Cognitive development and non-aerobic physical fitness in preschoolers: a longitudinal study

Desenvolvimento cognitivo e aptidão física não-aeróbica em pré-escolares: um estudo longitudinal

Abstract

Introduction: Early childhood is the most critical period of healthy motor and cognitive development in human life and increased physical activity may provide health benefits across childhood and adolescence. Objective: The aim of this study was to quantify the relationship between non-aerobic physical fitness and cognitive development in preschool children. Methods: Participants included children from a longitudinal study in the city of Rio de Janeiro, Brazil (N=1380, first year; N=1320, second year). Non-aerobic physical fitness was assessed with the Sitting-Rising Test (SRT) and cognitive development with the Performance Indicators for Primary Schools (PIPS). Results: non-aerobic physical fitness and cognitive development (0.25 for language and 0.17 mathematics, $p<0.05$) were positively correlated. The hierarchical linear regression models revealed that baseline measurements of non-aerobic physical fitness presented a small but significant association with prospective mathematic performance but not language after controlling for confounder variables (ES=0.16 for mathematics first year; ES=0.11 for mathematics second year). Conclusions: These results suggest an association between non-aerobic physical fitness and children's cognitive development in early school years.

Keywords: Early childhood. Cognition. Motor skills. Longitudinal study.

Resumo

Introdução: A primeira infância é o período mais crítico do desenvolvimento motor e cognitivo saudável na vida humana e o aumento da atividade física pode trazer benefícios à saúde durante a infância e a adolescência. Objetivo: O objetivo deste estudo foi quantificar a relação entre aptidão física não-aeróbica e desenvolvimento cognitivo em pré-escolares. Métodos: Os participantes incluíram crianças de um estudo longitudinal na cidade do Rio de Janeiro, Brasil (N = 1380, primeiro ano; N = 1320, segundo ano). A aptidão física não-aeróbica foi avaliada com o Teste Sentar-Levantar (TSL) e o desenvolvimento cognitivo com o Performance Indicators for Primary Schools (PIPS). Resultados: a aptidão física não-aeróbica e o desenvolvimento cognitivo correlacionaram-se positivamente (0,25 para linguagem e 0,17 matemática, $p <0,05$). Os modelos de regressão linear hierárquica revelaram que as medidas iniciais de aptidão física não-aeróbica apresentaram uma pequena, mas significativa associação com o desempenho matemático futuro, mas não com linguagem após o controle de variáveis confundidoras (ES = 0,16 para matemática no primeiro ano; ES= 0,11 para matemática no segundo ano). Conclusões: esses resultados sugerem uma associação entre a aptidão física não-aeróbica e o desenvolvimento cognitivo das crianças nos primeiros anos escolares.

Unitermos: Primeira infância. Cognição. Habilidades motoras. Estudo longitudinal.

Introduction

Human development is a diverse and complex area of study that can be divided into the cognitive, motor, affective (socioemotional) and physical domains (Bloom, 1956; Payne & Isaacs, 2011), where the motor dimension assumes a close relationship with cognitive aspects

(Gallahue et al., 2019; Piaget, 1952). Throughout childhood, there are periods when learning or skill improvements occur faster and easily, in what is considered “windows of opportunity” or sensitive/critical periods (Knudsen, 2004; Lent & Oliveira, 2018). Early childhood is the most critical and rapid period of complete and healthy motor and cognitive development in human life (UNICEF, 2017) and increased stimulation by physical activity or intervention programs may provide health benefits across childhood and adolescence (Zeng et al., 2017). Thus, a more comprehensive understanding of the relationship between cognition and aspects of motor development can offer relevant information for the elaboration of public policies in the educational area.

Although interest in the relationship between exercise and cognition has grown in the past decade, the literature on the benefits of physical activity and physical fitness on cognition has been mostly addressed in research with older children or adults (Stillman et al., 2016). Systematic reviews on this topic (Bidzan-Bluma & Lipowska, 2018; Santana et al., 2017) indicated a positive association between physical fitness and cognition, however, they pointed to the need for more research on this topic, mainly coming from studies with a design that allows a higher degree of causal inference (Randomized Control Trials – RCTs or longitudinal studies). Moreover, since the physical fitness-cognition research has a greater focus on the aerobic component of physical fitness (Stillman et al., 2016), there is a paucity of scientific data regarding the non-aerobic components and their relationship with cognitive development in preschool children (Houwen et al., 2017; Kao et al., 2017).

Physical fitness can be operationalized as a set of measurable health and skills-related attributes including cardiorespiratory (aerobic) fitness, muscular strength, power and endurance, body composition, flexibility, balance, agility, coordination and reaction time (American College of Sports Medicine, 2017; Caspersen et al., 1985). This set of attributes can be divided into two dimensions: the aerobic dimension (aerobic fitness), having as a component the individual's aerobic/cardiorespiratory condition; and the non-aerobic dimension (non-aerobic physical fitness), which include at least four components: muscle strength/power, balance, flexibility and body composition (Araujo, 2015). The components of non-aerobic physical fitness, also called musculoskeletal fitness, can be considered the basis for performing tasks of gross and fundamental motor skills, and they have been positively associated with cognitive and academic performance in children and adolescents from 4 to 18 years old children (de Bruijn et al., 2019; Esteban-Cornejo et al., 2014; van der Fels et al., 2014).

Thus, in order to contribute to the body of knowledge in the area of physical fitness-cognition research in early childhood, this longitudinal study aims to analyze the association between non-aerobic physical fitness and cognitive development in the 1st and 2nd year of preschool in Brazilian children. The research question is: "Is there an association between non-aerobic physical fitness and cognitive development in children enrolled in preschool – ages 4 and 5?"

Cognition, Physical Fitness and Motor Skills

Studies that investigated the relationship between components of physical fitness and cognition in older children and adolescents found a positive relationship between these variables. A cross-sectional study (Kao et al., 2017) investigated the relationship between components of physical fitness, and working memory in pre-adolescents, and demonstrated that both components of physical fitness were positively related to working memory. Academic performance measurements (mathematics and reading) were not significantly related to the non-aerobic component (musculoskeletal fitness), while the aerobic component was only related to the performance in mathematics. A longitudinal study with 1,286 students from 14 public schools showed that adolescents who improved their aerobic fitness or remained in the healthy aerobic fitness zone for three years presented significantly better results in language but not in mathematics skills (Sardinha et al., 2016). Aadland et al. (2017) used data from the Active Smarter Kids trial in a sample of 1,129 10-year-old children, followed over seven months, to investigate if executive function mediated the prospective relationships between indices of physical activity and academic performance. They did not find any potential moderating influence of executive function on physical activity and academic performance; however, a small mediation effect of executive function was observed for the relation between motor skills and academic performance in numeracy. Similarly, Davis et al. (2011) examined the influence of participating in regular aerobic exercise (after school exercise program) on executive functions and academic performance in elementary school children in a randomized controlled trial. This study showed that physically active children who participated in 40 minutes of exercise per school day experienced significant improvements in mathematics performance as compared to sedentary peers after controlling for race, parent education, and baseline scores. In addition, brain areas associated with executive function (prefrontal and parietal regions) have shown greater activity in those physically active.

The evidence described suggests that there is a differential relationship between physical fitness components and academic domains: some studies have reported positive links between aerobic fitness with mathematics, but not with reading, whereas others have found improvements in language but not in mathematics (Donnelly et al., 2016).On the other hand, the effects of physical activity interventions on the academic performance of children and adolescents tend to be larger on mathematics skills than on language skills (Alvarez-Bueno et al., 2017; van Dusen et al., 2011) and executive functions also tend to be stronger predictors of performance in mathematics than in language (Pascual et al., 2019). So, in children between 5- to 10-year-old, one possible explanation is that executive functions could mediate the path of physical fitness-cognition relationship especially on mathematic skills (Aadland et al., 2017; Alloway & Archibald, 2008; Roebers et al., 2014).

Investigations focusing on early childhood also indicate positive relations between physical fitness components and cognition domains. In a cross-sectional study, children at risk for motor coordination difficulties, assessed with the Movement Assessment Battery for Children-2, showed significantly worse performance in executive functions (rated by parents) compared with typically developing children, independent of age, sex, socioeconomic status and attention-deficit-hyperactivity disorder (ADHD) symptomatology (Houwen et al., 2017). The information on the trajectory of gross motor skills from birth to 4 years of age is a significant predictor of both working memory and processing speed in school-aged children (Piek et al., 2008). A longitudinal study (Niederer et al., 2011) with a sample of preschool children had shown that baseline results of aerobic (shuttle run test) and some non-aerobic fitness components (agility and dynamic balance) were associated with improvements in executive functions nine months later, where modest associations were observed between aerobic fitness with attention and dynamic balance with working memory. Wick, Kriemler and Granacher (2021) examined the effects of an exercise program on enhancing different aspects of physical fitness (muscle strength/power, balance, coordination, and motor skills) and cognitive performance in preschool children. The results suggest that the intervention group (10-week exercise program) had higher gains in jump performance (muscle power), with a similar trend toward improvements in attentional capacity, compared with active control children who followed the regular kindergarten curriculum of preschool children.

Methods

Participants and study design

The data used in the paper is part of a larger longitudinal preschool study undertaken in the city of Rio de Janeiro, Brazil. More detailed information regarding the study design, sample and instruments were described elsewhere (Bartholo et al., 2020). The Ethics Committee from the Federal University of Rio de Janeiro (Philosophy and Human Sciences Center) approved the research. Informed written consent was obtained from parents/guardians in addition to the children's oral consent.

The study presents a probabilistic single-stage cluster sample (school as the primary sampling unit) stratified by characteristics of preschool provision and local authority of the public municipal system. The study considered all the children enrolled in the first year of preschool (first year of compulsory education in the Brazilian educational system), of 46 public schools in the year 2017, as eligible to participate in the study. Children with visual and hearing impairment or inability to participate in physical assessments were excluded from the analysis. Those diagnosed with special educational needs, such as ADHD, Down syndrome, autism spectrum disorder, participated in the study and were included in the analysis. A total of three waves of data collection for the cognitive and non-aerobic physical fitness were conducted: a) 1st wave at the beginning of the first year in school (March/April 2017); b) 2nd wave at the end of the first year in school (November/December 2017); c) 3rd wave at the end of the second year in school (November/December 2018). For this study, only those children who provided data on both cognitive and non-aerobic physical fitness measurements at baseline and follow-up were included. A total of 1,380 children provided data for baseline and 2nd wave whereas for baseline and 3rd wave, 1,320 children.

Measurement of variables

Non-aerobic physical fitness

The non-aerobic physical fitness was assessed using the Sitting-Rising Test (Araujo, 1999). Through the assessment of the motor skills for both sitting and rising from the floor, the SRT evaluates the components of non-aerobic physical fitness (muscle strength, balance, flexibility, body composition) simply and reliably, which presents several advantages such as short application time (less than 5 minutes), high safety and meaningless cost[1](Lira & Araújo, 2000). Research using the SRT included populations from early childhood (Aguiar et al., 2019; Ventista, 2015) to adulthood (Brito et al., 2014).

The measurement of the SRT consists of simply quantifying how many supports (hands and / or knees or, still, the hands on the knees or legs) the individual uses to sit and rise from the floor. Independent scores are given for each of the two acts - sitting and rising. The maximum score is 5 for each of the two acts. Half a point is subtracted for any noticeable unbalance. The best result of the two attempts for each act is chosen as representative of the individual. A composite score is obtained from the sum of the sitting and rising actions, allowing a total of 21 possible points on a scale ranging from 0 to 10 (0, 0.5, 1,...., 9.5, 10). Previous studies have shown that SRT scoring is highly reliable (Lira & Araújo, 2000).

Cognitive development

The cognitive development was assessed using an adapted version of the Performance Indicator for Primary Schools (PIPS) (Bartholo et al., 2020; Tymms et al., 1997, 2004). The instrument is composed of a set of dimensions of cognitive assessment measurements, such

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[1] SRT should be administered on a flat, non-slip surface. To perform the test, the individual must be barefoot, without socks and without clothing that may restrict their mobility. The evaluator requests that the individual, from the standing position, perform the action of sitting without using the hands (or supports) and without unbalance. On the ground, the evaluator requests that the individual perform the action of rising without using the hands (or supports) and without unbalance.

as: a) handwriting – the child is requested to write his name; b) vocabulary – identifying objects in a series of images; c) ideas about reading – to assess concepts about print; d) phonological awareness – rhymes and word repetition; e) identification of letters; f) recognition of words and reading – sentences and comprehension; g) ideas about mathematics – understanding of mathematical concepts; h) counting and numbers; i) addition and subtraction problems without symbols; j) shapes identification; k) digit Identification; and l) mathematical problems including sums with symbols[2]. Measurements for the language (items "b" to "f") and mathematics (items "g" to "l") sections were constructed using Rasch modeling (Bond & Fox, 2015), using the Winstep software.

Body composition

Additional information for the height and weight of the children were collected and the Ponderal Index (PI) was calculated at the start of compulsory education. Height was measured in the nearest millimeter (Alturexata stadiometer) and children were weighed to the nearest 0.1 kg (Lider portable scale P150), with bare feet and wearing light clothing. PI was calculated as height (cm)/ $\sqrt[3]{\text{weight (kg)}}$. Height and weight were only collected once – during the 1st wave. The use of a body composition measure as a control variable is important because the actions of sitting and rising from the floor are a basic human movement which is related to muscle strength and power, lower limb flexibility, and motor coordination, and those are influenced by body dimensions (Ricardo & Araújo, 2001).

Socio economic status (SES)

The SES index used Rasch measurement, including items from parents' questionnaire related to durable assets ownership and access to amenities (e.g. car, washing machine,

[2] For a more detailed presentation of the PIPS test, its potential uses and limitations, see(Tymms et al., 1997).

computer, tablet, printer, internet and cable TV services), parents' education level, household crowding and poverty (beneficiaries of cash transfer programs).

Procedure

In each wave of data collection, children were individually tested (in small groups of two or three) in a quiet room at their school. The first assessment was the SRT, presented as a "challenge"[3] to increase motivation and create a friendly atmosphere. The evaluation process lasted between 15 and 25 minutes and was applied by researchers that were previously trained in the assessment tools. School staff members could stay in the same room as the children during assessments if requested.

Data analyses

For descriptive statistics, data are presented as mean and standard deviation or proportions. Bivariate relationships between all key variables were examined using Spearman's correlations. To assess the longitudinal relationship between non-aerobic physical fitness and cognitive development, hierarchical linear regression models were estimated, using the cognitive measures in the 2nd and 3rd waves of the longitudinal study as outcome variables and the non-aerobic physical fitness measure as a predictor, adjusting for confounding variables (including baseline cognitive development measures). The analyses were made using SPSS version 23. All testing was two-tailed and at a significance level of 5% of probability. Table 1 presents a description of all variables included in the models.

[3] The researchers asked the children: "*Let's do a challenge! Can you follow these movements just like this little guy? Try to sit and then stand up, slowly and without the assistance of your arms or knees!*" Then, a short cartoon video with the correct actions of sitting and rising from the floor was presented.

Table 1. *variables used in the hierarchical linear models.*

Name	**Type**	**Description**
Dependent variables		
Language 2nd Wave	Continuous	Language measurement at the end of first year of preschool
Language 3rd Wave	Continuous	Language measurement at the end of second year of preschool
Mathematics 2nd Wave	Continuous	Mathematics measurement at the end of first year of preschool
Mathematics 3rd Wave	Continuous	Mathematics measurement at the end of second year of preschool
Independent variables		
Language baseline (1st Wave)	Continuous	Language measurement at the beginning of first year of preschool
Mathematics baseline(1st Wave)	Continuous	Mathematics measurement at the beginning of first year of preschool
Sex	Dummy	0= girl1= boy
Age (years)	Continuous	Age at the data collection

Sitting-Rising Test	Continuous	non-aerobic physical fitness measure in the beginning of first year of preschool
Socio economic status (SES)	Continuous	Index with information about socioeconomic status, housing conditions and the home learning environment
Special Educational Needs (SEN)	Dummy	Children diagnosed with learning problems or disabilities (ADHD, Down syndrome, autism spectrum disorder)
Ponderal index	Continuous	Height (cm) / $\sqrt[3]{\text{weight (kg)}}$

Results

Descriptives

Table 2 shows the descriptive statistics of the participants in each time point of data collection. The performance of preschool children in the SRT indicates that most of them achieved high scores. Indeed, the most frequent score was the perfect “10”. This result became more visible over time, which indicates a ceiling effect for this age group.

Table 2. *Descriptive statistics of the participants*

	1st Wave	2nd Wave	3rd Wave
Age*	4.41 (0.36)	5.08 (0.36)	6.08 (0.36)

Sex (boy) †	52.9%	53.2%	52.1%
Ponderal index*	40.74 (2.02)	-	-
SES*	0.30 (1.41)	0.29 (1.46)	0.25 (1.43)
SEN	2,1%	-	-
SRT*	8.48 (1.44)	8.98 (1.30)	9.14 (1.40)
PIPS			
Language*	-0.28 (0.96)	0.27 (0.89)	0.92 (0.98)
Mathematics*	-2.79 (1.33)	-1.85 (1.39)	-0.59 (1.56)

Note: SES = Socio economic status; SEN = Special Educational Needs; PIPS = Performance Indicator for Primary Schools; SRT = Sitting-Rising Test *mean (SD) †proportions

Bivariate correlations

Correlations between all key variables in the first wave of data collection are presented in Table 3. The SRT was weakly correlated with statistically significant coefficients with all measurements except SES. Performance in both cognitive tests was positively associated with the SRT. Older children showed better performance in SRT as well as those with higher values of Ponderal Index (indicating a better height/weight relationship). Sex (coded boy = 1) presents a negative correlation with SRT, indicating that girls outperformed boys in this task. Children diagnosed with SEN showed worse performance in SRT.

Table 3. *Bivariate correlations between all key variables (1st Wave)*

	1.	2.	3.	4.	5.	6.	7.	8.
1. SRT	-	**.25**	**.17**	**.19**	**.23**	**-.15**	-.01	**-.10**
2. Language		-	**.58**	**.28**	.02	**-.10**	**.25**	**-.08**
3. Mathematics			-	**.27**	.01	-.04	**.24**	.01

4. Age	-	**.21**	-.02	-.02	-.01
5. Ponderal Index		-	-.01	-.05	.02
6. Sex (boy)			-	.03	**.06**
7. SES				-	**.05**
8. SEN					-

Note: SES = Socio economic status; SRT = Sitting-Rising Test; SEN = Special Educational Needs. Significant correlation coefficients are in bold. $p<0.05$

Hierarchical linear regression analyses

Table 4 and Table 5 (first and second year of preschool, respectively) presents the four-step hierarchical regression analyses that were performed for language and mathematics performance as dependent variables to examine the relationship of non-aerobic physical fitness measure after controlling for potential confounders (baseline cognitive measures, sex, age, body composition and socioeconomic status). After that, effect sizes for the coefficients of the SRT were calculated using the approach suggested by Tymms (2004).

To examine the unique influence of the Sitting-Rising Test, the demographic variables were entered in Model 1 (sex, age, diagnose of special educational needs and socioeconomic status). Then, children's baseline cognitive measure was entered (Model 2). Model 3 added the SES at the school level. At last, in Model 4, the Ponderal index (body composition) was included. To understand the impact of the considerable reduction of cases due to the use of the Ponderal Index in Model 4, an additional model, identical to Model 3, was estimated but only using those that had body composition measures (Model 3.1).

Table 4a. *Hierarchical linear regression models estimating 2nd Wave mathematics measurements (first year of preschool)*

	Model 1	Model 2	Model 3	Model 3.1	Model 4
Mathematics					
SRT	**0.12** (0.02)	**0.05** (0.02)	**0.05** (0.02)	**0.05** (0.02)	**0.04** (0.02)
SEX	0.05 (0.06)	0.08 (0.04)	0.08 (0.04)	0.08 (0.05)	0.08 (0.05)
AGE	**0.42** (0.04)	**0.11** (0.03)	**0.11** (0.03)	**0.12** (0.03)	**0.12** (0.03)
SES	**0.33** (0.03)	**0.11** (0.02)	**0.11** (0.02)	**0.11** (0.02)	**0.12** (0.02)
SEN	-0.46 (0.27)	-0.33 (0.19)	-0.34 (0.19)	-0.31 (0.21)	-0.33 (0.21)
Mathematics (baseline)		**0.97** (0.02)	**0.97** (0.02)	**0.96** (0.03)	**0.96** (0.03)
Ponderal Index					0.05 (0.03)
SES (school)			0.03 (0.03)	0.01 (0.03)	0.01 (0.03)
Explained Variance					
school	40%	67%	66%	86%	86%
child	17%	57%	58%	57%	57%
ICC	0.04	0.04	0.04	0.02	0.02
Null Model					
Var (school)	0.10				
Var (child)	1.78				
ICC	0.05				
N	1670	1670	1670	1380	1380

Note: SES = Socio economic status; ICC = intraclass correlation coefficient; SRT = Sitting-Rising Test; SEN = Special Educational Needs. Significant correlation coefficients are in bold. $p<0.05$

Table 4b. *Hierarchical linear regression models estimating 2nd Wave language measurements (first year of preschool)*

	Model 1	Model 2	Model 3	Model 3.1	Model 4
Language					
SRT	**0.07** (0.01)	0.00 (0.01)	0.00 (0.01)	-0.01 (0.01)	-0.01 (0.01)
SEX	**-0.09** (0.04)	-0.01 (0.03)	-0.01 (0.03)	0.00 (0.03)	0.00 (0.03)
AGE	**0.26** (0.02)	**0.08** (0.02)	**0.09** (0.02)	**0.09** (0.02)	**0.08** (0.02)
SES	**0.19** (0.02)	**0.06** (0.01)	**0.06** (0.01)	**0.05** (0.02)	**0.05** (0.02)
SEN	**-0.76** (0.16)	**-0.25** (0.12)	**-0.26** (0.12)	**-0.36** (0.14)	**-0.36** (0.14)
Language (baseline)		**0.55** (0.02)	**0.55** (0.02)	**0.55** (0.02)	**0.56** (0.02)
Ponderal Index					0.02 (0.02)
SES (school)			**0.04** (0.02)	0.02 (0.02)	0.02 (0.02)
Explained Variance					
school	44%	70%	73%	76%	76%
child	20%	53%	53%	52%	52%
ICC	0.04	0.04	0.04	0.03	0.03
Null Model					
Var (school)	0.04				
Var (child)	0.67				
ICC	0.06				
N	1670	1670	1670	1380	1380

Note: SES = Socio economic status; ICC = intraclass correlation coefficient; SRT = Sitting-Rising Test; SEN = Special Educational Needs. Significant correlation coefficients are in bold. $p<0.05$

In the first year of preschool (estimating 2nd wave cognitive measures) significant associations were found between SRT and Mathematics even after controlling for contextual variables in Model 1 (ES=0.23). The inclusion of baseline mathematics scores in Model 2 explained additional variance in relation to the null model (67% at school level; 53% at child level), and the effect size for SRT reduced slightly (0.20). Entering the SES at the school level (Model 3) did not change the model, and when all predictors were added, Model 4 explained 86% of the variance at the school level and 57% at the child level. Results indicate that every additional point in the SRT at the beginning of preschool had an effect size of 0.16 in mathematics scores at the end of the year after controlling for baseline cognitive measure, sex, age, body composition, diagnose of special educational needs and socioeconomic status. The analysis of Model 3.1 shows that the reduction of cases did not have a substantial impact on the results.

For language scores, the association with SRT were significant only in Model 1 presenting an effect size of 0.38. In the subsequent models, the non-aerobic physical fitness measurement loses statistical significance, and the effect size values are negligible.

Table 5a. *Hierarchical linear regression models estimating 3rd Wave mathematics measurements (second year of preschool)*

	Model 1	Model 2	Model 3	Model 3.1	Model 4
Mathematics					
SRT	**0.12** (0.02)	**0.06** (0.02)	**0.06** (0.02)	**0.06** (0.02)	**0.05** (0.02)

SEX	**0.17** (0.07)	**0.21** (0.06)	**0.21** (0.06)	**0.17** (0.06)	0.17 (0.06)
AGE	**0.42** (0.04)	**0.15** (0.04)	**0.15** (0.04)	**0.16** (0.04)	**0.16** (0.04)
SES	**0.32** (0.03)	**0.13** (0.03)	**0.12** (0.03)	**0.11** (0.03)	**0.11** (0.03)
SEN	**-1.48** (0.31)	**-1.30** (0.25)	**-1.31** (0.25)	**-1.26** (0.28)	**-1.28** (0.28)
Mathematics (baseline)		**0.87** (0.03)	**0.87** (0.03)	**0.86** (0.04)	**0.86** (0.04)
Ponderal Index					0.06 (0.03)
SES (school)			0.06 (0.03)	0.07 (0.04)	0.07 (0.04)
Explained Variance					
school	50%	68%	71%	79%	79%
child	19%	45%	45%	43%	43%
ICC	0.04	0.04	0.03	0.02	0.02
Null Model					
Var (school)	0.15				
Var (child)	2.29				
ICC	0.06				
N	1603	1603	1603	1320	1320

Note: SES = Socio economic status; ICC = intraclass correlation coefficient; SRT = Sitting-Rising Test; SEN = Special Educational Needs. Significant correlation coefficients are in bold. $p<0.05$

Table 5b. *Hierarchical linear regression models estimating 3rd Wave language measurements (second year of preschool)*

	Model 1	Model 2	Model 3	Model 3.1	Model 4

Language					
SRT	**0.07** (0.01)	0.00 (0.01)	0.00 (0.01)	0.00 (0.01)	0.00 (0.01)
SEX	**-0.14** (0.04)	-0.05 (0.03)	-0.05 (0.03)	-0.06 (0.04)	-0.06 (0.04)
AGE	**0.24** (0.02)	**0.09** (0.02)	**0.09** (0.02)	**0.09** (0.02)	**0.09** (0.02)
SES	**0.21** (0.02)	**0.09** (0.02)	**0.09** (0.02)	**0.08** (0.02)	**0.08** (0.02)
SEN	**-0.95** (0.18)	**-0.41** (0.15)	**-0.42** (0.15)	**-0.41** (0.16)	**-0.41** (0.16)
Language (baseline)		**0.53** (0.02)	**0.53** (0.02)	**0.52** (0.02)	**0.52** (0.02)
Ponderal Index					0.01 (0.02)
SES (school)			**0.06** (0.02)	0.05 (0.03)	0.05 (0.03)
Explained Variance					
school	43%	52%	57%	56%	56%
child	27%	51%	51%	51%	51%
ICC	0.08	0.10	0.09	0.09	0.09
Null Model					
Var (school)	0.10				
Var (child)	0.86				
ICC	0.10				
N	1603	1603	1603	1320	1320

Note: SES = Socio economic status; ICC = intraclass correlation coefficient; SRT = Sitting-Rising Test; SEN = Special Educational Needs. Significant correlation coefficients are in bold. $p<0.05$

The longitudinal analyzes of the second year of preschool were conducted with the same procedures and presented similar results. Regarding the association of mathematic scores and SRT, coefficients in Model 1 shows an ES= 0.19. Adding baseline mathematics scores, Model 2 increased the explained variance (68% at school level; 45% at child level) and SRT reduces its effect size (0.13). Model 3 shows insignificant changes and with Model 4 the explained variance was 79% and 43% at school and child level, respectively. Although slightly less than the end of the first year of preschool, the increase of each additional point on the SRT scale remains significant with an effect size of 0.11.

In the association of SRT and language, we found the same trend: a moderate effect size (0.32) in Model 1 and after that negligible effect sizes with no statistical significance.

Discussion

This study aimed to quantify the longitudinal link between non-aerobic physical fitness and cognitive development in a large sample of preschool children. The bivariate correlations suggest a significant but weak association of the SRT with both cognitive measurements. In the linear hierarchical models, the baseline measurements of the SRT were related to some improvements in cognitive parameters depending on the academic domain involved. In language, the relationship of non-aerobic physical fitness measurements did not remain significant after adjustment, in the first and second years of preschool. On the other hand, the SRT was related to mathematics performance after controlling for confounding variables. The increase of one point in the SRT scale at the beginning of the first year of preschool represented effect sizes of 0.16 and 0.11 at the end of the first and second year of preschool, respectively. The small magnitude of the relations found in our study is similar to previous studies (Aadland et al., 2017; van Dusen et al., 2011), but there are two reasons to believe that what we have reported is more important than the small effect sizes imply. The first is that the

SRT could only pick out children with difficulties since most could easily complete the task perfectly. A non-aerobic physical fitness test that discriminated across the full range may have revealed a stronger association. Secondly, the effect sizes were for one point on the SRT and the sample includes some cases that had scored 2.5 below the 10's perfect score. That corresponds to effect sizes of 0.40 and 0.27 respectively for the two waves and represents four to five months of learning progress (Higgins et al., 2016).

The SRT is a screening test that assesses, through simple motor tasks, at least four components of non-aerobic physical fitness, namely muscle strength/power, flexibility, balance, and body composition. SRT has been used to measure non-aerobic physical fitness in several different populations and middle-aged and older subjects. The results suggest that the SRT is a good predictor of all-cause mortality (Brito et al., 2014). Additionally, Ventista (2015) found a moderate association between the SRT and MABC-2 (Movement Assessment Battery for Children- 2nd edition) in preschool children. Recently, age- and sex-reference scores were made available for a sample of 6,141 adults (Araújo et al., 2020). The possibility of a ceiling effect in young children is expected (Araujo, 1999) and was also found in this study. The results corroborates the claim that performing the actions of sitting and rising from the floor is simple and could be considered fundamental human skills (Green & Williams, 1992) learned very early in life (Gallahue et al., 2019). More importantly, the inability to perform these actions, when measured by the SRT, may indicate some adverse changes in the components of non-aerobic physical fitness such as: overweight, low flexibility, poor balance, low muscle strength/power, poor motor coordination, or, quite often, some degree of combination of these.

Other studies, however, have not observed statistically significant associations between non-aerobic physical fitness components (musculoskeletal fitness) and academic achievement (Castelli et al., 2007; Torrijos-Niño et al., 2014). Further, the finding that non-aerobic physical fitness components were associated with math scores but not on language is consistent with some previous studies (Aadland et al., 2017; Eveland-Sayers et al., 2009). Whilst others studies, however, had found that this relationship occurred in both academic domains (de Bruijn et al., 2019; Esteban-Cornejo et al., 2014; Haapala et al., 2014).

These mixed results could be explained by the different analytical approaches across studies, different measurements and inconsistency in controlling for potentially confounding variables (Kao et al., 2017). Additionally, problems can arise when academic decisions are made according to statistical significance; it is confounded with sample size which had a high range across the studies.

The results reported in this paper were based on large sample sizes with outcomes at two points in time separate by a year. The results were unequivocal. There was a link between non-aerobic physical fitness and mathematics but not with language for young children. Any explanation of the link must therefore discriminate between language and mathematics.

The previous explanation includes a) during several motor and cognitive tasks brain regions namely the prefrontal cortex, the cerebellum, and the basal ganglia show co-activity (Diamond, 2000); b) these skills might have a similar developmental timetable with an accelerated maturation during early and middle childhood (5-10 years old) (Anderson et al., 2001; van der Fels et al., 2014); c) both motor and cognitive skills have several common underlying processes, such as sequencing, monitoring, and planning (Roebers & Kauer, 2009); d) motor skills training induces brain plasticity through increases in brain-derived neurotrophic factor levels and tyrosine kinase receptors, synaptogenesis and motor map reorganization in the motor cortex (Adkins et al., 2006). A further suggestion involves a mediation process by executive functions as a possible mechanism (Alloway & Archibald, 2008; Roebers et al., 2014).

But, whilst each explanation may have some merit, none discriminates between language and mathematics and, a full explanation is beyond the scope of this paper. One possibility is that the link between arithmetical concepts and finger counting is fundamental (Andres et al., 2008) and that this provides the link between physical development and mathematics but not language. Further empirical work would be needed to explore this in more detail.

Strengths and limitations

The strength of the present study is partly that it was based on a large sample size of children at the beginning of the first year of compulsory education in Brazil. Also, the longitudinal design allows analyzing the relationship between non-aerobic physical fitness and academic performance at various time points. The non-aerobic physical fitness components were assessed with the Sitting-Rising Test, a well-known and objective assessment tool that is easily administered and provides a reliable measure (Lira & Araújo, 2000). The cognitive assessment is based on skills and domains of knowledge that research has shown to be the best predictors of later success at school (Tymms, 1999). This study has also some limitations. SRT presents a celling effect for this age group, therefore, we may have lost some discriminative power among those with a score of 10. It was only feasible to collect data of height and weight (Ponderal Index) in the 1st Wave.

Conclusion

Our findings indicate that non-aerobic physical fitness is associated with the cognitive development of preschool children (ages 4 and 5). Future studies should investigate how the development of non-aerobic physical fitness components across childhood relates to cognitive development and, more importantly, if controlled interventions (RCTs) focused on non-aerobic physical fitness components could increase cognition in children. Moreover, future studies should seek to better understand the mechanisms of the physical fitness-cognition relationship specifically using executive function measurements as a mediation process. Our findings, along with other studies (de Bruijn et al., 2019; Esteban-Cornejo et al., 2014; Niederer et al., 2011) suggest that the non-aerobic physical fitness components could contribute to a child's cognitive development in addition to other health-related benefits. This message should encourage educational policymakers to translate this finding and assure opportunities for healthy development and lifestyle for preschool-aged children.

Acknowledgements

The authors thank all families and schools for their participation, and the research assistants who contributed to the data collection.

Funding

This work was supported by the Inter-American Development Bank [BR - T1347; BR - T1397]; the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), Brazil [439085 / 2018]; the Fundação de Amparo à Pesquisa do Estado do Rio de Janeiro (FAPERJ), Rio de Janeiro, Brazil [239759]; and the Instituto Alfa e Beto.

Notes

1. SRT should be administered on a flat, non-slip surface. To perform the test, the individual must be barefoot, without socks and without clothing that may restrict their mobility. The evaluator requests that the individual, from the standing position, perform the action of sitting without using the hands (or supports) and without unbalance. On the ground, the evaluator requests that the individual

perform the action of rising without using the hands (or supports) and without unbalance.

2. For a more detailed presentation of the PIPS test, its potential uses and limitations, see (Tymms et al., 1997).
3. The researchers asked the children: "*Let's do a challenge! Can you follow these movements just like this little guy? Try to sit and then stand up, slowly and without the assistance of your arms or knees!"* Then, a short cartoon video with the correct actions of sitting and rising from the floor was presented.

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