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Gender differences in children's physical literacy and physical activity: a network analysis

Diferenças de gênero no letramento corporal e atividade física de crianças: uma análise de redes

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ABSTRACT

Introduction: Physical literacy is a multidimensional construct that encompasses physical, cognitive, and psychological competencies essential for adopting an active lifestyle. However, significant knowledge gaps remain in understanding gender disparities across these domains, particularly when examined through complex analytical approaches. Objective: To investigate differences between boys and girls in physical activity and the cognitive (knowledge and understanding), psychological (motivation and confidence) and physical (physical fitness and motor coordination) domains of physical literacy in children, as well as to identify which variables have greater centrality using network analysis. Methods: A total of 439 schoolchildren aged 8 to 12 years from twelve public schools in Lagoa do Carro, Pernambuco, Brasil, participated in the study. The cognitive and psychological domains of physical literacy were assessed using transculturally adapted questionnaires from the Canadian Assessment of Physical Literacy – Second Edition, while the physical domain was measured through physical fitness tests and gross motor coordination. Physical activity was evaluated using the Physical Activity Questionnaire for Children questionnaire. Demographic variables such as gender, chronological age, biological maturity and body mass index were also assessed and included in the statistical analysis. Results: Network analysis revealed gross motor coordination as the most central variable for both sexes. Among girls, the network was denser, with gross motor coordination showing high betweenness (2.689) and closeness (1.408); among boys, the network was sparser, with elevated strength (1.835) and expected influence (1.800). Notably, only among boys did the psychological domain exhibit high betweenness (1.161). Conclusion: Gross motor coordination plays a structurally central role in the physical literacy and physical activity networks for both genders, though it assumes distinct centrality functions. Gender-sensitive and system-based approaches are essential to promote active and equitable lifestyles from early childhood.

Keywords: Gender studies; Exercise; Child; Nonlinear dynamics.

RESUMO

Introdução: O letramento corporal é um constructo multidimensional que integra competências físicas, cognitivas e psicológicas essenciais à adoção de um estilo de vida ativo. Entretanto, persistem lacunas de conhecimento na compreensão das desigualdades de gênero nesses domínios, especialmente quando analisadas sob abordagens complexas. Objetivo: Investigar as diferenças entre meninos e meninas nos níveis de atividade física e os domínios cognitivo (conhecimento e compreensão), psicológico (motivação e confiança) e físico (aptidão física e coordenação motora) do letramento corporal em crianças, bem como identificar que variáveis possuem maior centralidade a partir da análise de redes. Métodos: Participaram 439 escolares de oito a 12 anos de 12 escolas de Lagoa do Carro, Pernambuco, Brasil. Os domínios cognitivo e psicológico do letramento corporal foram avaliados com questionários adaptados transculturalmente do Canadian Assessment of Physical Literacy – Second Edition, enquanto o domínio físico foi mensurado por testes de aptidão física e coordenação motora grossa. A atividade física foi avaliada pelo questionário Physical Activity Questionnaire for Children. Variáveis demográficas como gênero, idade cronológica, maturação biológica e índice de massa corporal também foram avaliados e considerados na análise estatística. Resultados: A análise de redes revelou que a coordenação motora grossa foi a variável mais central em ambos os gêneros. Nas meninas, a rede foi mais densa com coordenação motora grossa apresentando alta intermediação (2,689) e proximidade (1,408); nos meninos, a rede foi mais esparsa, com elevada força (1,835) e influência esperada (1,800). Apenas nos meninos, o domínio psicológico obteve elevada intermediação (1,161). Conclusão: A coordenação motora grossa desempenha um papel central nas redes de ambos os gêneros, porém assumindo papéis distintos de centralidade. Abordagens sistêmicas e sensíveis ao gênero são necessárias para promoção de um estilo de vida ativo e equitativo na infância.

Palavras-chave: *Estudos de gênero; Exercício físico; Criança; Dinâmica não linear.*

Introduction

Adopting an active lifestyle during childhood is essential for physical, cognitive, and social development[1], with impacts that tend to continue into adulthood[2]. For children and adolescents aged 6 to 17, the recommendation is at least 60 minutes of moderate to vigorous physical activity (PA) per day, on at least three days a week[3]. This includes activities that strengthen the musculoskeletal system, such as jumping, pulling, or pushing[3]. However, in Brazil[4] and worldwide[5], over 80% of children and adolescents do not meet the minimum PA recommendations. The situation becomes even more complex when analyzed from a gender perspective, as a higher percentage of boys (26.7%) meet the PA recommendations compared to girls (9.3%)[4].

Understanding gender disparities related to various aspects of active lifestyles is a complex and multifactorial challenge. Understanding gender disparities related to various aspects of active lifestyles is a complex, multifactorial challenge. These differences are influenced by various factors, including individual characteristics such as age and biological maturation[6], physical traits such as physical fitness and motor performance[7], behavioral attributes such as adherence to PA and sports[8], environmental conditions such as the availability of practice spaces[9], and political influences such as public policies supporting gender equity in PA promotion[10]. Since these factors interact dynamically and interdependently, approaches that integrate physical, cognitive, and psychological skills are essential.

In the face of the challenge of understanding how children and adolescents become engaged in PA throughout their lives, the concept of physical literacy (PL) has gained prominence in global literature[11]. The PL is a conceptual structure consisting of three interrelated domains: the cognitive domain, which involves knowledge and understanding of the elements necessary for adopting an active and healthy lifestyle; the psychological domain, which is linked to the motivation and confidence required for engaging in PA and sports; and the physical domain, which concerns the motor competence and physical fitness necessary for effectively participating in PA throughout life[12].While the International Physical Literacy Association[12] recognizes these three domains as central, various instruments are used to assess PL around the world. These instruments meet the specific needs of each region, culture, and philosophical basis[13,14], but hinder the implementation of tools that are used uniformly globally. In Canada, one of the countries that has proposed measures of PL, the behavioral domain is considered[15]. However, countries such as Australia and Wales consider the social domain but not the behavioral domain in their assessments.

Studies conducted in the Northern hemisphere have reinforced the relevance of PL. In Canada, for instance, Bélanger et al.[16] found that children who did not meet PA recommendations had significantly lower PL psychological domain scores, averaging 12.4 points out of 18, compared to 13.3 points for those who met the recommendations. In Spain, adolescents with higher levels of PL demonstrated greater handgrip strength and lower-limb power[17]. Additionally, boys tend to have higher PL scores than girls, particularly in the physical domain[18]. These findings suggest that the domains of PL interact dynamically and are influenced by various individual, social, and environmental factors. Properly understanding these interrelationships requires analytical approaches that consider the complexity and nonlinear nature of these phenomena.

In this sense, nonlinear approaches have been proposed to understand these components and their interactions[19], which form a complex, dynamic system. Network analysis emerges as a complementary alternative to traditional statistical models, enabling the investigation of multidimensional, nonlinear relationships between variables[20]. While linear models, such as correlations and regressions, are limited in their ability to capture such dynamics, network analysis enables the identification of connectivity and relevance patterns between variables based on centrality indicators such as betweenness, closeness, strength, and expected influence.

Despite the growing body of evidence on the importance of PL, research exploring the complex interrelationships between PA and PL domains, as well as other health indicators in boys and girls, which has not yet been examined using network analysis. This approach is essential for understanding the central elements (relevant nodes and pathways) that can promote gender equity in the adoption of active and healthy lifestyles. Given the above, the present study aims to investigate the differences between boys and girls in PA levels and the cognitive (knowledge and understanding), psychological (motivation and confidence), and physical (physical fitness and motor coordination) domains of PL in children, as well as to identify which variables have greater centrality based on network analysis.

Methods

Sample

This research is part of the "Healthy Life in Lagoa do Carro" study, which analyzed the relationship between physical and motor development and the health aspects of children and adolescents in Lagoa do Carro, Pernambuco, Brazil. It is a population-based, observational study with a cross-sectional design[21]. In this study, 1,359 children between the ages of five and fifteen who were enrolled in all twelve public elementary schools (six rural and six urban) were evaluated between April and November 2018, in accordance with the school calendar. A detailed description of the schools' characteristics can be found in the study by Maia et al.[22]

Since the PL assessment is only valid for children between eight and twelve years of age[23,24], only participants in this age group who did not have disabilities, disorders, or other physical or cognitive restrictions that prevented them from taking the measurements and/or questionnaires were considered. Furthermore, only participants who completed all the measurements in this study were considered. Thus, the final sample consisted of 439 children (216 girls, 49.2%; and 223 boys, 50.8%), aged between eight and twelve years (10.2 ± 1.2 years).

The children were assessed individually over two days. On the first day, anthropometric measurements were taken, and questionnaires and gross motor coordination (GMC) tests were administered. The following day, physical fitness tests were conducted. Missing data was collected during an additional visit when necessary. All children from each school were invited to participate, resulting in a response rate of over 95%. Parents or guardians provided informed consent for their child's participation in the study. The study adhered to the principles of the Declaration of Helsinki and received approval from the Research Ethics Committee of the University of Pernambuco (CAAE: 83143718.3.0000.5192; CEP/UPE: 2520417) as well as formal consent from the principals of all participating schools.

Instruments and procedures

- **Anthropometry**

Anthropometric measurements (height and body mass) were obtained in accordance with the Lohman, Roche, and Martorell[25] standard, employing a digital scale (Filizola, São Paulo, Brazil), with a precision of 0.1 kilograms, and a portable stadiometer (Sanny, São Paulo, Brazil), with a precision of 0.1 centimeters. Based on these measurements, body mass index (kg/m^2) was calculated.

- **Biological maturation**

Biological maturation was assessed using the maturity offset[26] calculation. This calculation uses gender-specific equations based on age, height, sitting height, and lower limb length. This method estimates the number of years it will take to reach peak growth velocity. A positive maturity offset value indicates how many years the participant is beyond peak height velocity, while a negative value indicates how many years the participant is before peak height velocity.

- **Physical activity**

The Physical Activity Questionnaire for Children, adapted cross-culturally for Brazilian children[27], was used to measure PA. The instrument includes nine questions about PA practices over the past seven days. These questions cover the frequency of PA and sports during free time, as well as moderate to vigorous PA during physical education classes, recess, and specific daily periods (morning, afternoon, evening, and weekend). Additionally, the questionnaire asks about the intensity of PA during the last seven days and the frequency of intense PA each day of the week. Answer options are scored on a Likert scale from one to five points.

- **Physical literacy**

The PL, which includes cognitive, psychological, and physical domains, was evaluated using different instruments. The physical domain included measures of physical fitness and GMC, while the cognitive and psychological domains of the PL were assessed using cross-culturally adapted and validated versions for Brazilian children[13,24] of questionnaires from the Canadian Assessment of Physical Literacy – Second Edition[15]. Since only the questionnaires were adapted and not the entire Canadian Assessment of Physical Literacy - Second Edition instrument, the raw scores for these domains were treated separately with the same weighting.

- **Cognitive domain**

The cognitive domain questionnaire covers four areas of knowledge and understanding: (1) knowledge of daily PA recommendations and sedentary behavior, (2) knowledge of definitions related to cardiorespiratory and musculoskeletal fitness, (3) understanding of ways to improve physical competence, and (4) understand-

ing of what it means to be healthy. For the first three areas, participants were asked to select one of four possible answers, only one of which was correct. For the fourth area, participants circled what "being healthy" meant to them. They received one point for a correct answer and zero for an incorrect one. The total number of points could range from zero to nine and was used for analysis purposes.

- **Psychological domain**

The psychological domain questionnaire contains eight items and comprises three areas: (1) perceived competence in PA and sports, (2) predilection, or liking PA, and (3) adequacy, or feeling good enough, in PA. For the perceived competence items, children were asked to rate themselves on a scale from 1 to 10, with higher values indicating greater competence. For the predilection and adequacy items, participants first circled the statement that best described their situation (e.g., "Some children don't have much fun playing sports," or "Other children have fun playing sports"), and then chose whether that statement was "Really true for me" or "Almost true for me." The perceived competence item scores (1–10) were divided by four, and the predilection and adequacy responses were scored from 0.6 to 2.5. The sum of these scores was used to analyze the data, which could range from 4.1 to 20 points.

- **Physical domain**

The physical domain was measured using GMC and physical fitness, as detailed below.

- **Gross motor coordination**

GMC was assessed using the Körperkoordinationstest für Kinder[28] battery, which includes the following tests:

- Walking backwards: the child walks backward on a balance beam 3 m in length, with a progressive reduction of widths (6.0 cm, 4.5 cm, and 3.0 cm). A maximum of 24 steps (eight per trial) were counted for each balance beam, which comprises a maximum of 72 steps (24 steps × 3 beams) for this test.
- Jumping sideways: the child makes consecutive jumps from side to side over a small beam (60 cm × 4 cm × 2 cm) as fast as possible for 15 seconds. The number of jumps over two trials was summed.
- Hopping for height on one foot: the child is instructed to hop on one foot at a time over a stack of foam squares; after a successful hop with each foot, the height is increased by adding a square (50 cm × 20 cm × 5 cm)
- Moving sideways: the child begins by standing with both feet on one platform (25 cm × 25 cm × 2 cm supported on four legs 3.7 cm high), places the second platform alongside the first and steps on to it, the first platform is then placed alongside the second and the child steps on to it, the sequence continues for 20 seconds. The number of relocations was counted. It was summed over two trials.

The raw scores from all the tests were summed up to obtain a total GMC score.

- **Physical fitness**

Physical fitness was assessed using the Fitnessgram[29], American Alliance for Health, Physical Education, Recreation and Dance[32] and *Projeto Esporte Brasil*[31] tests. The following measures were used: (1) meters covered in the Progressive Aerobic Cardiovascular Endurance Run (PACER; cardiorespiratory fitness); (2) distance reached in the sit-and-reach test (flexibility); (3) maximum handgrip strength of the dominant limb (upper-limb strength); (4) maximum distance in the horizontal jump (lower-limb strength and power); (5) speed in meters per second (m/s) in the 20-meter linear run (speed); and (6) speed in m/s in the 4x10-meter shuttle run (agility). For analysis purposes, the results of each test were treated individually.

Quality control

Data quality control was assessed in four phases. First, the project coordinators conducted systematic training with the team of evaluators on the methodological procedures. A pilot study was then conducted in a school in Lagoa do Carro to determine the approximate time required for data collection. Third, reliability procedures were conducted in the field. Three to five students from each school were randomly selected on alternate assessment days and retested one week apart for a total of 42 students. The technical measurement error was 0.2 cm for height, 0.1 kg for body mass, and 0.1 cm for sitting height, respectively. Test-retest reliability for motor tests ranged from 0.81 (WB) to 0.96 (HH) for GMC and from 0.81 (4x10-meter shuttle run) to 0.95 (sit-and-reach) for physical fitness. The final stage involved double entering the information and checking all the data for tabulation errors or inconsistencies.

Statistical analysis

Descriptive statistics (means and standard deviations) were calculated for each variable, stratified by gender. The Kolmogorov-Smirnov test was used to assess normality, and the Levene test was used to assess homogeneity of variance. Differences between genders were assessed using a t-test for independent samples. To obtain greater reliability of the results and correct for deviations from sample normality and differences between group sizes, bootstrapping procedures were carried out (1000 resamples). The effect size was estimated using Cohen's d, considering the following cut-off points: <0.20 (trivial), 0.20–0.59 (small), 0.60–1.19 (moderate), 1.20–1.99 (large), 2.00–3.99 (very large), and ≥4.0 (extremely large).

Network analysis was used to examine the relationships between chronological age, biological maturation, PA, PL, physical fitness, GMC, and body mass index, separately by gender. The network is represented by a topology graph in which the nodes correspond to the variables and their relationships (lines)[32]. Blue lines indicate direct associations, and red lines indicate inverse associations[32]. Additionally, the thickness and intensity of the lines show the magnitude of the associations. Each node's importance within the network is determined by its centrality, representing its structural relevance; higher values indicate greater relevance[33]. Four indices were considered to analyze the centrality of the nodes: betweenness, which indicates a node's position on the average path between another pair of nodes; closeness, defined as the inverse of the average shortest distance between a node and the other nodes in the network; strength, which is the sum of all the weights of the paths connecting a node to the others; and expected influence, which estimates the magnitude of the relationships based on the negative and positive edges connecting a node to the others.

The Fruchterman and Reingold[34] algorithm was applied to calculate and visualize the network. The data shows the relative space between the variables, separating the weaker associations while keeping the strong ones together. To increase the network's accuracy, the "Markov pair random fields" algorithm was used. The regulation was determined by an absolute minimum selection and contraction operator designed to manage the network's sparse nature[33]. The extended Bayesian information criterion was used to mitigate spurious associations. The hyperparameter (y) establishes the amount of the extended Bayesian information criterion that selects sparse models. For this analysis, y was set to 0.50. Network analysis uses absolute minimum shrinkage to obtain the precision matrix. After standardization, the matrix portrays the associations between the variables in the network. These analyses were conducted using JASP 19.2 software.

Results

Table 1 shows the gender differences in all variables. Boys were slightly older and less mature, with a lower body mass index. The boys were also more active, had a higher GMC and performed better in the physical fitness tests, except for flexibility, which showed no difference between the genders (Table 1). There were no significant gender differences in the cognitive and psychological domain scores of the PL (p > 0.05).

Table 1 – Descriptive data (mean ± standard deviation) of the participants (n = 439).

Variables	Girls (n = 216)	Boys (n = 223)	t	p	d de Cohen
Age (years)	10.02 ± 1.16	10.34 ± 1.22	-2.97	0.04	0.15
Maturity offset (years)	-1.66 ± 1.11	-3.03 ± 0.99	13.59	< 0.001	1.30
Body mass index (kg/m2)	18.28 ± 3.81	17.58 ± 2.89	2.08	0.04	0.20
Physical literacy – Motivation and Confidence (points)	14.67 ± 3.31	15.17 ± 2.89	-1.80	0.07	0.16
Physical literacy – Knowledge and Understanding (points)	5.23 ± 1.40	5.07 ± 1.45	1.16	0.24	0.11
Physical activity (points)	2.49 ± 0.74	2.78 ± 0.77	-3.90	< 0.001	0.38
Körperkoordinationstest für kinder-KTK (points)	151.57 ± 38.37	177.17 ± 45.06	-6.32	< 0.001	0.61
Progressive Aerobic Cardiovascular Endurance Run (m)	352.87 ±181.31	476.59 ±262.66	-5.77	< 0.001	0.54
Handgrip strength (KgF)	16.01 ± 4.39	17.61 ± 4.47	-3.80	< 0.001	0.36
Sit and reach (cm)	25.28 ± 6.52	24.66 ± 6.57	0.99	0.32	0.09
Standing long jump (cm)	112.50 ± 21.26	128.29 ± 22.97	-7.44	< 0.001	0.71
20-m linear run (m/s)	4.15 ± 0.49	4.57 ± 0.47	-8.79	< 0.001	0.85
4x10-m shuttle run(m/s)	2.69 ± 0.25	2.91 ± 0.30	-8.11	< 0.001	0.78

Figures 1a and 1b illustrate the relationships between PL variables in the cognitive, psychological, and physical domains (including physical fitness tests and GMC), as well as in the PA and demographic indicators (e.g., age, biological maturation, and body mass index), separately by gender.

Table 2 summarizes the network analysis and presents the centrality indicators. Among the girls, 39 of the 78 possible nodes were observed, resulting in a sparsity value of 0.500. Among the boys, only 27 of the possible 78 nodes were connected, leading to higher sparsity (0.654). These results suggest that boys' and girls' networks differ in density and connectivity.

In betweenness, the variable with the highest centrality for girls was GMC (2.689). For boys, higher values were found for age (2.364), GMC (1.161), and the PL motivation and confidence score (1.161). In the closeness indicator, the highest value among girls was GMC (1.408), while among boys the highest value was observed for the PL knowledge and understanding score (0.927). Regarding strength, girls showed high values for biological maturity (1.462) and GMC (1.396), while boys showed high values for GMC (1.835) and chronological age (1.272). Finally, the highest values in expected influence were observed for biological maturity (1.895) and GMC (1.241) among girls and for GMC (1.800) and age (1.420) among boys. These results demonstrate the strong capacity of these variables to influence other nodes in the network.

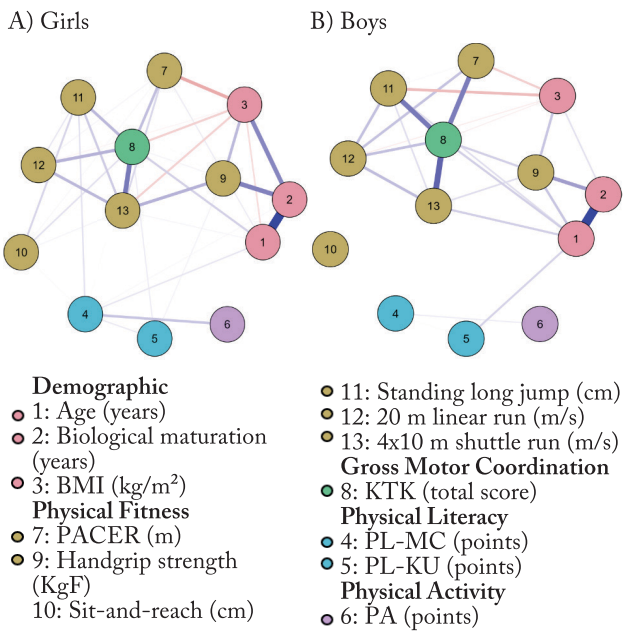

Figure 1 – a and b. Network for associations between body literacy variables for the cognitive (PL-KU, knowledge and comprehension), psychological (PL-MC, motivation and confidence), physical (physical fitness and gross motor coordination tests), physical activity and demographic indicators (age, biological maturation and body mass index) domains, separately by gender (boys and girls). Red lines, negative associations; blue lines, positive associations. Note. PA, Physical activity; BMI, Body mass index; PL-KU, Physical literacy - knowledge and comprehension; PL-MC, Physical literacy - motivation and confidence; KTK, Körperkoordinationstest für Kinder; PACER, Progressive Aerobic Cardiovascular Endurance Run.

Discussion

This study is the first to use network analysis to explore the interrelationship between the cognitive, psychological, and physical domains of PL and PA, focusing on the gender gap. Our findings, based on a complex systems approach, contribute to the understanding of central variables that may be fundamental for the formulation of strategies and public policies to address gender inequality in Brazilian children aged eight to twelve. This ensures that GMC can boost children's integral development and consequently equitable access to movement opportunities and the adoption of active and healthy lifestyles in boys and girls.

The gender differences observed in physical fitness, GMC, and PA measures corroborate previous studies indicating that boys engage in PA and sports more frequently from childhood onwards[7,35]. These inequalities are not solely due to biological predisposition but rather are the result of the social construction of gender roles[36]. In this construction, boys tend to be encouraged to play sports and engage in vigorous PA, while girls face cultural, institutional, and environmental barriers[10].

Network analysis provides a deeper understanding of these inequalities, showing that GMC acts as a central node for both genders but with different structural properties. For girls, the GMC stood out due to its high degree of betweenness, closeness, and strength. This suggests that the GMC plays a prominent role in connecting the different components of the network. For boys, the GMC showed high strength and expected influence. These findings establish GMC as a primary hub linking variables associated with children's lifestyles, reinforcing its pivotal role in fostering complete and healthy motor development during childhood[19].

Network analysis shows that the girls' network had fewer sparse connections, resulting in a more interconnected and cohesive structure than the boys. This high density suggests that the assessed variables, such as GMC, physical fitness, motivation, and confidence, are closely related and mutually dependent. According to graph theory, highly dense networks can paradoxi-

cally be more structurally fragile[20]. This is because in strongly connected systems, weakening a single component can more easily spread to others and negatively affect the network's overall functioning. Thus, in the girls' network, a loss of motivation or confidence, or low physical fitness, for example, could negatively affect other aspects of PL and PA practice. Conversely, sparse networks, as observed in the boys' network, tend to be less susceptible to this type of systemic propagation. However, they depend more on central nodes with greater strength and influence, such as GMC[33].

These findings suggest that, for girls, intervention strategies should be designed to develop and protect the integrity of greater centrality.

These findings suggest that intervention strategies for girls should focus on developing and protecting the integrity of greater centrality, particularly in contexts of social vulnerability where adverse external factors can hinder motor development and exacerbate inequalities in GMC acquisition[41]. Recent studies have indicated that interventions to promote GMC should encourage movement variability, autonomy, cognitive engagement, and creativity[38]. By requiring exploration of creative solutions and resolution of motor problems imposed by task constraints and the environment, these interventions holistically boost PA, cognition, and socio-emotional skills[38]. For these benefits to be realized fully and equitably, interventions must be sensitive to gender-specific challenges posed by social vulnerability.

Among demographic variables, age was a central node in boys' networks, particularly in measures of expected influence and betweenness. Thus, advancing age represents a progressive accumulation of movement opportunities and skills that develop the physical component of PL, particularly GMC and physical fitness[39]. In girls, however, biological maturation showed greater strength and expected influence. This difference underscores the importance of considering the maturation period in girls' PL, an area that has not yet been explored in the literature, particularly given the hormonal changes that promote greater fat accumulation in girls[40], unlike boys, who tend to gain lean mass during puberty.

The psychological dimension of PL, including motivation and confidence, only played a relevant role in the boys' network and was directly associated with PA and age. Studies show that boys tend to report greater perceived competence and motivation for PA as a result of greater exposure to organized sports, practice, and

Table 2 – Measures of centrality for the variables age, biological maturation, physical activity, body mass index, physical fitness, gross motor coordination and physical literacy, according to gender

Variables	Betweenness		Closeness		Strength		Expected influence	
	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys
Age (years)	0.740	2.364	0.664	-0.266	0.730	1.272	0.744	1.420
Maturity offset (years)	0.480	0.067	0.562	-0.388	1.462	0.717	1.895	0.900
Body mass index (kg/m²)	-0.170	-0.808	0.502	-0.843	0.838	-0.088	-1.458	-1.343
Physical literacy – Motivation and Confidence (points)	-0.820	1.161	-1.768	0.557	-1.337	-1.088	-0.931	-0.789
Physical literacy – Knowledge and Understanding (points)	0.610	0.286	-0.817	0.927	-0.757	-1.223	-0.345	-0.915
Physical activity (points)	-0.820	-0.808	-1.586	0.037	-1.296	-1.247	-0.888	-0.938
Körperkoordinationstest für kinder-KTK (points)	2.689	1.161	1.408	0.655	1.396	1.835	1.241	1.800
Progressive Aerobic Cardiovascular Endurance Run (m)	-0.820	-0.808	0.156	-0.313	-0.296	-0.035	-0.915	-0.291
Handgrip strength (KgF)	-0.430	-0.261	0.574	0.521	0.155	0.213	0.575	0.428
Sit and reach (cm)	-0.820	-0.808	-1.094	-0.242	-1.080	-1.344	-0.671	-1.029
Standing long jump (cm)	0.220	-0.480	0.485	0.383	-0.328	0.426	0.088	-0.050
20-m linear run (m/s)	-0.820	-0.808	-0.042	0.437	-0.491	0.094	-0.198	0.139
4x10-m shuttle run(m/s)	-0.040	-0.261	0.955	-0.046	1.004	0.467	0.865	0.666
Summary of network analysis	Girls				Boys			
Number of nodes	13				13			
Number of connected nodes	39 / 78				27 / 78			
Sparsity	0.500				0.654			

positive reinforcement in school and family contexts[10]. Despite the important role of the psychological aspect of PL for boys, future research should address other elements that influence movement opportunities during childhood. These elements include parental and friend support, socioeconomic status, and access to public policies that ensure equitable access to PA programs.

Lagoa do Carro has one of the lowest human development indexes (0.609) in the state of Pernambuco, ranking 3,927th out of 5,565 municipalities nationwide. Additionally, the Social Vulnerability Index indicates high vulnerability in Lagoa do Carro (0.471), particularly in the domains of urban infrastructure (0.465) and income and work (0.436), as well as in the human capital domain (0.512). More than 90% of school-age children in the municipality receive government assistance (Bolsa Família), which is only available to families with a per capita income of less than 178 reais. The municipality also has accentuated insecurity, disorderly traffic, and a lack of public spaces for recreation and leisure. This reduces opportunities to practice PA and restricts access to diverse motor experiences.

Despite the findings, there are some limitations that need to be considered. First, the cross-sectional design prevents attributing causality to the observed relationships. Additionally, PA was assessed using subjective measures, which may be susceptible to social desirability and recall bias. For logistical and financial reasons, PA was not assessed using accelerometers, although subjective measures of PA have been used internationally in PL studies. The questionnaires used to assess PA were previously adapted and validated for the Brazilian context. However, it should be noted that psychological and cognitive domains are subjective, which may imply additional psychometric limitations, especially in different cultural contexts. Finally, the exclusive sample from Lagoa do Carro may limit generalization to other age groups, geographic regions, or more favorable socioeconomic strata. However, it should be noted that the sample included over 90% of schoolchildren between the ages of eight and twelve enrolled in the Lagoa do Carro municipal school system.

Among its strengths, we highlight network analysis as a promising tool for understanding the complexity of these systems and their implications for gender equality. Network analysis is relevant to society because it can identify interrelationships and central nodes in the set of variables that influence children's health, such as PL, PA, physical fitness, and GMC. This in-depth understanding of gender-specific vulnerabilities and points of influence is crucial for designing more effective, targeted interventions. Nevertheless, longitudinal studies using network analysis are necessary to follow the evolution of these structures over time. This will continuously strengthen the foundation for educational programs and public policies that promote an active and healthy lifestyle from childhood. These programs must be sensitive to gender and social context.

The results of this study show that GMC, from the physical domain, emerged as a central variable in the PL and PA networks for both genders but with different degrees of centrality. Motivation and confidence, from the psychological domain of PL, play a significant role exclusively among boys. Meanwhile, biological maturation is more influential among girls. Network analysis proved to be a powerful tool for revealing the interdependence between variables and highlighting specific paths for promoting active lifestyles with gender equity. These findings reinforce the importance of interventions that promote GMC development, motivation, and confidence to practice PA, especially in contexts of high social vulnerability. Public policies and programs promoting an active lifestyle in childhood should incorporate integrated, systemic, and gender-sensitive approaches to promote full, healthy, and equitable development from childhood onward.

Conflict of interest

The authors declare no conflict of interest.

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Authors' contribution

Lira Filho RS: Software development, implementation, and testing; Data analysis; Research; Data curation; Data presentation design; Writing the original manuscript; Writing - review and editing; Approval of the final version of the manuscript. Oliveira G: Data analysis; Writing of the original manuscript; Writing - revision and editing; Approval of the final version of the manuscript. Oliveira NS: Research; Data curation; Writing - revision

and editing; Approval of the final version of the manuscript. Lourenço ABF and Sobral IRS: Research; Writing - review and editing; Approval of the final version of the manuscript. Barros TAR: Design of the data presentation; Writing of the original manuscript; Writing - revision and editing; Approval of the final version of the manuscript. Pacheco ALG and Bandeira PFR: Design of the data presentation; Writing - revision and editing; Approval of the final version of the manuscript. Santos MAM: Provision of tools; Project management; Receipt of funding; Writing - revision and editing; Approval of the final version of the manuscript. Prazeres TMP: Research; Provision of tools; Supervision; Project management; Writing - revision and editing; Approval of the final version of the manuscript. Henrique RS: Conceptualization; Methodology; Development, implementation and testing of software; Validation of data and experiments; Data analysis; Research; Provision of tools; Data curation; Supervision; Project administration; Design of data presentation; Receipt of funding; Writing of the original manuscript; Writing - revision and editing; Approval of the final version of the manuscript.

Statement regarding the use of artificial intelligence tools in the process of writing the article

The authors did not use artificial intelligence tools to prepare the manuscript.

Availability of research data and other materials

After publication, the data will be available on demand to the authors.

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Reviewers' assessment

The reviews of this article were originally conducted in Portuguese. This version has been translated using ChatGPT and subsequently reviewed by the Chief Editors.

Reviewer A

Anonymous

Format

- Does the article comply with the manuscript preparation rules for submission to the Revista Brasileira de Atividade Física e Saúde?
  Yes
- Regarding formal aspects, is the manuscript well structured, containing the sections: introduction, methods, results, and discussion (with the conclusion as part of the discussion)?
  Yes
- Is the language appropriate, and is the text clear, precise, and objective?
  Yes
- Was any evidence of plagiarism observed in the manuscript?
  No

Suggestions/comments:

- Nothing to comment

Abstract

- Are the abstract (in Portuguese) and the abstract (in English) appropriate (containing: objective, information about study participants, variables studied, main results, and a conclusion) and do they reflect the content of the manuscript?
  Yes

Suggestions/comments:

- Minor corrections: include the abbreviation PA (physical activity). Replace the keyword exercise with physical activity.

Introduction

- Was the research problem clearly explained and delimited?
  Yes
- Is the research problem adequately contextualized in relation to the knowledge already available, moving from general to specific?
  Yes
- Are the reasons that justify (including the authors' assumptions about the problem) the need for the study well established in the writing?
  Partially
- Are the references used to support the presentation of the research problem current and relevant to the topic?
  Yes
- Was the objective clearly presented?
  Yes

Suggestions/comments:

- Include more information on how this score (LC) is calculated and what the "weight" of each domain in this score is.
- Page 4, lines 4–5: In Canada, for example, Belanger et al.15 observed that children who did not meet PA recommendations had significantly lower scores in the psychological domain of LC. What was this value? Provide more contextualization of the result interpretations.
- Include more information about the need for this study at the end of the introduction, contextualizing the research problem.

Methods

- Are the methodological procedures generally appropriate for the study of the research problem?
  Yes
- Are the methodological procedures adopted for the study sufficiently detailed?
  Yes
- Was the procedure adopted for participant selection or recruitment appropriate for the research problem and described in a sufficient, clear, and objective manner?
  Yes
- Were details provided on the instruments used for data collection, their psychometric properties (e.g., reproducibility, internal consistency, and validity), and, where relevant, the operational definition of variables?
  Yes
- Is the data analysis plan appropriate and adequately described?
  Yes
- Were the inclusion and/or exclusion criteria for

study participants described and appropriate?
Yes
- Did the authors provide information on the ethical procedures adopted for the study?
Yes

Suggestions/comments:
- Include more information on how this score (LC) is calculated and what the "weight" of each domain in this score is.

Results

- Is the use of tables and figures appropriate and does it facilitate the adequate presentation of the study results?
Yes
- Is the number of illustrations in the article consistent with the journal's submission guidelines?
Yes
- Are the number of participants at each stage of the study, as well as the number and reasons for losses and refusals, presented in the manuscript?
Yes
- Are participant characteristics presented and sufficient?
Yes
- Are the results presented appropriately, highlighting the main findings and avoiding unnecessary repetition?
Yes

Suggestions/comments:
- Review the line colors in Figures 1a and 1b: Red lines = negative associations; Blue lines = positive associations. In the file, the lines appear lilac or purple.
- Did the authors collect any socioeconomic data to characterize the sample? If so, I suggest including them in Table 1.

Discussion

- Are the main findings of the study presented?
Yes
- Are the study's limitations and strengths presented and discussed?
Yes
- Are the results discussed in light of the study's limitations and existing knowledge on the subject?
Yes
- Are the potential contributions of the main findings to scientific development, innovation, or real-world interventions discussed by the authors?
Partially

Suggestions/comments:
- Page 12, lines 3–7: Include more information on the practical implications of this important study. For example, how can this analysis help physical education teachers, school administrators, and policymakers? What is the contribution of the knowledge generated by this article to the work of these professionals and to decision-making in the field?
- Page 13, lines 9–13: "These findings suggest that, for girls, intervention strategies should be designed to develop and protect the integrity of the most central components (CMG), especially in contexts of social vulnerability, where adverse external factors may destabilize the network more easily." I suggest including examples of intervention strategies here.
- Page 14, lines 20–23: "Among the strengths, we highlight network analysis as a promising tool for understanding the complexity of these systems and their implications for gender equity. However, longitudinal studies using network analysis are suggested to follow the evolution of these structures over time. The findings of this study reinforce the importance of educational programs and public policies that promote LC and CMG from childhood, with approaches sensitive to gender and social context." I suggest emphasizing once again, in practical terms, the importance of using this type of analysis for society.

Conclusion

- Was the study conclusion presented appropriately and consistent with the study objective?
Yes
- Is the study conclusion original?
Yes

Suggestions/comments:
- Nothing to comment

References

- Are the references up-to-date and sufficient?
Yes
- Is the majority composed of original research articles?
Yes
- Do the references meet the journal's standards [quantity and format]?
Yes

- Are the in-text citations appropriate, i.e., do the statements in the text cite references that truly support such statements?
  Yes
  Suggestions/comments:
- Nothing to comment

Comments to the author

- The article addresses a relevant and timely topic. It is well written and complies with the journal's standards. As a suggestion, I recommend explaining the calculation of the LC score more clearly and highlighting the importance of interpreting the results in practical contexts, including some examples to illustrate these points.
- Minor wording adjustments are also needed to improve clarity. Detailed comments are described in the review and highlighted in the attached file.

Final decision

- Minor revisions required

Reviewer B

Anonymous

Format

- Does the article comply with the manuscript preparation guidelines for submission to the Revista Brasileira de Atividade Física e Saúde?
  Yes
- Regarding formal aspects, is the manuscript well structured, containing the following sections: introduction, methods, results, and discussion (with the conclusion as part of the discussion)?
  Yes
- Is the language appropriate, with the text being clear, precise, and objective?
  Yes
- Was any evidence of plagiarism observed in the manuscript?
  No
  Suggestions/comments:
- The article format complies with the journal's standards.

Abstract

- Are the abstract (in Portuguese) and the abstract (in English) appropriate (including: objective, information on study participants, variables studied, main results, and a conclusion) and do they reflect the manuscript's content?
  Yes
  Suggestions/comments:
- The abstract is adequate.

Introduction

- Was the research problem clearly explained and delimited?
  Yes
- Is the research problem adequately contextualized in relation to the existing knowledge, moving from general to specific?
  Yes
- Are the justifications (including the authors' assumptions about the problem) for the need for the study well established?
  Yes
- Are the references used to support the presentation of the research problem current and relevant to the topic?
  Yes
- Was the objective clearly stated?
  Yes
  Suggestions/comments:
- The research problem and study objective are clear and consistent with the research proposal.

Methods

- Are the methodological procedures generally adequate for the study of the research problem?
  Yes
- Are the methodological procedures adopted for the study sufficiently detailed?
  Yes
- Was the procedure adopted for the selection or recruitment of participants adequate for the research problem and clearly and objectively described?
  Partially
- Were details provided about the instruments used for data collection, their psychometric properties (e.g., reproducibility, internal consistency, validity), and, when applicable, the
- operational definition of variables?
  Yes
- Is the data analysis plan adequate and sufficiently described?
  Yes
- Were the inclusion and/or exclusion criteria for par-

ticipants described and appropriate for the study?
Yes
- Did the authors provide clarification about the ethical procedures adopted in conducting the study?
Yes

Suggestions/comments:
- In the "Methods" section, regarding the study sample, it would be helpful to explain how the schools were selected and to provide their characterization, such as location (peripheral or central), since these factors may influence the results.

Results
- Is the use of tables and figures appropriate and does it facilitate the proper presentation of study results?
Yes
- Is the number of illustrations in the article consistent with the journal's submission guidelines?
Yes
- Are the number of participants at each stage of the study, as well as the number and reasons for dropouts and refusals, presented in the manuscript?
Yes
- Are the participants' characteristics presented and sufficient?
Partially
- Are the results presented adequately, highlighting the main findings and avoiding unnecessary repetition?
Yes

Suggestions/comments:
- The results are appropriately presented in the study.

Discussion
- Are the main findings of the study presented?
Yes
- Are the limitations and strengths of the study presented and discussed?
Yes
- Are the results discussed in light of the study's limitations and the existing knowledge on the subject?
Yes
- Do the authors discuss the potential contributions of the main findings to scientific development, innovation, or practical application?
Yes

Suggestions/comments:
- The discussion is consistent with the study's findings and engages with the authors cited throughout the text.

Conclusion
- Was the study conclusion presented appropriately and coherently with the study objective?
Partially
- Is the study conclusion original?
Yes

Suggestions/comments:
- The conclusion could further explore the study's findings; it is too succinct. I suggest highlighting the main results.

References
- Are the references up to date and sufficient?
Yes
- Are most of them composed of original research articles?
Yes
- Do the references comply with the journal's formatting guidelines [quantity and style]?
Yes
- Are in-text citations appropriate, i.e., do the statements in the text cite references that indeed substantiate them?
Yes

Suggestions/comments:
- The references are appropriate.

Comments to the author
- The study presents a relevant proposal on the theme of Physical Literacy, a contemporary topic widely discussed nowadays. The research covers a context of different schools and numerous children, presents good methodological organization by using various investigative instruments, and demonstrates great potential for advancing the study of the topic.

Final decision
- Minor revisions required