Sibling's resemblance in health- and performance-related fitness among Brazilian youth

Semejanza entre hermanos en la aptitud física relacionada con la salud y el rendimiento entre los jóvenes brasileños

Authors

Thaliane Mayara Pessôa dos Prazeres [1]
Rafael dos Santos Henrique [2]
Leonardo Gomes de Oliveira Luz [3]
Murilo Gominho Antunes Correia Junior [1]
Mariana do Nascimento Sena Oliveira [1]
Marcella Dantas Ribeiro [1]
Tércio de Araújo do Rego Barros [2]
Victor Ferreira Lima [2]
Douglas Eduardo Ferreira Maia [2]
Paulo Felipe Ribeiro Bandeira[4]
Carol Virgínia Góis Leandro [2]
Marcos André Moura-dos-Santos [1]

[1]University of Pernambuco (Brazil)
[2]Federal University of Pernambuco (Brazil)
[3]Federal University of Alagoas (Brazil)
[4]Regional University of Cariri (Brazil)

Corresponding author:
Thaliane Mayara Pessôa dos Prazeres
thalianemayara@hotmail.com

How to cite in APA

Pessôa dos Prazeres, T. M., dos Santos Henrique, R., Gomes de Oliveira Luz, L., Gominho Antunes Correia Junior, M., do Nascimento Sena Oliveira, M., Dantas Ribeiro, M., de Araújo do Rego Barros, T., Ferreira Lima, V., Eduardo Ferreira Maia, D., Ribeiro Bandeira, P. F., Virgínia Góis Leandro, C., & Moura-dos-Santos, M. A. (2025). Sibling's resemblance in health- and performance-related fitness among Brazilian youth. *Retos*, *66*, 491–504. https://doi.org/10.47197/retos.v66.110390

Abstract

Introduction: Physical fitness (PF) is recognized as a crucial element for fostering various health and performance benefits in children and adolescents. Although PF is determined by genetic and environmental factors, little is known about the degree of influence of these factors on PF expression among siblings.

Objective: This study aims to examine the degree of sibling resemblance on PF components as well as estimate the influence of individual and contextual factors on sibling resemblance on PF among Brazilian children.

Methodology: The sample comprised 784 pairs of siblings (405 boys; 5-15 years), from Lagoa do Carro, Brazil. PF was assessed with the 20-m shuttle run, standing long jump, handgrip strength, shuttle run, 20-m dash, and sit and reach. Anthropometry, biological maturation, gross motor coordination, and school characteristics were also measured.

Results: In general, sibling intraclass correlations differed significantly across sib-ship types for all PF tests. Same-sex siblings (brother-brother or sister-sister) had higher resemblance in the sit and reach, shuttle run, standing long jump, and 20-m dash tests (ρ between 0.06 and 0.36), while opposite-sex pairs (brother-sister) showed higher resemblance in 20-m shuttle run, handgrip, and total PF tests (ρ between 0.05 and 0.27). Further, both individual and school characteristics were associated with the magnitude of sibling resemblance.

Conclusions: Our results show significant sibling resemblance in PF traits in Brazilian children. In addition, individual and school characteristics are associated with different PF traits and influence the magnitude of intrapair shared variance, especially for brother-brother siblings.

Keywords

Children; Physical Fitness; School; Siblings.

Resumen

Introducción: La aptitud física (AF) es reconocida como un elemento crucial para favorecer diversos beneficios para la salud y el desempeño en niños y adolescentes. Aunque la AF está determinada por factores genéticos y ambientales, poco se sabe sobre el grado de influencia de estos factores en la expresión de la AF entre hermanos.

Objetivo: Este estudio busca examinar el grado de semejanza entre hermanos en los componentes de la AF, así como estimar la influencia de factores individuales y contextuales en la semejanza entre hermanos en la AF entre niños brasileños.

Metodología: La muestra comprendió 784 pares de hermanos (405 de sexo masculino; 5-15 años), de Lagoa do Carro, Brasil. La AF se evaluó con el 20-m shuttle run, el salto de longitud de pie, la fuerza de prensión de la mano, el shuttle run, la carrera de 20 m y el sentarse y alcanzar. También se midieron la antropometría, la maduración biológica, la coordinación motora gruesa y las características escolares.

Resultados: En general, las correlaciones intraclase entre hermanos difirieron significativamente entre los distintos tipos de parentesco para todas las pruebas de AF. Los hermanos del mismo sexo (hermano-hermano o hermana-hermana) tuvieron un mayor parecido en las pruebas de sentarse y alcanzar, shuttle run, salto de longitud de pie y carrera de 20 metros (ρ entre 0,06 y 0,36), mientras que las parejas de distinto sexo (hermano-hermana) mostraron un mayor parecido en las pruebas de 20-m shuttle run, la fuerza de prensión de la mano y AF total (ρ entre 0,05 y 0,27). Además, tanto las características individuales como las escolares se asociaron con la magnitud del parecido entre hermanos.

Conclusiones: Nuestros resultados muestran una significativa semejanza entre hermanos en las características de la AF en niños brasileños. Además, las características individuales y escolares están asociadas con diferentes características de FP e influyen en la magnitud de la varianza compartida intrapareja, especialmente para los hermanos.

Palabras clave

Aptitud física; Hermanos; Instituciones Académicas; Niño.

Introduction

Physical fitness (PF) is a critical aspect to achieve various health benefits in children and adolescents (Galán-Arroyo et al., 2024). Several studies have shown that it affects various health outcomes, such as adequate weight status (García-Hermoso et al., 2019; Dykstra et al., 2024), metabolic health (Reuter et al., 2021; Rodríguez-Gutiérrez et al., 2024), cognition (Haapala et al., 2018; Manzano-Sánchez, Gutiérrez-Espinoza, & López-Gil, 2024), among others (Lema-Gómez et al., 2021; Haapala et al., 2024). Furthermore, children and adolescents who exhibit higher levels of PF tend to be more active and achieve superior PF scores in adulthood in adulthood (García-Hermoso et al., 2022). Consequently, understanding the factors that influence PF is essential.

PF can be determined by genetic and environmental factors (Pereira et al., 2017a). Family aggregation studies serve as a method to assess the genetic contribution of a given phenotype among family members, including twins, parents and siblings (Bouchard et al., 1997; Plomin et al., 2013). This influence is quantified through intraclass correlation (ρ). For instance, Sallis et al. (1989) reported low to moderate levels of resemblance in cardiorespiratory fitness measured on a cycle ergometer among siblings from diverse cultural backgrounds, with intraclass correlation coefficients (ρ) ranging from 0.25 to 0.57 (Sallis et al., 1989). Additionally, Malina and Mueller (1981) found that, depending on the type of sibling pair, brother pairs exhibited greater similarity (ρ between 0.30 and 0.57) compared to sister pairs (ρ between 0.27 and 0.44) in static strength tests (handgrip, push and pull) and gross motor performance tests (standing long jump, 35-y dash, and throwing). Pereira et al. (2017), in turn, examined the degree of resemblance across various PF components, including morphological, muscular, motor, and cardiorespiratory. Their findings indicated that resemblance was higher in the morphological component (ρ between 0.15 and 0.60) compared to the muscular (ρ between 0.08 and 0.30), motor (ρ between 0.09 and 0.47) and cardiorespiratory components (ρ between 0.11 and 0.50) (Pereira et al., 2017a). It is noteworthy that in this study, the intraclass correlation values were adjusted for biological, behavioral, and sociodemographic variables such as age, sex, biological maturation, socioeconomic status and level of physical activity.

Typically, siblings have 50% of their genes in common, which are identical by descent (Falconer & Mackay 1996), additionally, they share common environments. However, they may differ in various aspects, including age, gender, physical development and other health-related attributes. Additionally, engage in activities that are not shared with their sibling, such as play and activities that lack the participation of their sibling (Plomin et al., 2013). In many Latin American countries, especially in regions with greater social vulnerability, contextual factors, such as geographic location, access to equipment for physical activities, health practices and public policies, are also factors that can influence the expression of a particular phenotype (Flores-Mendoza et al., 2015; Santos et al., 2022). School serve as a critical indicator of socioeconomic vulnerability, as it is negatively related to PF and cognitive performance (Lemes et al., 2021). In this sense, analyzing the degree of resemblance between siblings using statistical models that allow the addition of a range of covariates at the individual and contextual levels can help to understand why individuals from the same family show similarities or differences.

Therefore, this study has two objectives: (1) to investigate the degree of sibling resemblance (between brother-brother, sister-sister and brother-sister pairs) in PF components; (2) to estimate the influence of individual (age, biological maturity, body mass index, blood pressure and gross motor coordination) and contextual (infrastructure and policies and practices of the school) factors on sibling resemblance on PF among Brazilian children.

Method

Participants

This study is part of the Healthy Life Project in Lagoa do Carro: a family-based study, which investigates the relationships between physical growth, motor development markers and health aspects in children and adolescents residing in Lagoa do Carro, northeastern Brazil. It is a cross-sectional and school-based design (Thomas, Nelson, & Silverman, 2015), following the recommendations of Strengthening the Reporting of Observational Studies in Epidemiology (Von Elm et al., 2014). All children who had siblings enrolled in public schools from Lagoa do Carro and carried out the measurements were included. Within each school, all children were invited to participate, and the response rate was >95%.

The sample consisted of 784 individuals (405 boys), aged 5-15 years (9.52±2.61), belonging to 274 families, varying from two, three and four siblings, 57.1%, 33.7% and 9.2% respectively, which represents more than half of the municipality's school population. Children were assessed individually on the two days, firstly in anthropometric measurements and gross motor coordination tests; later, on PF tests. If necessary, missing data were collected during an additional visit. All data were collected between April 2018 and November 2018, according to the school calendar. No seasonality is to be expected given that the temperature and weather conditions are stable during this period.

Parents or legal signed informed consent to certify their agreement regarding their child's participation. The study was conducted according to the Helsinki Declaration and approved by the Ethics and Research Committee of the University of Pernambuco (CAAE: 83143718.3.0000.5192; CEP/UPE: 2.520.417), as well as the approval of all participating schools.

Instruments and procedures

Physical Fitness

PF tests were selected from FitnessGram (Welk & Meredith, 2008), PROESP (Gaya et al., 2012), and EUROFIT (American Alliance for Health, Physical Education and Recreation, 1980) standardized test batteries. The following theses were administered:

1. 20-m Shuttle run: Participants run between two parallel lines set 20 meters apart, following increasing speeds dictated by an audio signal at each stage. The speed increases progressively by 0.5 km/h per minute. The test concludes when the participant is unable to maintain the required pace or voluntarily withdraws. The number of laps completed, and the final stage reached were recorded to determine the total distance in meters covered.
2. Handgrip strength: Participants were instructed to exert maximum force with their dominant hand on a portable dynamometer (TKK, model 5001) for 2 to 5 seconds. Two attempts were performed, with an interval of approximately 10 seconds between them. The force produced in each attempt was recorded in kilograms-force (kgf), and the arithmetic mean of the three measurements was used for analysis.
3. Standing long jump: Participants performed a standing horizontal jump, starting from a static position with both feet together. Two attempts were allowed, with intervals of 5 to 10 seconds between jumps. The distance for each attempt, measured in centimeters from the starting line to the closest point of contact with the ground, was recorded.
4. Sit and reach: Participants must sit with fully extended knees, placing the plantar region of the feet completely on the Wells bench. They were instructed to flex their trunk and reach forward as far as possible along a centimeter scale affixed to the top of the bench. The distance reached was recorded in centimeters and the arithmetic mean of the two measurements was used for analysis.
5. 20-m dash: Participants performed a maximal-effort sprint between two parallel lines set 20 meters apart. Starting from a standing position with one foot just behind the starting line, they were instructed to sprint as fast as possible and fully cross the finish line. The test concluded when the participant crossed the second line, and the completion time was recorded in seconds. The arithmetic mean of the two measurements was used.
6. Shuttle run: Participants performed a maximal effort run between two parallel lines set 10 meters apart. Two wooden or foam blocks were placed beyond one of the lines. Participants ran to retrieve the first block, returned to the starting line to place it down, and then repeated the task to retrieve the second block. The time taken to complete the test was recorded in seconds and the arithmetic mean of the two measurements was considered.

A general PF score was also used: firstly, the results of the individual tests were transformed into z-scores; then, an unweighted sum of the entire z-score was computed.

Anthropometry

Stature was measured with children's head in the Frankfurt plane with a portable stadiometer (Sanny, Brazil) to the nearest 0.1 cm. Body mass was measured with children wearing light clothing and without shoes using a portable digital scale (Glicomed, Brazil) to the nearest 0.1 kg. Body mass index (BMI) was obtained by the ratio of body mass to squared stature (kg/m2). All measurements were performed following the procedures suggested by Lohman, Roche and Martorel (1988).

Biological maturation

Biological maturation was estimated using the maturity offset (Mirwald et al., 2002), which uses sex-specific equations from data on age, stature, sitting height, and lower limb length to predict the distance in years that each participant is from reaching peak height velocity (PHV). A positive maturity offset value represents the number of years the participant is beyond the PHV, while a negative value represents the number of years the participant is before the PHV

Blood pressure

Systolic and diastolic blood pressure (SBP and DBP) was measured by an oscillometric electronic device was used (OMRON, model HEM 742; Omron Healthcare, Hoofddorp, Netherlands), with an adequate pediatric cuff size (10 to 35 cm). Three consecutive measurements were taken with children in a seated position with their torso leaning against the chair and arms relaxed, with a minimum rest of 5 min before the first measurement and a 2 min interval between the other measurements, following national guidelines (Malachias et al., 2016). The average of three measurements was considered.

Gross motor coordination

Gross motor coordination was assessed with the Korperkoordinationstest für Kinder battery (KTK; Kiphard, & Schilling, 1974), which includes the following tests: (1) walking backwards along a balance beam, (2) jumping sideways, (3) hopping for height on one foot, and (4) moving sideways. The raw scores of each test were summed to express the overall GMC score. This approach was advocated by Schilling (2015).

School information

Aspects related to the school context, as well as policies and practices related to physical activity and healthy eating at school were obtained by applying an adapted version of the ISCOLE questionnaire to the principals of participating schools; in addition, a direct observation of the school environment was carried out by the researchers. The questionnaire includes items related to infrastructure and spaces (e.g., location, size and physical structure etc.), curricular and extracurricular activities (e.g., attendance of physical education classes, sports in after-school hours), policies and practices related to physical activity (e.g., intra- and inter-school sporting events etc.) (Katzmarzyk et al., 2013)

Data quality control

Data quality control was assessed in three stages. Firstly, a steering committee provided systematic training to the team members on all methodological procedures. After, a pilot study was conducted at a school from Lagoa do Carro to verify the approximate time of data collection. Thirdly, a reliability-in-field procedure was used, such that three to five students were randomly selected on alternating assessment days and re-tested. Reliability-in-field procedures were used, where three to five students (42 in total) from each school were randomly selected on alternating assessment days and re-tested a week apart. TEM for stature, body mass and sitting height were 0.2 cm, 0.1 kg and 0.1 cm, respectively. Test-retest reliabilities for motor tests ranged from 0.81 (4 x 10-m shuttle run) to 0.95 (handgrip strength) for PF, and between 0.81 (walking backwards) and 0.96 (hopping for height on one foot) for GMC. Finally, double entry of information and systematic checks of all data entries were done to identify and correct putative input errors.

Data analysis

Descriptive statistics and analysis of variance (ANOVA) were performed to assess differences among brother-brother (BB), sister-sister (SS) and brother-sister (BS) pairs using SPSS 23 (IBM SPSS Corporation, New York, USA), with Bonferroni post-hoc applied when necessary. Given the nested structure of the data (i.e., sib-ships pairs), multilevel modeling was employed. The null model compared a constrained model, which assumed equal intraclass correlation (ρ) across sibling pairs, to a model that allowed ρ to vary freely among sibling pairs (M1), both without covariates. Model 2 (M2) incorporated individual covariates, including age, age2, maturity offset, BMI, SBP and GMC. The final model (M3) included the M2 and added school characteristics, such as area, school size, recess area [<29m as reference], obstacles and irregularity in the recess area, presence of sports courts and PE classes, and availability of extracurricular sports and competitions between schools. All covariates were centered at their respective means, as recommended by Hox (2010). Separate intraclass correlations (ρ) and 95% confidence intervals (95% CI) for the three sibling types (BB, SS and BS) were also calculated, accordingly suggested by Hedeker and Mermelstein (2012). Intraclass correlations were computed in three forms: unadjusted, partially adjusted (including individual characteristics), and fully adjusted (including school characteristics). In all models, the BB pairs served as the reference category. All parameters were estimated using maximum log likelihood (Goldstein et al., 2002). Model comparisons were conducted using the likelihood ratio test. All analyses were performed in STATA 14, with the alpha level set at 0.05.

Results

Descriptive statistics for all PF tests, anthropometry, biological maturation, blood pressure, and gross motor coordination are shown in Table 1. Sibling pairs had similar chronological ages, but SS pairs were more mature than BB pairs. However, BB pairs had higher values than BS pairs on BMI. Stature, body mass, and blood pressure did not differ between sibling pairs.

For PF tests, BB pairs had better performance in the 20-m shuttle run tests than SS pairs and were stronger than SS and BS pairs. BB pairs outperformed BS and SS pairs in the standing long jump, 20-m dash and shuttle run, as well as BS pairs were better than SS pairs in these tests. Finally, BB and BS pairs presented better gross motor coordination than SS pairs.

Table 1. Descriptive characteristics (Mean±SD) and comparisons by sib-types (n=784).

Variables	SS (n=180)	BB (n=206)	BS (n=398)	F	Post-hoc
Age (years)	9.22±2.60	9.77±2.64	9.55±2.59	2.15	
Maturity offset (years)	-2.45±2.10	-3.08±2.06	-2.76±2.05	4.36*	SS>BB
Anthropometry					
Stature (cm)	134.15±16.83	136.96±15.05	135.76±15.92	1.49	
Body mass (kg)	32.75±13.67	34.45±12.99	32.35±11.59	1.95	
BMI (kg/m²)	17.38±3.54	17.80±3.61	17.00±2.90	4.10*	BB>BS
Blood pressure					
Systolic (mmHg)	103.05±15.22	103.57±13.93	101.73±13.32	1.31	
Diastolic (mmHg)	65.22±11.51	65.15±11.51	63.67±11.53	2.00	
Physical fitness					
20-m Shuttle run (m)	346.62±173.41	442.43±249.94	394.57±238.16	7.24**	BB>SS
Handgrip strength (kgf)	14.49±6.07	17.66±8.24	16.05±7.56	8.71**	BB>SS and BS
Sit and reach (cm)	27.42±5.44	26.51±6.19	26.18±6.10	2.51	
Standing long jump (cm)	99.63±23.35	118.51±27.29	111.92±25.82	24.21***	BB and BS>SS; BB>BS
20-m dash (s)	5.18±0.73	4.65±0.54	4.80±0.64	31.4***	BB and BS>SS; BB>BS
4x10-m shuttle-run (s)	15.81±2.09	14.55±1.97	14.98±1.87	18.78***	BB and BS>SS; BB>BS
Gross motor coordination					
KTK sum (score)	130.25±45.19	130.25±45.19	145.74±51.37	10.83***	BB and BS>SS

Note: BMI, body mass index; KTK, Korperkoordinationstest für Kinder. *p<0.05; **p<0.01; ***p<0.001.

School characteristics are presented in Table 2. The number of schools in rural and urban areas was the same (50.0%), and the number of students in the schools ranged from 26 to 440. Most schools had ample spaces for recess (75.0%), but 66.7% had obstacles (e.g., pillars), and 58.3% had irregularities in the floor. Further, 83.3% of schools did not have multi-sports courts. Finally, 83.3% of the schools did not have physical education classes or extracurricular sports, and only 25.0% held sports competitions between schools.

Table 2. Descriptive characteristics for school-level variables.

Characteristics	Mean±SD
School size (number of students)	164.67±115.82
	n (%)
Area	
Rural	6 (50.0)
Urban	6 (50.0)
Physical structure of the school	
Playground area	
< 30m²	3 (25.0)
30m² to 49m²	4 (33.3)
> 50m²	5 (41.7)
Playground characteristics	
With obstacles	8 (66.7)
Without obstacles	4 (33.3)
With floor irregularity	7 (58.3)
Without floor irregularity	5 (41.7)
Multi-sports court	
Yes	2 (16.7)
No	10 (83.3)
Policies and practices	
Physical education classes	
Present	2 (16.7)
Absent	10 (83.3)
Extracurricular sports	
Present	2 (16.7)
Absent	10 (83.3)
Sports competitions between schools	
Present	3 (25.0)
Absent	9 (75.0)

The associations between individual and school covariates, and health-related PF tests are shown in Table 3. Model 3 fit the data significantly better than model 2 for all PF tests, meaning that school variables were important in explaining sibling resemblance after adjustments for all individual characteristics.

For 20-m shuttle run, all sibs exhibited similar scores to BB pairs, which averaged β=195.47±83.28. Older siblings, less mature, with lower BMI and higher GMC, and those studying in smaller schools, had better cardiorespiratory fitness. In the handgrip strength, SS and BS had lower values than BB pairs, which averaged β=13.44±1.15. Older siblings, with higher BMI and GMC showed higher values. Further, siblings from urban areas and who took PE classes had more static strength. For sit and reach test, younger siblings but biologically more mature, and who studied in smaller schools performed better.

Table 3. Estimates and standard errors (SE) for each health-related physical fitness test.

Fixed effects	20-m SR (m) Estimate±SE	Handgrip (kgf) Estimate±SE	Sit and reach (cm) Estimate±SE
Intercept (BB)	195.47±83.28**	13.44±1.15***	29.99±2.20***
SS	-0.52±25.78	-1.13±0.41**	-0.49±0.79
BS	-29.11±22.56	-0.83±0.37*	-0.88±0.66
Age (years)	45.94±9.93***	1.48±0.14***	-1.08±0.28***
Age^2 (years)	3.07±2.20	0.15±0.03***	0.01±0.05
Maturity offset (years)	-38.51±10.71***	-0.13±0.15	0.70±0.30*
BMI (kg/m^2)	-18.65±3.03***	0.50±0.05***	0.02±0.09
SBP (mmHg)	0.26±0.69	0.01±0.01	0.02±0.02
GMC (sum of points)	1.77±0.25***	0.03±0.00***	0.01±0.01
Area (reference: rural)	26.56±49.09	1.52±0.76*	-1.62±1.45
Size (n of students)	-0.35±0.17*	0.01±0.00	-0.01±0.01*
Recess area: $30m^2$ to $49m^2$	62.45±70.38	1.65±0.96	-2.01±1.79
Recess area: $>49m^2$	110.31±68.41	1.41±0.93	0.25±1.73
Obstacles (reference: no)	61.74±101.51	-1.34±1.57	-2.45±2.8
Court (reference: no)	-164.67±0.27	-0.43±1.74	1.87±3.36
Floor irregularity (reference: no)	-89.23±111.84	1.36±1.74	0.94±3.15
PE classes (reference: no)	199.04±226.08	4.87±2.26*	6.53±4.62
Extracurricular sports (reference: no)	0	0.93±2.81	-4.75±5.32
Competitions between schools (reference: no)	195.47±83.28	-5.27±2.79	-2.58±5.41

Note: 20-m SR, 20-m Shuttle run; BB, brother-brother; SS, sister-sister; BS, brother-sister; BMI, body mass index; GMC, Gross motor coordination; PE, physical education; SBP, systolic blood pressure. *p<0.05; **p<0.01; ***p<0.001.

Table 4 shows associations between individual and school covariates, and performance-related PF tests. In the standing long jump, BB pairs (β=97.88±6.59) outperformed BB pairs at baseline. Younger siblings, less mature and those with better motor coordination jumped greater distances. Siblings who studied in schools with higher playgrounds also performed better. In the 20-m dash, BB pairs had β=4.98±0.20 at baseline. SS required more time to cover the 20-m distance than BB pairs. Older and more mature siblings, as well as siblings more coordinated and with lower BMI were faster. In addition, those from schools with more students and irregularities on the playground floor performed worse. For shuttle run, SS and BS had similar performance to BB pairs. Older and less mature siblings performed better, as did those with better GMC and blood pressure. Siblings who studied in schools with fewer students, but which had higher and better playgrounds (no obstacles and irregularities), and which offered extracurricular sports performed better. However, siblings who attended schools that held inter-school competitions performed worse. Finally, older siblings, more coordinated and who study in schools with PE classes, have higher total PF scores.

Table 4. Estimates and standard errors (SE) for each performance-related physical fitness test.

Fixed effects	SLJ (cm)	20-m dash (m/s)	4x10-m shuttle-run (m/s)	PF total (z-score)
	Estimate±SE	Estimate±SE	Estimate±SE	Estimate±SE
Intercept (BB)	97.88±6.59***	4.12±0.18***	2.46±0.08***	-2.01±1.03
SS	-7.68±2.28**	-0.19±0.06**	-0.06±0.03*	-1.01±0.36**
BS	-2.01±1.78	-0.05±0.05	-0.03±0.02	-0.69±0.27*
Age (years)	6.08±0.87***	0.10±0.02***	0.06±0.01***	0.81±0.12***
Age^2 (years)	-0.43±0.16**	-0.01±0.01**	-0.01±0.01**	0.02±0.03
Maturity offset (years)	-2.57±0.95**	-0.09±0.02***	-0.04±0.01***	-0.41±0.14**
BMI (kg/m^2)	-0.50±0.27	-0.02±0.01*	-0.01±0.01	-0.04±0.04
SBP (mmHg)	0.09±0.06	-0.00±0.00	0.01±0.00	0.01±0.01
GMC (sum of points)	0.21±0.02***	0.01±0.00***	0.01±0.00***	0.04±0.00***
Area (reference: rural)	-7.87±4.20	0.04±0.10	0.05±0.05	0.32±0.61
Size (n of students)	-0.01±0.02	-0.00±0.00***	0.01±0.00**	-0.00±0.00*
Recess area: 30m^2 to 49m^2	6.32±5.21	0.02±0.15	0.12±0.07	0.99±0.86
Recess area: >49m^2	11.26±5.03*	0.08±0.15	0.08±0.06	1.65±0.84*
Obstacles (reference: no)	-5.53±7.90	0.20±0.21	-0.24±0.10**	-1.10±1.18
Court (reference: no)	1.27±9.41	-0.12±0.22	0.28±0.12**	0.35±1.32
Floor irregularity (reference: no)	14.12±9.00	-0.68±0.23**	0.38±0.11**	0.16±1.33
PE classes (reference: no)	-18.80±14.32	-0.07±0.37	-0.29±0.19	-0.69±2.96
Extracurricular sports (reference: no)	-11.69±15.17	0.45±0.37	0.58±0.19**	0
Competitions between schools (reference: no)	30.84±16.33	-0.40±0.44	2.46±0.08**	0.46±2.56

Note: BB, brother-brother; SS, sister-sister; BS, brother-sister; BMI, body mass index; GMC, Gross motor coordination; PE, physical education; PF, Physical fitness; SBP, systolicblood pressure; SLJ, Standing long jump. *p<0.05; **p<0.01; ***p<0.001.

Intraclass correlations for fitness variables adjusted and unadjusted for individual and school characteristics are presented in Table 5. In general, BB pairs had higher resemblance in the sit and reach, and shuttle run tests; SS pairs showed higher resemblance in standing long jump and 20-m dash, while BS pairs showed higher resemblance in 20-m shuttle run, handgrip and total PF.

Significant variations in the ρ coefficients were also found after adjustments for individual and school characteristics (Models 2 and 3). For example, for 20-m shuttle run, the unadjusted correlation was 0.19 and 0.11 for BB and SS, and decreased to 0.07 and 0, respectively. In contrast, the BS correlation increased after the inclusion of all covariates (from 0.22 to 0.27). For handgrip strength, BS pairs correlation increased after adjustments (from 0 to 0.24), while BB and SS pairs did not change substantially. In the standing long jump, the unadjusted correlation was 0.17, 0.15, and 0.07 for BB, SS, and BS pairs, with a significant reduction after the inclusion of covariates, especially for BB and BS (from 0.06 and 0, respectively); SS pairs correlations did not change substantially. For the 20-m dash, BB unadjusted correlation was 0.04 and increased to 0.23 after adjustments; BB and BS pairs had slight changes. In the shuttle run test, correlations increased significantly for BB pairs (from 0.10 to 0.19) and dropped for SS pairs (from 0.36 to 0.24). However, BS pairs correlations did not change. Finally, for the sit-and-reach test and total PF, correlations did not change substantially for all sib-types.

Table 5. Intraclass correlation coefficients (ρ) and their 95% confidence intervals for each test of physical fitness: unadjusted and adjusted for individual and school characteristics (Models 1, 2 and 3).

Variables and Models	BB (95%CI)	SS (95%CI)	BS (95%CI)	LL	ΔLL
20-m Shuttle Run (m)					
Null model				-3827.08	
M1 (without covariates and different ρ)	0.19 (0.05 to 0.49)	0.11 (0.01 to 0.56)	0.22 (0.10 to 0.42)	-3816.40	10.68**
M2 (individual characteristics)	0.11 (0.01 to 0.55)	0	0.26 (0.14 to 0.45)	-3672.61	143.79***
M3 (school characteristics)	0.07 (0.01 to 0.71)	0	0.27 (0.15 to 0.46)	-3664.38	8.23***
Handgrip (kgf)					
Null model				-2623.97	
M1 (without covariates and different ρ)	0.10 (0.01 to 0.50)	0.21 (0.07 to 0.47)	0	-2613.08	10.89**
M2 (individual characteristics)	0.05 (0.01 to 0.80)	0.28 (0.12 to 0.52)	0.20 (0.09 to 0.38)	-1756.00	857.08***
M3 (school characteristics)	0.06 (0.00 to 0.76)	0.18 (0.04 to 0.51)	0.24 (0.13 to 0.42)	-1744.21	11.79***
Sit and reach (cm)					
Null model				-2254.43	
M1 (without covariates and different ρ)	0.34 (0.19 to 0.53)	0.09 (0.01 to 0.60)	0.12 (0.03 to 0.35)	-2250.00	4.43ns
M2 (individual characteristics)	0.32 (0.17 to 0.53)	0.10 (0.01 to 0.60)	0.13 (0.03 to 0.39)	-2057.73	192.27***
M3 (school characteristics)	0.36 (0.20 to 0.56)	0.12 (0.01 to 0.56)	0.11 (0.02 to 0.40)	-2051.18	6.55**
SLJ (cm)					
Null model				-2884.01	
M1 (without covariates and different ρ)	0.17 (0.04 to 0.47)	0.15 (0.03 to 0.50)	0.07 (0.01 to 0.48)	-2881.49	2.52ns
M2 (individual characteristics)	0.03 (0.00 to 0.97)	0.22 (0.06 to 0.50)	0	-2600.31	281.18***
M3 (school characteristics)	0.06 (0.01 to 0.78)	0.14 (0.02 to 0.52)	0	-2588.82	11.49***
20-m dash (m/s)					
Null model				-471.42	
M1 (without covariates and different ρ)	0.08 (0.01 to 0.59)	0.33 (0.17 to 0.55)	0.07 (0.01 to 0.45)	-468.94	4.48***
M2 (individual characteristics)	0.17 (0.05 to 0.49)	0.32 (0.15 to 0.56)	0.07 (0.01 to 0.47)	-316.92	152.02***
M3 (school characteristics)	0.17 (0.05 to 0.49)	0.29 (0.12 to 0.55)	0.01 (0.01 to 0.99)	-292.76	24.14***
4x10-m shuttle run (m/s)					
Null model				-181.52	
M1 (without covariates and different ρ)	0.06 (0.00 to 0.76)	0.27 (0.11 to 0.51)	0.10 (0.02 to 0.38)	-179.97	1.55ns
M2 (individual characteristics)	0.21(0.07 to 0.48)	0.24 (0.09 to 0.51)	0.13 (0.04 to 0.38)	-103.06	76.91***
M3 (school characteristics)	0.24 (0.09 to 0.50)	0.26 (0.20 to 0.52)	0.13 (0.04 to 0.38)	-86.64	16.42***
PF (z-score)					
Null model				-1494.37	
M1 (without covariates and different ρ)	0.04 (0.00 to 0.99)	0.18 (0.07 to 0.41)	0.12 (0.03 to 0.40)	-1493.06	1.31ns
M2 (individual characteristics)	0.24 (0.10 to 0.48)	0.28 (0.13 to 0.50)	0.18 (0.07 to 0.41)	-1205.71	287.35***
M3 (school characteristics)	0.23 (0.09 to 0.49)	0.29 (0.14 to 0.50)	0.12 (0.03 to 0.42)	-1199.00	6.71***

Note: SLJ, standing long jump; PF, physical fitness; BB, brother-brother; SS, sister-sister; BS, brother-sister; LL, Log-likelihood; *p<0.05; **p<0.01; ***p<0.001.

Discussion

Based on an ecological perspective and a multilevel modeling analysis, our study examined sibling resemblance in PF, as well as the associations of individual and contextual characteristics in the expression of these markers. While the degree of resemblance between sibling pairs varied across studies, these discrepancies can be attributed to factors such as sample size, age group, statistical methodologies, and the covariates considered. Our findings indicate that siblings exhibit similarities in several traits. However, the variation in the magnitude of correlations is influenced by the type of sibling pair (i.e., brother-brother, sister-sister, or brother-sister) and the statistical adjustments made for covariates.

Several studies have analyzed the resemblance between sibling pairs, but few have examined the degree of resemblance between pairs of the same or opposite sex, which limits the possibility of comparison between studies (Pereira et al., 2017a; Sallis et al., 1989; Santos et al., 2022). After adjusting for individual and school characteristics, we observed low correlations (< 0.50) across all traits. Notably, same-sex pairs exhibited greater resemblance than opposite-sex sibling pairs in flexibility (favoring BB pairs), speed (favoring SS pairs), and agility (favoring both BB and SS pairs). These pairs exhibited a greater resemblance in cardiorespiratory fitness and static strength. Only the standing long jump and the total PF were very low across all sibling types (ICC < 0.20). Pawlak (1984) reported higher correlations in SS pairs (ρ = 0.44) and BB (ρ = 0.24) in comparison to BS pairs (ρ = 0.21) regarding handgrip strength among adolescents. Vasquez et al. (2007), in their analysis of the resemblance among Portuguese sibling pairs aged 10 to 18 years, reported values ranging from 0.22 (curl-up) to 0.49 (1-mile run/walk) for same-sex siblings. In contrast, opposite-sex pairs exhibited correlation coefficients from 0.02 for the trunk lift test to 0.14 for the curl-up test, although not adjusted for covariates. In their study, Pereira et al. (2017a) demonstrated that the resemblance among Portuguese siblings aged 9 to 20 years varied from 0.11 for the 1-mile run/walk test to 0.54 for handgrip strength in same-sex siblings, and from 0.09 for the standing long jump to 0.14 for the 1-mile run/walk test in opposite-sex siblings. This study considered various covariates, including biological factors (e.g., age and biological maturation), behavioral factors (e.g., physical activity and daily television viewing time), and demographic factors (e.g., socioeconomic status). More recently, Santos (2022) evaluated siblings aged 6 to 15 years from three different regions of Peru and observed that adjustments for individual characteristics and geographic region often resulted in a reduction (e.g., in handgrip strength and standing long jump) or complete annulment (e.g., in shuttle run) of the similarity between sibling pairs.

The differences observed in comparison to previous studies could be attributed to the age and ethnic composition of each sample, the diversity of adjustment covariates in the data analysis, and the sociodemographic, cultural, and financial characteristics of families in each region. Siblings share on average half of their genes due to ancestry (Falconer & Mackey, 1996; Schutte, Bartels, & Geus, 2017) and a shared family environment. Studies evaluating the degree of similarity between siblings in morphological traits, such as body composition (Pereira 2017a) and somatotype (Pereira et al., 2017b), show that siblings of the same sex tend to show more similarity than siblings of the opposite sex. As is well known, boys and girls undergo different processes of change as a result of biological maturation. Boys tend to gain more muscle mass and skeletal tissue, while girls tend to gain more adipose tissue, especially due to the development of the breasts and greater accumulation of fat in the hips (Malina, Bouchard, & Bar-Or, 2004), which tends to impact performance in PF tests, and justify why siblings of the opposite sex tend to show less similarity in most tests.

However, they may also differ in various physical and behavioral characteristics, as well as in their unique experiences within non-shared environments (Plomin et al., 2013). Lagoa do Carro, a city in northeastern Brazil, has one of the lowest human development indices (0.609) in the state of Pernambuco and ranks 3927th out of 5565 municipalities nationwide. Notably, over 90% of school children in the municipality receive government assistance, which is available only to families with a per capita income of less than 178 reais (approximately $30 per person per month). This precarious situation adversely affects critical aspects of public health, including the lack of potable water supply and inadequate sewage network coverage. Furthermore, the community experiences significant insecurity, disorganized traffic, and a scarcity of public spaces for recreation and leisure, which restricts opportunities for physical activity and limits access to motor experiences.

The influence of contextual factors on health behavior is well-established (Bauman et al., 2012; Swinburn et al., 2011). In childhood and adolescence, school is one of the most important contexts in child development particularly in health education (Spruijt-Metz, 2011), both in terms of opportunities for diverse physical activity and motor experiences, which can significantly impact PF, and in terms of preventive health interventions such as promoting healthy eating and preventing obesity (Harrison & Jones, 2012; Henrique et al., 2017). After adjusting for individual characteristics and the school context, we observed changes in the resemblance values, especially in BB pairs. One possible explanation this finding may relate to participation in physical and sporting activities offered in schools. While schools for younger children often have limited space for outdoor exercise and provide few sports programs, schools for older children have regular physical education classes and intramural and intermural sports. These activities tend to be more popular among boys than girls, who generally engage in less exercise or sports at school. Consequently, girls often participate in play and active games at home or in their neighborhoods, which diminishes the influence of age differences between sisters on their participation.

Multilevel analysis revealed that individual sibling characteristics were differently associated with performance on PF tests, with the magnitude and direction of some associations differing across studies. First, we found that chronological age was associated with better performance on all tests from PF, except for the general PF score. Conversely, biological maturation exhibited a negative relationship with cardiorespiratory fitness performance, standing long jump, speed, and agility, while showing a positive association with the flexibility component. Santos et al. (2022), studying Peruvian siblings aged 6 to 15 years, found that maturation progression was not significantly associated with performance in the standing long jump and shuttle run tests (Santos et al., 2022). In contrast, Pereira et al. (2017a), who studied Portuguese siblings aged 9 to 20 years, reported that advancements in maturation were linked to shorter completion times in speed and agility tests, as well as improved performance in the standing long jump test (Pereira et al., 2017a). These discrepancies may be influenced by variations in age range and other cultural factors, although further studies are needed to confirm these statements.

Body mass index is a well-established correlate of cardiorespiratory fitness, with research indicating that higher BMI is associated with lower aerobic capacity. It is plausible to assume that a higher BMI may also impact performance in sprint tests, as excess weight directly affects the mechanical efficiency of movement, particularly in tasks that require the body to be moved through space (Henrique et al., 2018). This interpretation extends to the observed relationship between GMC and PF, especially in tests that involve the displacement of the center of mass, both vertically and horizontally. The increase in inertia associated with higher body mass directly influences the mechanical work required to perform motor tasks (Jabbour & Majed, 2019). Furthermore, GMC has been positively correlated with improved performance in static strength (e.g. handgrip) and dynamic strength (e.g., standing long jump) tasks, as well as with overall PF scores, a trend frequently observed in studies involving non-sibling participants (Utesch et al., 2019). Interestingly, systolic blood pressure was found to be negatively associated with shuttle run performance, i.e., the higher the systolic blood pressure, the longer it took to complete the test. Future research should explore the underlying reasons for this association.

Regarding school characteristics, our findings indicate that children attending schools with more students performed worse on most tests of cardiorespiratory fitness, flexibility, speed and agility. However, students in schools with ample recreational areas and without irregularities in the courtyard floor demonstrate better performance in PF motor components, particularly in tests involving speed, agility and lower limb strength. Although there is a lack of studies confirming these results, it is reasonable to suggest that such infrastructural features facilitate participation in games and active play, which often involve running, changing directions and jumping in different directions. However, when a school has a high student enrollment without a corresponding increase in available space, it is intuitive to conclude that this may limit opportunities for diverse motor experiences.

Conversely, children attending schools that offer physical education classes tend to perform better on static strength tests and exhibit higher overall performance PF. A recent meta-analysis involving over 50,000 young individuals demonstrated that both the quantity and duration of physical education classes are fundamental aspects that have a positive impact on overall PF; but only the quality of these classes influences the development of motor skills (García-Hermoso et al., 2022; García-Hermoso et al., 2020). Additionally, children enrolled in schools that provide extracurricular sports or participate in interschool sports competitions also had better agility. Notably, school sports programs typically include soccer, which is the most popular sport in the country, as well as dance forms such as ballet and frevo, a regional dance specific to the state, while inter-school competitions include soccer (for boys) and dodgeball (for girls), a popular game that often involves speed and agility.

The present study has some limitations which need to be recognized. First, the cross-sectional design precludes the ability to establish causal relationships among the observed variables. Despite the size of our sample, and the representativeness for the population of Lagoa do Carro, given that more than half of the population of schoolchildren in the entire municipality was assessed, it is still not representative of the entire Brazilian population. Therefore, caution is warranted when generalizing these results. Additionally, the inclusion of objective measurements from physical activity with accelerometers could contribute to a better understanding of sibling resemblance in PF traits and their correlates. Unfortunately, logistical and financial constraints prevented the inclusion of such measurements in the current study. The absence of sociodemographic and family information should also be acknowledged; however, we recommend that future research consider analyzing how these factors influence the degree of resemblance between pairs of siblings.

Nevertheless, this study possesses several noteworthy strengths. First, the observed siblings come from socially deprived backgrounds, which distinguishes this study from many previous investigations and adds to the literature in this area. This context enriches the literature by highlighting the various associated factors at different levels that directly influence the observed intraclass correlations. Finally, the application of a multilevel analytical model that integrates individual and environmental data is a significant merit, as it captures the interplay between these factors in relation to PF.

Practical Applications

Public policies and actions designed to develop PF should acknowledge that some components of PF significantly influenced by genetic factors and tend to exhibit greater similarity among siblings of the same sex. However, it is essential to recognize that PF traits are also substantially shaped by biological characteristics and environmental exposures. Therefore, physical education teachers, coaches, and other professionals should adopt approaches that consider both genetic and environmental factors, implementing strategies that foster the individual development of each person. When working with siblings, it is crucial to encourage their individual differences to mitigate potential negative effects of sibling relationships, such as rivalry, added pressure, or unfavorable comparisons. Strategies that enable everyone to perceive their own progress and achievements can contribute to a more positive environment, fostering mutual support and shared interests in physical activities.

Conclusions

In conclusion, our findings indicate a significant sibling resemblance in PF traits among Brazilian children. Notably, the association favors same-sex pairs in terms of static and dynamic strength, speed, agility, and flexibility, while opposite-sex pairs demonstrate greater resemblance in cardiorespiratory fitness and overall PF scores. Furthermore, both individual and school characteristics are linked to various PF traits and significantly influence the magnitude of intrapair shared variance, particularly among boys. These results reinforce that PF is shaped not only by genetic factors but also by a combination of shared and unique environmental influences that affect PF expression.

Acknowledgements

The authors thank all children and parents for their participation in the study, and to the schools who participated in this study. Also, we thank all the team members of the Healthy Life Project in Lagoa do Carro: a family-based study who contributed to the data collection.

Financing

This study was supported by the National Council for Scientific and Technological Development (CNPq) under grant 303621/2023-0 and the Foundation for Science and Technology Development of the State of Pernambuco (FACEPE) under grant APQ-1762-4.09/22 and APQ-0742-4.09/22.

References

American Alliance for Health Physical Education Recreation and Dance. (1980). Health Related Fitness Test Battery Manual.

Bauman, A. E., Reis, R. S., Sallis, J. F., Wells, J. C., Loos, R. J. F., & Martin, B. W. (2012). Correlates of physical activity: Why are some people physically active and others not? The Lancet, 380(9838), 258–271. https://doi.org/10.1016/S0140-6736(12)60735-1.

Bouchard, C., Malina, R. M., & Perusse, L. (1997). Genetics of Fitness and Physical Performance. Human Kinetics: Champaign, IL, USA.

Dykstra, B. J., Griffith, G. J., Renfrow, M. S., Mahon, A. D., & Harber, M. P. (2024). Cardiorespiratory and Muscular Fitness in Children and Adolescents with Obesity. Current Cardiology Reports, 1-9. https://doi.org/10.1007/s11886-024-02036-3.

Falconer, D. S., & Mackey, T. F. C. (1996). Introduction to Quantitative Genetics.pdf (4th ed.). Longamn Scientific & Technical.

Flores-Mendoza, C., Mansur-alves, M., Ardila, R., Rosas, R. D., Guerrero-leiva, M. K., Emilia, M., Maqueo, L., Gallegos, M., Reategui, N., & Burga, A. (2015). Fluid intelligence and school performance and its relationship with social variables in Latin American samples. Intelligence, 49, 66–83. https://doi.org/10.1016/j.intell.2014.12.005.

Galán-Arroyo, C., Mendoza-Muñoz , D. M. ., Mañana-Iglesia, C., & Rojo-Ramos , J. (2024). Physical fitness, indicator of healthy preadolescent development. *Retos, 52*, 447–456. https://doi.org/10.47197/retos.v52.99772.

García-Hermoso, A., Izquierdo, M., & Ramírez-Vélez, R. (2022). Tracking of physical fitness levels from childhood and adolescence to adulthood : a systematic review and meta-analysis. Translational Pediatrics, 11(4), 474–486. https://doi.org/10.21037/tp-21-507.

García-Hermoso, A., Ramírez-Vélez, R., Cavero-Redondo, I., Lee, D. C., Izquierdo, M., & Ekelund, U., ... & Ortega, F. B. (2020). Association of physical education with improvement of health-related physical fitness outcomes and fundamental motor skills among youths: A systematic review and meta-analysis. JAMA Pediatrics, e200223. https://doi.org/10.1001/jamapediatrics.2020.0223.

García-Hermoso, A., Ramírez-Vélez, R., & Cavero-Redondo, I. (2019). Is muscular fitness associated with future health benefits in children and adolescents? A systematic review and meta-analysis of longitudinal studies. Sports Medicine, 49, 1079–1094. https://doi.org/10.1007/s40279-019-01098-6.

Gaya, A., Lemos, A., Gaya, A. R., Teixeira, D., Pinheiro, E., & Moreira, R. (2012). Projeto Esporte Brasil PROESP-Br: Manual de testes e avaliação.

Goldstein, H., Browne, W., & Rasbash, J. (2002). Multilevel modelling of medical data. Statistics in Medicine, 21(23), 3291–3315. https://doi.org/10.1002/sim.1264.

Haapala, E. A., Lintu, N., & Väistö, J. (2018). Longitudinal associations of fitness, motor competence, and adiposity with cognition. Medicine and Science in Sports and Exercise, 50(3), 465–471. https://doi.org/10.1249/MSS.0000000000001455.

Haapala, E. A., Leppänen, M. H., Skog, H., Lubans, D. R., Viitasalo, A., Lintu, N., ... & Lakka, T. A. (2024). Childhood Physical Fitness as a Predictor of Cognition and Mental Health in Adolescence: The PANIC Study. Sports Medicine, 1-11. https://doi.org/10.1007/s40279-024-02107-z

Harrison, F., & Jones, A. P. (2012). A framework for understanding school based physical environmental influences on childhood obesity. Health & Place, 18(3), 639–648. https://doi.org/10.1016/j.healthplace.2011.12.009.

Hedeker, D., & Mermelstein, J. (2012). Modeling between-subject and within-subject variances in ecological momentary assessment data using mixed-effects location scale models. Statistics in Medicine, 31(27), 3328-3336. https://doi.org/10.1002/sim.5338.

Henrique, R. S., Gomes, T. N., Tani, G., & Maia, J. A. R. (2018). Association between body mass index and individual characteristics and the school context: A multilevel study with Portuguese children. Jornal de Pediatria, 94(3), 313–319. https://doi.org/10.1016/j.jped.2017.06.017.

Henrique, R. S., Bustamante, A. V., Freitas, D. L., Tani, G., Katzmarzyk, P. T., & Maia, J. A. (2018). Tracking of gross motor coordination in Portuguese children. Journal of Sports Sciences, 36(2), 220–228. https://doi.org/10.1080/02640414.2017.1297534.

Hox, J. J., Moerbeek, M., & Van de Schoot, R. (2017). Multilevel analysis: Techniques and applications (3rd ed.). Routledge.

Jabbour, G., & Majed, L. (2019). Mechanical efficiency at different exercise intensities among adolescent boys with different body fat levels. Frontiers in Physiology, 10, 1–9. https://doi.org/10.3389/fphys.2019.00265.

Katzmarzyk, P. T., Barreira, T. V., Broyles, S. T., Champagne, C. M., Chaput, J. P., & Fogelholm, M., ... & Church, T. S. (2013). The International Study of Childhood Obesity, Lifestyle and the Environment (ISCOLE): design and methods. BMC Public Health, 13(900). https://doi.org/doi.org/10.1186/1471-2458-13-900.

Kiphard, E. J., & Schilling, F. (1974). Körperkoordinationstest für Kinder: KTK. Beltz.

Lema-Gómez, L., Mario, C., Paternina, A., López, C. E., Petro, J., Petro, J. P., ... & Velásquez, F. P. (2021). Family aspects, physical fitness, and physical activity associated with mental-health indicators in adolescents. BMC Public Health, 21, 2317. https://doi.org/10.1186/s12889-021-12403-2.

Lemes, V., Gaya, A. R., Sadarangani, K. P., & Aguilar-Farias, N. (2021). Physical fitness plays a crucial mediator role in relationships among personal, social, and lifestyle factors with adolescents' cognitive performance in a structural equation model: The Cogni-Action Project. Frontiers in Pediatrics, 9, 656916. https://doi.org/10.3389/fped.2021.656916.

Lohman, T. G., Roche, A. F., & Martorell, R. (1988). Anthropometric standardization reference manual. Human Kinetics Books.

Malachias, M. V. B., Souza, W. K. S. B., Plavnik, F. L., Rodrigues, C. I. S., Brandão, A. A., Neves, M. F. T., ... & Franco, R. J. (2016). 7ª Diretriz Brasileira de Hipertensão Arterial. Arquivos Brasileiros de Cardiologia, 107(Suppl. 3), 1–83. https://doi.org/10.5935/abc.20160164.
Malina, R. M., & Mueller, W. H. (1981). Genetic and Environmental Influences on the Strength and Motor Performance of Philadelphia School Children. Human Biology, 53(2), 163–179. http://www.jstor.org/stable/41464608.
Malina, R. M. , Bouchard, C., & Bar-Or, O. (2004). Growth, maturation, and physical activity. Human kinetics. Human Kinetics: Champaign, IL, USA.
Mirwald, R. L., Baxter-Jones, A. D. G., Bailey, D. A., & Beunen, G. P. (2002). An assessment of maturity from anthropometric measurements. Medicine & Science in Sports & Exercise, 34(4), 689–694. https://doi.org/10.1097/00005768-200204000-00020.
Pawlak, K. (1984). Heritability of strength and speed: Methods of testing and evaluation. In N. Wolanski & A. Siniarski (Eds.). Genetics of psychomotor traits in man (pp. 117–135). College of Physical Education.
Pereira, S., Katzmarzyk, P. T., Gomes, T. N., Souza, M., Chaves, R. N., Santos, F. K., Santos, D., & Hedeker, D. (2017a). A multilevel analysis of health-related physical fitness: The Portuguese sibling study on growth, fitness, lifestyle, and health. PLoS ONE, 12(2), e0172013. https://doi.org/10.1371/journal.pone.0172013.
Pereira, S., Katzmarzyk, P. T., Gomes, T. N., Souza, M., Chaves, R. N., Santos, F. K. D., & Maia, J. A. R. (2017b). Multilevel modelling of soma- totype components: The Portuguese sibling study on growth, fitness, lifestyle and health. Annals of Human Biology, 44, 316–324. https://doi.org/10.1080/03014460.2016.1243727.
Plomin, R., Defries, J. C., & Knopik, V. S. (2013). Behavioral Genetics (Sixth Edit). Worth Publishers.
Reuter, C. P., Brand, C., Silveira, J. F. C., Schneiders, L. B., Renner, J. D. P., Borfe, L., & Burns, R. D. (2021). Reciprocal longitudinal relationship between fitness, fatness, and metabolic syndrome in Brazilian children and adolescents: A 3-year longitudinal study. Pediatric Exercise Science, 33(2), 74–81. https://doi.org/10.1123/pes.2020-0101.
Rodríguez-Gutiérrez, E., Torres-Costoso, A., Lucas-de la Cruz, L., Mesas, A. E., Martínez-Vizcaíno, V., & Díez-Fernández, A. (2024). The impact of reduced muscular fitness on cardiometabolic risk factors in children aged 9–11 years. Acta Paediatrica, 113(6), 1364-1372. https://doi.org/10.1111/apa.17178.
Sallis, J. F., Patterson, T. L., Morris, J. A., Nader, P. R., & McKenzie, T. L. (1989). Familial Aggregation of Aerobic Power: The Influence of Age, Physical Activity, and Body Mass Index. Research Quarterly for Exercise and Sport, 60(4), 37–41. https://doi.org/10.1080/02701367.1989.10607458
Santos, C., Bustamante, A., Vasconcelos, O., Pereira, S., Garganta, R., Lightfoot, J. T., Tani, G., Hedeker, D., Katzmarzyk, P. T., & Maia, J. (2022). Sibling Resemblances in Physical Fitness in Three Distinct Regions in Peru : The Peruvian Sibling Study on Growth and Health. Behavior Genetics, 52(3), 195–204. https://doi.org/10.1007/s10519-022-10099-7
Schilling F. (2015). Sum of raw scores of each KTK test. Personal Communication. Marburg: Philipps-Universität Marburg, 2015.
Schutte, N. M., Bartels, M., & de Geus, E. (2017). Genetics of physical activity and physical fitness. In: N. Armstrong & W. van Mechelen (Eds.), Oxford textbook of children's sport and exercise medicine (3rd ed., pp. 293–302). Oxford University Press.
Spruijt-Metz, D. (2011). Etiology, Treatment and Prevention of Obesity in Childhood and Adolescence: A Decade in Review. Journal of Research on Adolescence, 21(1), 129–152. https://doi.org/10.1111/j.1532-7795.2010.00719.x.
Swinburn, B. A., Sacks, G., Hall, K. D., Mcpherson, K., Finegood, D. T., Moodie, M. L., & Gortmaker, S. L. (2011). The global obesity pandemic: shaped by global drivers and local environments. The Lancet, 378(9793), 804–814. https://doi.org/10.1016/S0140-6736(11)60813-1.
Utesch, T., Bardid, F., Büsch, D., & Strauss, B. (2019). The relationship between motor competence and physical fitness from early childhood to early adulthood: A meta-analysis. Sports Medicine, 49(4), 541–551. https://doi.org/10.1007/s40279-019-01068-y.
Vasques, C., Vitor, P. L., Seabra, A., Fermino, R. C., & Maia, J. (2007). Sibling similarities in physical fitness. Revista Portuguesa de Ciências do Desporto, 7(1), 9.
Von Elm, E., Altman, D. G., Egger, M., Pocock, S. J., Gøtzsche, P. C., & Vandenbroucke, J. P. (2007). The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement:

guidelines for reporting observational studies. Bulletin of the World Health Organization, 85(11), 867-872. https://doi.org/10.2471/BLT.07.045120.

Welk, G. J., & Meredith, M. D. (2008). FITNESSGRAM®/ACTIVITYGRAM® reference guide (3rd ed.). The Cooper Institute.

Thomas, J. R., Nelson, J. K., & Silverman, S. J. (2022). Research methods in physical activity. Human kinetics.

Authors' and translators' details:

Thaliane Mayara Pessôa dos Prazeres	thalianemayara@hotmail.com	Author
Rafael dos Santos Henrique	rafael.shenrique@ufpe.br	Author & Translator
Leonardo Gomes de Oliveira Luz	leonardoluz.ufal@gmail.com	Author
Murilo Gominho Antunes Correia Junior	murilogominho@hotmail.com	Author
Mariana do Nascimento Sena Oliveira	mariana_sena89@hotmail.com	Author
Marcella Dantas Ribeiro	marcella.dantas@upe.br	Author
Tércio Araújo do Rêgo Barros	tercio.araujo@ufpe.br	Author
Victor Ferreira Lima	victor.ferreiralima@ufpe.br	Author
Douglas Eduardo Ferreira Maia	douglas.maia@ufpe.br	Author
Paulo Felipe Ribeiro Bandeira	paulo.bandeira@urca.br	Author
Carol Virgínia Góis Leandro	carol.leandro@ufpe.br	Author
Marcos André Moura dos Santos	mmoura23@gmail.com	Author