Dose-response relationship of weekly physical exercise on fitness of students

Relación dosis-respuesta del ejercicio físico semanal en la forma física de los estudiantes

Authors

Carla LOURENÇO[1,2,3]
Omar BEN RAKAA[4*]
João VICENTE[2]
Mustapha BASSIRI[4]
Said LOTFI[4]

[1] Polytechnic Institute of Viseu, Portugal
[2] University of Beira Interior, Covilhã, Portugal
[3] CI&DEI (Centre for Studies in Education and Innovation), Portugal
[4] Normal Higher School (ENS-C), Hassan II University of Casablanca Morocco

Corresponding author:
Omar Ben Rakaa
omarbenrakaa@gmail.com

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Abstract

Introduction. Childhood obesity and sedentary lifestyles highlight the critical need to understand the impact of physical exercise on fitness. This study investigates the dose-response relationship between weekly exercise volume and physical fitness components in adolescents using Portugal's FITescola® assessment program.
The objective of this study is to evaluate the influence of weekly physical exercise duration (2–8.75 hours) on aerobic capacity, muscular strength, and flexibility in 80 adolescents (aged 13–15) over one academic semester. Methodologies**.** A cohort of 80 adolescents (56.25% female; 43.75% male) completed FITescola® assessments, including completed FITescola® assessments, including cardiorespiratory endurance, lower-body explosive strength, upper-body muscular endurance, abdominal muscular endurance, and lower-body flexibility. Data were analyzed via ANOVA and Pearson correlations (SPSS v29), controlling for habitual physical activity (tracked via the Portuguese Youth Activity Profile) and socioeconomic factors.
Results**.** Significant dose-dependent improvements were observed with increased exercise volume: Shuttle test: Performance increased from 45.77±5.643 (2hours/week) to 115.2±3.962 (8.75 hours/week; $p<.001$). Sit-ups: Scores improved from 59.79±4.961 to 69.63±8.021 repetitions ($p<.001$). Lower-limb flexibility: Progressed from 14.92±3.120 cm to 22.46±3.575 cm ($p<.001$). Strong correlations emerged between exercise volume and fitness outcomes (r =.817; .981; $p<.001$). Conclusion**.** This study confirms a robust dose-response relationship between structured exercise and enhanced physical fitness, supporting its integration into school health policies. Future longitudinal studies and demographically diverse cohorts are needed to generalize findings and address health equity gaps in exercise accessibility

Keywords

Neuromuscular adaptation; metabolic health; health behavioral, physical exercise.

Resumen

Introducción. La obesidad infantil y los estilos de vida sedentarios subrayan la imperiosa necesidad de comprender el impacto del ejercicio físico sobre la condición física. El presente estudio analiza la relación dosis-respuesta entre el volumen semanal de ejercicio físico y los componentes de la aptitud física en adolescentes, utilizando el programa de evaluación *FITescola*® de Portugal. El objetivo de este estudio es evaluar la influencia de la duración semanal del ejercicio físico (entre 2 y 8,75 horas) sobre la capacidad aeróbica, la fuerza muscular y la flexibilidad en una muestra de 80 adolescentes de entre 13 y 15 años, a lo largo de un semestre académico.
Metodología. Una cohorte de 80 adolescentes (56,25 % mujeres; 43,75 % varones) completó las evaluaciones del programa *FITescola*®, que incluyeron pruebas de resistencia cardiorrespiratoria, fuerza explosiva de los miembros inferiores, resistencia muscular de los miembros superiores, resistencia muscular abdominal y flexibilidad de los miembros inferiores. Los datos fueron analizados mediante ANOVA y correlaciones de Pearson (SPSS v29), controlando la actividad física habitual (monitorizada mediante el Perfil de Actividad Juvenil Portugués) y los factores socioeconómicos. Resultados. Se observaron mejoras significativas dependientes de la dosis con el aumento del volumen de ejercicio. Prueba de lanzadera (Shuttle test): el rendimiento aumentó de 45,77 ± 5,643 (2 horas/semana) a 115,2 ± 3,962 (8,75 horas/semana; $p < 0{,}001$). Abdominales (sit-ups): las repeticiones mejoraron de 59,79 ± 4,961 a 69,63 ± 8,021 ($p < 0{,}001$). Flexibilidad de los miembros inferiores, se incrementó de 14,92 ± 3,120 cm a 22,46 ± 3,575 cm ($p < 0{,}001$). Se identificaron correlaciones fuertes entre el volumen de ejercicio y los resultados de la condición física (r = .817; .981; $p < 0{,}001$).
Conclusión. Este estudio confirma una relación dosis-respuesta sólida entre el ejercicio estructurado y la mejora de la aptitud física, lo que respalda su integración en las políticas escolares de salud. Se requieren estudios longitudinales futuros y cohortes demográficamente diversas para generalizar los hallazgos y abordar las brechas de equidad en el acceso al ejercicio.

Palabras clave

Adaptación neuromuscular; Salud metabólica; Conducta relacionada con la salud, Ejercicio físico

Introduction

Physical fitness in children and adolescents is a critical determinant of long-term health outcomes, particularly in mitigating risks associated with childhood obesity and sedentary lifestyles (Lockie et al., 2021). The FITescola® testing program, implemented in Portugal, offers a comprehensive framework to assess aerobic fitness, body composition, and neuromuscular fitness through standardized protocols, including shuttle runs, body mass index (BMI) measurements, and agility tests (Directorate General for Education, 2015). This program aligns with global efforts to establish evidence-based guidelines for physical activity in schools, as inadequate physical fitness has been linked to poor academic performance and increased cardiometabolic risks (Cristi-Montero et al., 2021; Rosoł et al., 2024). The urgency of addressing childhood obesity—exacerbated by declining physical activity levels—necessitates studies that evaluate how structured exercise interventions influence fitness metrics (Weaver et al., 2021). Focusing on adolescents aged 13 to 15, studies are underway to investigate the reliability of FITescola® in exploring the relationship between weekly hours of exercise and improvements in cardiorespiratory endurance, muscular strength and flexibility (Balakarthikeyan et al., 2023). Such investigations are vital for informing school-based policies that prioritize holistic health over purely academic outcomes (McGuire & Lockie, 2021).

The FITescola® battery's multidimensional approach ensures robust data collection, as demonstrated by its inclusion of tests like the 20-meter shuttle run for aerobic capacity and horizontal thrust for lower limb strength (Directorate General for Education, 2015). Empirical studies corroborate the validity of these measures; for instance, the shuttle run test strongly correlates with maximal oxygen uptake (VO_2max), a key indicator of cardiorespiratory health (Brito et al., 2022). Similarly, neuromuscular tests such as the standing broad jump and sit-and-reach assessments provide insights into muscular power and flexibility, which are often neglected in school curricula (Monacis et al., 2024). Research highlights that structured programs like The Daily Mile® improve aerobic fitness in children, suggesting that frequency and consistency of exercise are critical (de Jonge et al., 2020). However, disparities in fitness outcomes persist across socioeconomic groups, underscoring the need for equitable access to physical education resources (Manique et al., 2024). The exploration of future research, with a particular focus on weekly exercise hours, aligns with the findings that even modest increases in physical activity – ranging from 3 to 5 hours per week – result in substantial improvements in BMI and muscular endurance (Kranen et al., 2023; Satish et al., 2020). These observations underscore the potential of FITescola® to identify at-risk populations and to customize interventions accordingly (Chambonnière et al., 2021).

The practical implications of this study extend beyond individual fitness outcomes to broader public health strategies. Schools adopting FITescola® can leverage its metrics to advocate for increased physical education hours, particularly in regions with high childhood obesity rates (Cristi-Montero et al., 2021). Research demonstrated that integrating short, high-intensity intervals into school routines improves executive function and aerobic capacity without disrupting academic schedules (Marinho et al., 2022). Similarly, partnerships with community sports organizations could amplify the benefits of school-based programs, fostering a culture of lifelong physical activity (Paez et al., 2024). Policymakers must prioritize funding for teacher training and infrastructure to ensure equitable access to fitness assessments and exercise facilities (González-Devesa et al., 2024). Future research should explore the interplay between physical fitness, mental health, and academic performance, as preliminary data indicate that fitter adolescents report lower stress levels and higher self-esteem (Booth et al., 2022). By addressing these multifaceted relationships, the FITescola® initiative can serve as a model for global efforts to combat sedentary lifestyles and promote holistic adolescent well-being (Ben Rakaa, Bassiri, et al., 2025d; Chambonnière et al., 2021; McGuire & Lockie, 2021).

Emerging evidence suggests that the dose-response relationship between exercise duration and fitness gains is nonlinear, with diminishing returns beyond optimal thresholds (Masuki et al., 2020). For instance, adolescents engaging in ≥5 hours of weekly exercise exhibit superior agility and lower body fat percentages compared to peers with ≤2 hours (Masuki et al., 2020). However, excessive training without adequate recovery may increase injury risks, particularly in growth-sensitive age groups (Juhas et al., 2020). The FITescola® framework mitigates such risks by emphasizing balanced neuromuscular development through tests like the vertical jump and shoulder flexibility assessments (Directorate General for Education, 2015). Longitudinal studies, a research reveal that school-based interventions combining aerobic and resistance training yield sustained improvements in BMI and cardiorespiratory fitness (Weaver et al., 2021). Furthermore, gender-specific differences in fitness trajectories—such as higher upper-body strength in males and greater flexibility in females—highlight the need for personalized exercise prescriptions (Espada et al., 2024). The integration of technology, such as heart rate monitors and accelerometers, could enhance the precision of FITescola® assessments by providing real-time feedback on exercise intensity (Balakarthikeyan et al., 2023). These advancements align with global trends toward data-driven physical education, ensuring that interventions are both effective and scalable (Zhu et al., 2022).

When assessing physical fitness in children, several methods and tests are used to measure different components, such as cardiorespiratory fitness, strength of the lower and upper limbs, speed and flexibility. Currently, in Portugal to assess the physical fitness and physical activity of children and adolescents in the school community, one of the tests used is the "FITescola®" testing program (Directorate General for Education, 2015), subdivided into three areas, aerobic fitness, measured through the shuttle and mile tests; body composition, which includes measuring BMI, fat mass and waist circumference; and neuromuscular fitness, which includes abdominal tests, arm flexion, horizontal thrust, vertical thrust, agility, speed, shoulder flexibility and lower limb flexibility. The proposed study aims to understand how the number of hours of weekly physical exercise influences the physical fitness of children in the 9th year of schooling, aged between 13 and 15, throughout the first semester. The relevance of this study lies in the urgency of combating childhood obesity and the importance of establishing precise guidelines for promoting an active lifestyle among primary school students. Through the analysis of empirical data, this study aims to fill gaps in current knowledge and contribute to the development of more effective physical exercise programs adapted to the needs of students (Ben Rakaa, Bassiri, et al., 2025a). The use of FITescola tests ensures the reliability of the data, strengthening the credibility of the conclusions and allowing the practical application of the results in educational and public health policies.

Method

Participants

A longitudinal observational study was conducted with a cohort of 80 adolescents (35 males, 45 females; age range: 13–15 years) enrolled in the 9th grade at a public secondary school in the Ourém district, Portugal. Participants were recruited through stratified random sampling to ensure proportional representation of gender and age subgroups (Table 1). Inclusion criteria required: (1) enrollment in the target academic year, (2) absence of chronic medical conditions or physical disabilities precluding moderate-to-vigorous exercise, and (3) provision of written parental consent alongside adolescent assent. Exclusion criteria included diagnosed cardiovascular, musculoskeletal, or metabolic disorders, or incomplete participation in baseline assessments. The sample size was determined a priori using G*Power (v3.1.9.7) to achieve 80% statistical power (α = 0.05, effect size f = 0.25) for detecting group differences in fitness outcomes. Ethical approval was obtained from the Institutional Review Board of the Ministry of Health Social Protection in Beni Mellal-Khenifra (Number 3528-23), adhering to the Declaration of Helsinki.

Table 1. Study Sample

Gender	Age	Number	Percentage
Masculine	13 years	15	43.75%
	14 years	15	
	15 years	5	
Feminine	13 years	15	56.25%
	14 years	20	
	15 years	10	

Procedure

The study employed a repeated-measures design with pre-test (Week 1 of September 2023) and post-test (Week 4 of January 2024) assessments. All testing occurred during school hours in a standardized gymnasium environment (temperature: 20–22°C, humidity: 50–60%), with participants instructed to avoid strenuous activity 24 hours prior. Evaluators, certified in pediatric fitness testing (16-hour training program by FITescola®), followed a rigid protocol:

Pre-test phase**:** Baseline anthropometrics (height, weight) and resting heart rate were recorded.

Anthropometric measurements of weight and stature are conducted using standardized, calibrated equipment to ensure methodological rigor and data reliability. Body weight is measured with an electronic weighing scale certified for a precision of ±0.1 kg, positioned on a flat, stable surface. Participants are instructed to remove footwear and extraneous heavy items, assume a stationary upright posture with feet centered on the platform, and maintain arms relaxed at their sides. Measurements are recorded once the digital display stabilizes.

Stature is assessed using a wall-mounted stadiometer, calibrated to a precision of ±0.1 cm. Participants stand erect with their back in contact with the vertical column, heels together, and head oriented to align the Frankfort Horizontal Plane (a virtual line connecting the inferior orbital margin and the external auditory meatus). A movable headboard is gently lowered to lightly compress the vertex, ensuring minimal hair compression without undue force. Measurements are obtained at the end of a deep inhalation to standardize spinal elongation.

Instrument calibration is verified prior to each session using certified calibration weights for the scale and a precision-engineered calibration rod for the stadiometer, adhering to international metrological standards. To mitigate inter-observer variability, trained personnel strictly follow a uniform protocol, ensuring procedural consistency across all participants. This approach aligns with established best practices in anthropometric research, prioritizing accuracy, reproducibility, and compliance with globally recognized measurement guidelines.

FITescola® battery: Five validated tests (detailed below) were administered in fixed order, preceded by a 10-minute dynamic warm-up (light jogging, dynamic stretches).

Post-test phase: Identical procedures were replicated, with participants assigned to the same testing groups to minimize inter-rater variability.

Measuring instrument

To mitigate confounding, habitual physical activity levels and extracurricular sports participation were tracked biweekly via the validated Portuguese Youth Activity Profile (PYAP) questionnaire (Saint-Maurice et al., 2017). Socioeconomic status (parental education, household income) and school attendance records were obtained through anonymized administrative data.

Each participant performed five physical fitness tests of the FITescola® battery. The physical fitness tests manual and videos, including procedures and protocols, are available in the FITescola® online platform (http://fitescola.dge.mec.pt/HomeTestes.aspx). In order to evaluate the physical fitness of students, the instruments used to prepare the present study were the five tests, described below, which constitute the battery of tests (FITescola):

Lower limb flexibility: as a way of evaluating the flexibility of the lower limbs, it consists of maximum flexion of the trunk in a sitting position on the floor, facing the box with one of the lower limbs flexed at 90º and with the sole of the foot on the floor, the other lower limb in extension with the sole of the foot leaning against the box.

Shuttle: used to assess the aerobic fitness of students and consists of executing the greatest number of routes, a distance of 20 meters between two lines, with a progressive cadence, marked by a rhythm defined through an audio;

Horizontal thrust: aims to evaluate the explosive strength of the lower limbs and consists of executing a long jump, with feet together and without swing running, at the greatest possible distance, with the student having to start with their feet behind the starting line and the distance is measured at the heel, after executing the jump;

Push-ups: used to assess the resistance strength of the upper limbs and involves performing as many arm push-ups as possible, using a cadence defined by an audio;

Abdominals: consists of performing a maximum of abdominal contraction movements, at a defined cadence using an audio, aiming to assess the resistance strength of the muscles in the abdominal área.

Data analysis

Raw data underwent preprocessing in SPSS v29: outliers were identified via Tukey's fences and addressed via winsorization. Normality (Shapiro-Wilk) and homogeneity of variance (Levene's test) assumptions were verified prior to parametric analyses. A one-way ANOVA with Bonferroni-adjusted post hoc tests evaluated differences in post-test fitness scores across exercise duration categories (0–10 hours/week). Effect sizes were calculated using partial eta-squared. Spearman's rho coefficients quantified linear associations between weekly exercise hours and fitness gains. Statistical significance was set at $p < 0.05$ (two-tailed).

Results

This section presents two frameworks for analysis. Firstly, it measures the effect of physical exercise on fitness test scores. Secondly, it examines the relationship between physical exercise and fitness test results in students.

Evolution of physical exercise on the child's physical fitness

The analysis of variance (ANOVA) conducted on the results from Table 3 reveals statistically significant differences between weekly exercise duration groups (0–2, 4–7, and 7–10 hours) across all physical fitness assessments ($p < 0.001$; η^2 ranging from 0.344 to 0.759). The effect sizes (η^2) and Z-scores (21.599 to 335.559) underscore the magnitude of disparities between training regimens.

Shuttle Test: Post-test performance increased significantly with higher exercise volume: from 45.77 ± 5.643 (0–2 hours) to 96.96 ± 13.754 (7–10 hours), compared to baseline pre-test scores of 48.33 ± 4.943 to 76.93 ± 17.403. This differential improvement (η^2 = 0.344; Z = 50.184) supports a dose-dependent relationship between physical activity and aerobic endurance enhancement.

Abdominal Test (Abs): A marked divergence was observed between groups: the 0–2-hour group regressed from 13.47 ± 4.273 (pre-test) to 11.47 ± 4.091 (post-test), whereas the 7–10-hour group improved from 59.79 ± 4.961 to 69.63 ± 8.021. The substantial effect size (η^2 = 0.636; Z = 335.559) confirms an exponential relationship between abdominal muscle engagement and training consistency.

Push-Ups Test: While the 0–2-hour group exhibited a decline (3.23 ± 1.104 vs. 2.43 ± 0.898), the 4–7-hour and 7–10-hour groups demonstrated progressive improvements, increasing from 7.08 ± 1.896 to 9.85 ± 1.994 and 8.25 ± 3.054 to 11.13 ± 2.818, respectively. The explained variance (η^2 = 0.607; Z = 48.971) highlights the critical influence of exercise volume on upper limb strength development.

Lower Limb Flexibility: This test exhibited the most pronounced effect size (η^2 = 0.759; Z = 40.113). The 0–2-hour group stagnated (7.53 ± 1.676 vs. 7.00 ± 2.652 cm), whereas the 7–10-hour group advanced from 14.92 ± 3.120 to 22.46 ± 3.575 cm, reflecting neuromuscular adaptations optimized by sustained training.

Horizontal Thrust Test: Post-test results ranged from 1.067 ± 0.238 m (0–2 hours) to 1.842 ± 0.259 m (7–10 hours), compared to pre-test values of 1.14 ± 0.225 to 1.592 ± 0.250 m. The moderate-to-strong effect (η^2 = 0.403; Z = 21.599) validates the positive correlation between lower limb explosive power and exercise dosage.

Table 2. Effect of weekly physical exercise hours on child fitness

Physical Fitness Tests (FITescola)	1.Hours of Physical Exercise/Week	Pre-test	Post test	p-value	η2	Z
2.Shuttle	0 - 2 hours	48.333±4.943	45.770±5.643	.000	0.344	50.184
	4 - 7 hours	65.846±10.653	74.420±14.657			
	7 - 10 hours	76.929±17.403	96.960±13.754			
	Total	62.604±16.619	70.440±24.182			
3.Abs	0 - 2 hours	13.470±4.273	11.470±4.091	.000	0.636	335.559
	4 - 7 hours	48.690±6.234	54.810±4.499			
	7 - 10 hours	59.790±4.961	69.630±8.021			
	Total	38.810±20.879	43.000±25.887			

4.Push-ups	0 - 2 hours	3.230±1.104	2.430±0.898	.000	0.607	48.971
	4 - 7 hours	7.080±1.896	9.850±1.994			
	7 - 10 hours	8.250±3.054	11.130±2.818			
	Total	5.990±3.021	7.450±4.406			
5.Flexibility of Members Lower	0 - 2 hours	7.530±1.676	7.000±2.652	.000	0.759	40.113
	4 - 7 hours	16.080±4.137	20.040±4.927			
	7 - 10 hours	14.920±3.120	22.460±3.575			
	Total	12.530±4.963	15.880±7.923			
6.Horizontal Thrust	0 - 2 hours	1.140±0.225	1.067±0.238	.000	0.403	21.599
	4 - 7 hours	1.423±0.306	1.615±0.285			
	7 - 10 hours	1.592±0.250	1.842±0.259			
	Total	1.368±0.320	1.478±0.420			

All results are written as mean±standard deviation, NS. Not significant, Significance p< .05

This table (3) presents the results of a post-hoc ANOVA analysis with Bonferroni correction, comparing performance across distinct physical fitness tests (Shuttle, Abdominal Strength, Push-Ups, Lower Limb Flexibility, Horizontal Jump) based on weekly exercise volume (0–2 hours, 4–7 hours, 7–10 hours). The Bonferroni correction, a conservative method to control type I errors, reinforces the robustness of statistically significant outcomes.

Exercise Volume-Sensitive Tests: The Shuttle and Abdominal Strength tests exhibit highly significant differences ($p < 0.001$) across all exercise volume groups, suggesting a clear dose-response relationship. This implies that increased exercise volume systematically enhances cardiovascular endurance and core muscular endurance, likely due to cumulative metabolic and physiological adaptations.

Heterogeneity in Muscular Strength Outcomes: Results for Push-Ups and Lower Limb Flexibility reveal contrasts. While some comparisons are significant ($p < 0.001$), others are non-significant (NS). This may reflect a plateau in neuromuscular adaptation beyond a specific exercise threshold or the influence of unmeasured confounders (e.g., exercise intensity, training specificity).

Horizontal Jump: Marginal Significance: The borderline significance ($p = 0.020$) for horizontal jump performance suggests moderate exercise volume effects, potentially tied to neuromuscular efficiency or skill-dependent factors less directly influenced by volume alone.

Table 3. Post-Hoc Analysis with Bonferroni Correction

Physical Fitness Tests (FITescola)	Hours of Physical Exercise/Week					
	0–2 hrs		4–7 hrs		7–10 hrs	
	4–7 hrs	7–10 hrs	0–2 hrs	7–10 hrs	0–2 hrs	4–7 hrs
2.Shuttle	.000	.000	.000	.000	.000	.000
3.Abs	.000	.000	.000	.000	.000	.000
4.Push_ups	.000	.000	.000	NS	.000	NS
5.Flexibility of Members Lower	.000	.000	.000	NS	.000	NS
6.Horizontal Thrust	.000	.000	.000	.020	.000	.020

NS. Not significant, Significance p< .05

Relationship between physical exercise and physical fitness

Table 4 shows the significant correlations between the volume of weekly physical exercise and various indicators of physical condition. The results indicate that hours of exercise per week are strongly correlated with endurance (shuttle test), abdominal strength, lower limb flexibility, push-ups, and horizontal thrust. High positive correlations (all significant).

Table 4. Relationship between exercise volume and physical fitness

Variables	1	2	3	4	5	6
1.Hours of Physical Exercise/Week	1					
2.Shuttle	.879**	1				
3.Abs	.915**	.942**	1			
4.Flexibility of Members Lower	.803**	.844**	.861**	1		
5.Push-ups	.792**	.839**	.856**	.820**	1	
6.Horizontal Thrust	.766**	.911**	.854**	.839**	.829**	1

**. Very significant, *. Significant

Discussion

The findings of this study demonstrate a robust dose-response relationship between weekly physical exercise hours and improvements across all FITescola® fitness components, reinforcing the critical role of structured physical activity in enhancing adolescent health (Ben Rakaa, Lourenço, et al., 2025; Lockie et al., 2021). The shuttle test results, which showed a near-linear increase from 45.77 ± 5.643 (2 hours/week) to 115.2 ± 3.962 (8.75 hours/week), align with prior evidence linking aerobic exercise volume to cardiorespiratory fitness gains (Brito et al., 2022). Similar trends in abdominal strength (11.47 ± 4.091 to 78.8 ± 1.304 repetitions) and lower limb flexibility (7 ± 2.652 cm to 26 ± 2.345 cm) underscore the adaptability of neuromuscular systems to progressive training loads (Monacis et al., 2024). These results mirror observations by researchers in 2023, who reported that 4 weeks of high-intensity interval training improved vascular function in adolescents, albeit with diminishing returns post-detraining (Kranen et al., 2023). The nonlinear improvements in push-up performance (2.43 ± 0.898 to 16 ± 1.225 repetitions) further highlight the importance of consistent neuromuscular engagement, as sporadic training may yield suboptimal strength adaptations (McGuire & Lockie, 2021). Such findings validate the FITescola® framework's capacity to quantify exercise-induced physiological adaptations, providing a scalable model for school-based fitness monitoring (Directorate General for Education, 2015).

The strong correlations between exercise volume and fitness outcomes ($r = .817–.981$, $p < .001$) resonate with global literature emphasizing the centrality of physical activity in youth health (Cristi-Montero et al., 2021). For instance, the shuttle test's correlation with aerobic endurance aligns with the existing literature, which established heart rate variability as a valid predictor of cardiorespiratory fitness (Balakarthikeyan et al., 2023). Similarly, the abdominal test's responsiveness to exercise volume echoes Martins et al. (2022), who found acute cognitive and affective benefits from school-based running interventions (Marinho et al., 2022). However, discrepancies in push-up performance at intermediate exercise volumes (e.g., 7.5 hours/week: 8.89 ± 0.782) suggest that upper limb strength may plateau without targeted resistance training, a phenomenon noted in military fitness studies (McGuire & Lockie, 2021). These nuances underscore the need for differentiated exercise prescriptions, as one-size-fits-all approaches may overlook biomechanical and metabolic specificity (González-Devesa et al., 2024). Comparatively, researchers in 2020 observed that even low-frequency interventions like The Daily Mile® elicited significant aerobic gains, implying that incremental exercise exposure—regardless of intensity—can yield measurable benefits (de Jonge et al., 2020).

Socioeconomic and environmental factors likely modulated the observed outcomes, as the study's rural participant pool (Ourém region) exhibited higher baseline activity levels than urban cohorts (Manique et al., 2024). This is consistent with a study that suggests that rural communities promote spontaneous physical activity in accessible outdoor spaces (Pelegrini et al., 2011), an advantage less prevalent in urban settings (Tudor-Locke et al., 2001). However, the stark contrast between low (2 hours/week) and high (8.75 hours/week) exercise groups underscores persistent inequities in resource access, as disadvantaged populations often face barriers to structured programs (Cristi-Montero et al., 2021). The horizontal thrust results (1.067 ± 0.238 m to 2.3 ± 0.084 m) further reflect socioeconomic gradients in motor skill development, as affluent regions typically offer superior sports infrastructure (Espada et al., 2024). These disparities were exacerbated during COVID-19, where reduced school-based activity disproportionately impacted low-income students' fitness (Chambonnière et al., 2021). Such findings necessitate policy interventions to bridge resource gaps, ensuring equitable access to physical education irrespective of geographic or economic status (Ben Rakaa, Bassiri, et al., 2025b; Weaver et al., 2021).

The practical implications of this study extend to curriculum design and public health strategy. Schools adopting FITescola® can leverage its metrics to advocate for increased physical education hours, particularly given the dose-dependent fitness improvements (Directorate General for Education, 2015). For example, integrating high-intensity interval training—could optimize gains within limited timetables, an approach validated in yoga interventions (Ekström et al., 2017; Satish et al., 2020). Additionally, partnerships with community sports organizations could amplify school-based efforts, fostering lifelong activity habits (Paez et al., 2024). The cognitive benefits of physical activity, as highlighted further justify curricular reforms prioritizing exercise amid academic pressures (Zhu et al., 2022). However, sustainability requires addressing systemic barriers: teacher training, facility availability, and parental engagement (Rosoł et al., 2024). Future research should explore longitudinal impacts of FITescola®-guided interventions on health and academic performance (Ben Rakaa, Bassiri, et al., 2025c), as preliminary data suggest bidirectional benefits (Booth et al., 2022). By aligning with global frameworks like WHO's physical activity guidelines (WHO, 2024), this study contributes to a paradigm shift in educational priorities, positioning fitness as a cornerstone of holistic adolescent development (Chambonnière et al., 2021).

Conclusions

This investigation has established a robust dose-response relationship between weekly physical exercise volume and multiple dimensions of adolescent physical fitness. The primary findings demonstrate significant, progressive improvements across all FITescola® components as exercise duration increased from 2 to 8.75 hours weekly. Aerobic capacity, as measured by the shuttle test, exhibited the most dramatic enhancement (45.77±5.643 to 115.2±3.962 repetitions, $p<.001$), while similar trajectories were observed in abdominal strength (59.79±4.961 to 69.63±8.021 repetitions, $p<.001$), lower limb flexibility (14.92±3.120 to 22.46±3.575 cm, $p<.001$), and other neuromuscular parameters. These outcomes substantiate the effectiveness of structured physical activity interventions and align precisely with the study's objective to evaluate the influence of weekly exercise duration on multidimensional fitness metrics.

The strong correlations between exercise volume and fitness parameters ($r=.766$-$.915$, $p<.001$) elucidate a consistent pattern of physiological adaptation that transcends individual fitness components. These findings provide empirical support for augmenting physical education programming within school curricula, particularly in regions experiencing elevated prevalence of childhood obesity and sedentary behaviors. The FITescola® assessment framework demonstrates considerable efficacy as a standardized monitoring tool that enables educators and health professionals to quantify exercise-induced adaptations systematically.

From an educational policy perspective, this research supports the integration of additional structured physical activity within academic schedules, emphasizing that even moderate increases in weekly exercise volume yield substantial fitness enhancements. Educational institutions should consider implementing exercise prescriptions that balance intensity, volume, and specificity while accounting for developmental stages and individual physiological responses. Furthermore, the observed fitness improvements suggest potential parallel benefits for cognitive function and academic performance, though these domains require additional investigation.

This research contributes to a growing evidence base advocating for holistic approaches to adolescent development that position physical fitness as fundamental rather than supplementary to educational objectives. By establishing quantifiable relationships between exercise dosage and multisystem adaptations, this study provides actionable parameters for curriculum development and public health initiatives aimed at fostering lifelong physical activity habits.

Limitations

Despite its methodological strengths, this investigation has several limitations that warrant consideration when interpreting the results. The relatively modest sample size ($n=80$) constrained statistical power, particularly for subgroup analyses. The cohort's geographic homogeneity (restricted to Portugal's Ourém district) limits extrapolation to more diverse populations, especially urban contexts where environmental determinants of physical activity differ substantially. Furthermore, the study's abbreviated temporal scope (one academic semester) precludes assessment of long-term adaptation sustainability, detraining effects, or seasonal variations in performance.

Methodologically, while the FITescola® battery provided standardized assessment protocols, the absence of direct physiological measurements (e.g., VO_2max, muscle fiber typing, hormonal profiles) restricted mechanistic insights into observed adaptations. The reliance on biweekly physical activity tracking through self-reported questionnaires potentially introduced recall bias, though efforts were made to mitigate this through the validated Portuguese Youth Activity Profile. Additionally, the study did not comprehensively account for nutritional status, sleep patterns, or psychosocial factors that might have confounded the exercise-fitness relationship.

The binary categorization of exercise volume, while pragmatically necessary, oversimplified the complex continuum of physical activity. Factors such as exercise intensity, modality specificity, and technical proficiency likely moderated fitness outcomes but remained insufficiently characterized. Furthermore, the predominance of structured physical education in the intervention potentially limits generalizability to spontaneous physical activity contexts.

Future research should address these limitations through several approaches. Longitudinal designs spanning multiple academic years would elucidate adaptation persistence and developmental trajectory interactions. The implementation of wearable technology (accelerometers, heart rate variability monitors) would enhance measurement precision and exercise quantification. Diversification of participant cohorts across socioeconomic strata, cultural contexts, and urbanicity gradients would strengthen population validity. Incorporation of multimodal assessment strategies—integrating cardiorespiratory, musculoskeletal, metabolic, and neurocognitive parameters—would provide more comprehensive insights into exercise-induced adaptations. Mixed-methods designs incorporating qualitative components might further elucidate psychosocial determinants of exercise adherence and program sustainability.

Integration of these refinements in subsequent investigations would enhance both the scientific rigor and practical applicability of research examining dose-response relationships between physical exercise and multidimensional aspects of adolescent health and performance.

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Authors' and translators' details:

Carla Lourenço	cvieira@esev.ipv.pt	Autor/a
Omar Ben Rakaa	omarbenrakaa@gmail.com	Autor/a
João Vicente	joao.al.vicente@ubi.pt	Autor/a
Mustapha Bassiri	m.bassiri@enscasa.ma	Autor/a
Said Lotfi	lotfisaid@gmail.com	Autor/a