 meters, respectively. In order to guarantee the performance of the races at the speeds corresponding to each stage, one of the researchers participated in the test to ensure that the ideal pace was maintained.

Countermovement and squat jump

Power performance was measured by countermovement jump and squat jump (knees at 90°), both initiated with the parallel position of the feet. Vertical jumping performances were evaluated in accordance with the descriptions of the Bosco protocols [26].

Motor coordination

Motor coordination capacity was assessed with KTK, described previously [27, 28], by using the motor quotient (MQ). MQ was derived from the gross values obtained in each KTK task; their summation resulted in the total MQ, reflecting 5 motor coordination levels: very high, high, normal, insufficient, and disturbance in global motor coordination [28].

KTK is divided into 4 subtests to evaluate motor coordination: (1) walking backward along balance beams of different widths; (2) hopping for height; (3) jumping sideways over a slat; and (4) moving sideways on boards, as described previously [27, 28]. Scores per subtest were converted into standardized MQ based on normative data [27, 28]. These standardized scores are adjusted for age (all subtests) and gender (hoping for height and jumping sideways over a slat). The MQs of all 4 subtests were then summed and transformed into the total MQ score.

Attention and executive function

Attention and EF were evaluated by visual search of pencil and paper tests described previously [29, 30]. The attention component was measured by the average performance on the attention cancellation test and the trail making test (part A). EF was determined with the attention cancellation test, trail making test (part A), trail making test (part B), and trail making test (part B-A). All the tests had their performance established in the maximum time of 1 minute and were classified in accordance with Seabra and Martins Dias [30]. These categories were divided into 2 performance classifications: (1) high and very high; (2) medium-low and very low. Stratifications were applied to perform the receiver operating characteristic (ROC) curve analysis. Finally, the task of the participants was to mark all stimuli equal to the target stimulus (symbols) previously determined. The attention cancellation test was carried out as described by Montiel and Capovilla [29].

Statistical analysis

Descriptive statistics with mean values and standard deviations were performed. The data normality was calculated with the Shapiro-Wilk test. Student's *t*-test was used for sex comparisons. The ROC curve is generated by plotting sensitivity on the y-axis as a function of [1 – specificity] on the x-axis. Sensitivity refers to the percentage of individuals who presented the outcome (in the case of the present study, it was the high and very high classification for attention and EF) and were correctly diagnosed through the indicator (i.e. true-positive), whereas the specificity describes the percentage of individuals who did not present the outcome and were correctly diagnosed through the indicator (true-negative).

The criterion used to obtain the cut-off points was the values with sensitivity and specificity closest to each other and not lower than 60%. The statistical significance of each analysis was verified by the area under the ROC curve and by the 95% confidence interval (CI). In this sense, a perfect indicator shows the area under the ROC curve of 1.00, while the diagonal line represents the area under the ROC curve of 0.50. For an indicator to have a significant discriminatory ability, the area under the ROC curve should be between 1.00 and 0.50, and the larger the area, the greater the discriminatory power of the respective indicator. The 95% CI is another determinant of predictive capacity, and for the anthropometric, physical, and motor indicators is considered a significant predictor of the performance of attention and EF; the lower limit of the CI cannot be < 0.50 [30].

Additionally, the bivariate and multivariate regression models between the anthropometric, physical, and motor indicators for attention and EF were used to calculate the odds ratio. Pearson's linear correlation test was applied to the performance indicator. Statistical significance of the results was set for $p < 0.05$. Statistical analysis of the data was performed by using the SPSS software version 23.0.

Ethical approval

The research related to human use has complied with all the relevant national regulations and institutional policies, has followed the tenets of the Declaration of Helsinki, and has been approved by the Ethics and Research Committee of the Catholic University of Brasília.

Informed consent

Informed consent has been obtained from the legal guardians of all individuals included in this study.

Results

The anthropometric, physical, motor, attention, and EF variables are described in Table 1.

The female children obtained higher values in the variables of triceps skinfold, ΣSF, and %BF, as well as lower values in the variables of waist circumference, waist-to-hip ratio, conicity index, 90° jump, countermovement jump, Yo-Yo test distance, single-transfer platform, and score and the sum of the MQ in comparison with the male children ($p < 0.05$). In addition, there were significant differences between males and females in %BF, unipodal jump, lateral jump, MQ (score), and MQ (sum).

The areas under the ROC curve with the respective CIs for the anthropometric indicators and strength, motor, and aerobic performances in the predisposition to the performance of attention and EF are presented in Tables 2 and 3, respectively.

In Table 2, the conicity index and the countermove-

Table 1. Characterization of the sample with anthropometric data, jumps, aerobic fitness, and motor coordination depending on sex

Variables	Females (*n* = 147)	Males (*n* = 124)	*p*-value
Body mass (kg)	26.9 ± 7.4	27.7 ± 8.6	0.41
Height (m)	1.3 ± 0.1	1.28 ± 0.1	0.19
Body mass index (kg/m^2)	16.7 ± 2.5	16.7 ± 3.0	0.97
Waist circumference (cm)	56.5 ± 6.2	58.5 ± 7.5	0.02
Hip circumference (cm)	67.8 ± 7.7	68.3 ± 8.6	0.61
Waist-to-hip ratio	0.8 ± 0.1	0.8 ± 0.05	0.01
Conicity index	1.1 ± 0.1	1.2 ± 0.1	0.01
Tricipital skinfold (mm)	15.1 ± 4.5	13.4 ± 4.5	0.01
Subscapular skinfold (cm)	9.9 ± 4.9	8.9 ± 4.6	0.11
Sum of skinfolds (mm)	24.8 ± 9.1	22.3 ± 8.7	0.02
Body fat (%)	22.4 ± 6.1	20.1 ± 6.4	0.01
Jump 90° (cm)	17.3 ± 3.9	19.0 ± 3.9	0.01
Countermovement jump (cm)	17.8 ± 4.1	19.9 ± 4.3	0.01
Yo-Yo test performance (m)	228.3 ± 114.9	392.9 ± 250.6	0.01
Balance beam (score)	86.6 ± 11.5	84.4 ± 10.7	0.1
Unipodal jump (score)	79.2 ± 12.7	91.2 ± 14.5	0.01
Lateral jump (score)	83.5 ± 12.2	96.1 ± 14.1	0.01
Transference of platform (score)	66.8 ± 10.7	71.0 ± 13.7	0.01
Motor quotient (sum)	315.9 ± 32.3	340.9 ± 34.3	0.01
Motor quotient (score)	78.8 ± 15.5	86.7 ± 16.2	0.01
Attention (score)	102.9 ± 17.2	102.1 ± 15.0	0.67
Executive function (score)	105.5 ± 12.2	106.2 ± 11.44	0.62

Table 2. Area under the ROC curve and 95% CI, cut-off point, sensitivity and specificity, and odds ratio between anthropometric, aerobic, and motor performance indicators and attention

	Variables	Area under the curve (95% CI)	Cut-off point	Sensitivity/ specificity	Odds ratio
Attention	Body mass index (kg/m^2)	0.62 (0.53–0.70)	< 17.42	(0.83–0.70)	0.47 (0.22–0.98)*
	Waist circumference (cm)	0.67 (0.59–0.75)	< 62.50	(0.91–0.72)	0.23 (0.08–0.61)*
	Conicity index	0.51 (0.44–0.59)		Not predictive	
	Sum of skinfolds (mm)	0.64 (0.57–0.71)	< 31.50	(0.95–0.70)	0.12 (0.38–0.41)*
	Body fat (%)	0.62 (0.54–0.70)	< 26.68	(0.90–0.80)	0.24 (0.1–0.60)*
	Yo-Yo test performance (m)	0.56 (0.50–0.64)	> 124	(0.98–0.88)	7.93 (1.05–59.78)*
	Jump 90° (cm)	0.44 (0.36–0.52)		Not predictive	
	Countermovement jump (cm)	0.42 (0.34–0.50)		Not predictive	
	Motor quotient (score)	0.68 (0.60–0.76)	> 69.50	(0.88–0.73)	2.80 (1.20–6.52)*

ROC – receiver operating characteristic, CI – confidence interval
* significant values according to 95% CI

Table 3. Area under the ROC curve and 95% CI, cut-off point, sensitivity and specificity, and odds ratio between anthropometric, aerobic, and motor performance indicators and executive function

	Variables	Area under the curve (95% CI)	Cut-off point	Sensitivity/ specificity	Odds ratio
Executive function	Body mass index (kg/m²)	0.69 (0.62–0.76)	< 18.62	(0.95–0.80)	0.33 (0.12–0.87)*
	Waist circumference (cm)	0.83 (0.77–0.88)	< 65.53	(0.98–0.88)	0.11 (0.01–0.85)*
	Conicity index	0.57 (0.50–0.65)		Not predictive	
	Sum of skinfolds (mm)	0.69 (0.63–0.75)	< 32.51	(0.98–0.88)	0.12 (0.02–0.91)*
	Body fat (%)	0.67 (0.61–0.74)	< 27.36	(0.95–0.85)	0.26 (0.08–0.88)*
	Yo-Yo test performance (m)	0.60 (0.52–0.67)	> 176	(0.83–0.70)	2.38 (1.17–4.84)*
	Jump 90° (cm)	0.33 (0.26–0.41)		Not predictive	
	Countermovement jump (cm)	0.30 (0.23–0.36)		Not predictive	
	Motor quotient (score)	0.97 (0.95–0.98)	> 69.50	(1–0.72)	1.48 (1.34–1.60)*

ROC – receiver operating characteristic, CI – confidence interval
* significant values according to 95% CI

Table 4. Linear Pearson correlation between the anthropometric variables, power strength, aerobic fitness, and motor coordination and attention and executive function

Variables	Attention (*r*)	Executive function (*r*)
Body mass index (kg/m²)	–0.26	–0.35
Waist circumference (cm)	–0.38	–0.56*
Hip circumference (cm)	–0.42*	–0.62*
Waist-to-hip ratio	0.07	0.15
Conicity index	–0.11	–0.16
Sum of skinfolds (mm)	–0.30	–0.38
Body fat (%)	–0.28	–0.36
Jump 90° (cm)	–0.16	–0.28
Countermovement jump (cm)	–0.15	–0.26
Yo-Yo test performance (m)	0.14	0.15
Motor quotient (score)	0.43*	0.63*
Attention (score)	1.0	0.75*
Executive function (score)	0.75*	1.0

* statistically significant correlation, $p < 0.05$

ment and 90° jumps did not present significant discriminatory power of attention performance (95% CI < 0.50). On the other hand, the analysis of the BMI, waist circumference, ΣSF, %BF, Yo-Yo test performance, and MQ (score) demonstrated significant prediction of attention performance (95% CI > 0.50).

In addition, children that reached values of BMI < 17.42 kg/m², waist circumference < 62.50 cm, ΣSF < 31.50 mm, and %BF < 26.68 had 53–88% higher odds of achieving high and very high attention performance. Children who ran the distance > 124 m in the Yo-Yo test and had an MQ score > 69.50 had 7.93 and 2.80 times more chances to reach the high and very high performance classification on attention, respectively.

In the analysis of the anthropometric, motor, and aerobic performance indicators, the significant predictors of EF performance (95% CI > 0.50) were BMI, waist circumference, ΣSF, %BF, Yo-Yo test performance, and MQ score.

In addition, the results of the odds ratio presented higher odds of obtaining a high and very high performance rating of EF in children who reached the values of BMI < 18.62 kg/m², waist circumference < 65.53 cm, ΣSF < 32.51 mm, and %BF < 27.36, representing the ratio of 67–89% (Table 3). Children who crossed a distance > 176 m in the Yo-Yo test and reached a score of MQ > 69.5 were 2.38 and 1.48 times more likely to reach the high and very high performance rating for EF, respectively.

The results of the correlation between the anthropometric variables, aerobic fitness, and motor coordination with attention and EF were demonstrated in Table 4. A moderate negative correlation was observed for attention and the hip circumference variables (r = –0.42), and a moderate positive correlation was reported for MQ score (r = 0.43). For EF, there was a moderate correlation with waist circumference (r = –0.56), hip circumference (r = –0.62), and MQ score (r = 0.63). Attention and FE correlated strongly (r = 0.75).

Discussion

The main results of the study demonstrated a predictive capacity of the anthropometric indicators: 53–88% for attention and 67–89% for EF. Cut-off points established by the ROC curve show values of BMI and %BF within the classification for eutrophic children of the age group analysed. The aerobic and motor performance was evidenced to directly influence attention and EF, reflecting the chance of children with greater aerobic fitness to reach 7.93 times higher performance in attention and 2.38 times in EF. Children who achieved a motor performance greater than the 69.5 score in the KTK test are 2.80 times more likely to achieve higher attention performance and 1.48 times more likely to achieve higher EF performance. The power showed no influence on attention or EF.

Although there are predictions of the variables mentioned above with EF and attention, some of them also present moderate correlations, such as waist circumference and MQ with negative and positive correlation, respectively, showing a possible relation of anthropometry and motor profile with EF and attention [31]. This model suggests that motor coordination may be a factor that could positively influence EF, and hence it could be a novel strategy for executive improvement. Further research is suggested in order to consolidate this evidence, as the cross-over design of our study does not allow to determine causality between the variables. However, an important finding of the present study is the bound between the correlation and the odds ratio of motor coordination and anthropometric variables with EF. In this sense, corroborating the present study, Schmidt et al. [32] verified motor core EFs and academic achievement in 236 children. The results suggested that each of the 3 motor abilities was positively related to children's academic achievement. Moreover, Geertsen et al. [5] observed a strong positive association of aerobic and motor performance with the best attention and EF responses in children aged 8–10 years.

Other studies reported similar results in children aged 7–10 years, highlighting the positive relationship of greater cerebral electrical activity, precision, memory, and academic ability with greater aerobic and motor competence; however, statistical power had no relation with these highlighted components [10, 13, 16].

Regarding body composition, higher anthropometric and body composition values seem to negatively affect EF and attention capacities, and also anthropometric and body composition values are highlighted in the eutrophic classification patterns, with a positive effect on attention and EF. Thus, Kamijo et al. [33] reinforce the findings of the present study, since they observed that children with high BMI and %BF presented lower inhibitory control capacity compared with those with normal body mass, a phenomenon that may directly influence school performance, as it was emphasized that body composition could directly impact on cognitive functions [33], a favourable condition for impairment of social environment, aerobic, strength, motor, and attention performance, as well as EFs [31].

Overweight and obesity, even during childhood, is a negative factor for brain development, a condition favourable to the development of neuro-structural deficits, and may negatively affect EF, as well as less cortex activation [16]. However, children in adequate body condition can benefit in physical, health, and EF aspects. Thus, it was observed that children with greater aerobic fitness and motor coordination were eutrophic and, moreover, these factors were associated with a higher development of attention and EF process in the following mechanism: aerobic fitness causes neurofunctional changes in the brain regions, such as increase in the vascularization and concentration of neurons, providing conditions for better cognitive processing and oxygenation.

Motor coordination is related to cerebral organization and its control by the responsibility of the cerebellum and its neural circuits interconnected with the prefrontal cortex. Thus, a motor action with greater levels of complexity will have the activation of its neural circuits recruited by the cerebellum and this electric activity will also act in the regions responsible for the control of attention and EF [4].

In this sense, physical exercise seems efficient not only for motor and cardiovascular development, but also for cognitive and executive gains in children and adolescents [34]. The positive effect of physical exercise on EF is better explored when acting with new and complex motor tasks. In these activities, we have a greater neural and cognitive recruitment, which can be explained in 3 domains: cognitive, associative, and autonomous, represented from the learning of the movement to its automatization; therefore, during the learning phases, there is a greater demand for and recruitment of attention in the initial phases, related to when the movement becomes autonomic [35, 36]. Indeed, it is interesting to diversify and explore the complexity of the movement to act on executive benefits; this integrated action will provide the specific neural adaptations responsible for motor and cognitive abilities, offering better answers with regard to EF [6].

In this context, it was observed that EF may be vulnerable to environmental interference. In addition, aerobic fitness, motor coordination, and body composition seem to interfere with EF response [37]. Therefore, preventing overweight, obesity, and sedentariness in childhood could be a key component of better academic and social performance [38, 39].

The present study has some limitations that should be mentioned. Firstly, one must consider the impossibility to define the neurophysiological mechanisms involved in the results found because of the cross-sectional design, which does not allow to establish a cause-effect relationship. Secondly, we did not evaluate the maturity status of the children, and this factor could influence attention and EF [37]; however, the effects of maturity would also impact on cardiorespiratory, motor, and anthropometric variables. The children involved in the study sample were in the age group of 6–10 years, and probably in their predominance they were not sexually mature.

However, regardless of the maturational process, the effects of acute and chronic intervention in physical exercises that consider aerobic fitness and motor exercise in improving the performance of EF in different groups are observed in studies, the body composition acts in a way opposite to the above [8, 9, 30, 34, 40–42].

In contrast, the present study identified anthropometric, aerobic, and motor performance indicators with discriminatory power over attention and EF regardless the sex. In addition, the need for future studies that would investigate the application of these indicators to cognitive performance is highlighted.

Another interesting result of the study was the lack of difference between the male and female children in attention and EF. In contrast, the literature suggests that girls of 6–10 years of age may present greater executive control compared with boys; however, the EFs did not differ between the groups. This response may be due to the boys achieving greater motor and cardiorespiratory performances than the girls, a condition that may have elsewhere influenced the difference in EFs between groups [3, 10, 12].

Conclusions

Recent research [1, 7, 13, 15] has presumed that body composition, cardiorespiratory fitness, and motor coordination are possible indicators of association in forming attention and EF; however, few studies have been performed in childhood to investigate the predictive capacity of these variables as possible indicators of the performance of attention and EF. This study explored these variables as predictors and their respective cut-off points of attention and EF in children. Therefore, it is concluded that EF seems to be directly influenced by anthropometric components, as well as aerobic and motor performance since the anthropometric, aerobic, and motor variables were pointed out as interesting indicators of EF promotion.

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Disclosure statement

No author has any financial interest or received any financial benefit from this research.

Conflict of interest

The authors state no conflict of interest.

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