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Research Article

JOURNAL OF ORTHOPAEDICS AND SPORTS MEDICINE

ISSN: 2688-5115

High-Intensity Interval Training Program in High-School Physical Education Classes for Promoting Fitness in Adolescents: A Randomized Controlled Trial

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Abstract

This study aims to investigate whether 16 weeks of High-Intensity Interval Training (HIIT) implemented on Physical Education classes (PEC), can improve physical fitness in high-school adolescents, with a specific focus on gender differences. This study was a two-arm randomized controlled trial design with adolescents (15-17 years). Twelve classes were randomized to either a 16 weeks of HIIT (HIIT-G, n = 106 students) implemented on PEC warm-up or a control group (CG, n = 123 students) of usual PEC warm-up. The HIIT sessions ranged from 14 to 20 all-out bouts intervals, adopting a 2:1 work-to-rest ratio. Post-intervention measures revealed a significant difference between groups in CRF and girls from HIIT-G increased their cardiorespiratory fitness (CRF) with significant difference between female groups and a medium to large effect size. The main findings from this study indicate that brief whole-body HIIT of an extremely low volume, over 16 weeks, can improve CRF in adolescent girls.

Keywords: Health; Cardiorespiratory fitness; Muscular fitness; Body composition; Physical exercise; Type 2 diabetes mellitus; Cardiovascular diseases; School-Aged Children

This project was registered on ClinicalTrials.gov (ID: NCT04022642)

Introduction

Low cardiorespiratory fitness (CRF), measured by maximal oxygen consumption (VO2max), is a powerful predictor of all-cause mortality and morbidity in young people [1]. Insufficient physical exercise (PE) but also other factors, such as overweight and obesity, and poor diet, are increasingly evident in the adolescent population, and could be decisive both for low CRF and the increasing incidence of different pathologies [2]. Over 50% of obese children will become obese adults, with a significant increase in the risk of developing asymptomatic diseases, including cardiovascular diseases, cancer, and type 2 diabetes mellitus [3]. Despite the numerous benefits of regular PE, western children and adolescents spend too much time in sedentary behaviors, which is worsening every decade [2,4-6]. Data related to Health Behavior in School-Aged Children (HBSC) associate a sedentary lifestyle with headaches, sadness, irritability, and nervousness [6]. Moreover, adolescents tend to become more inactive as their age increases [7]. Short leisure time, reduced access to facilities and low motivation to engage in physical exercise, are frequently reported barriers to poor adherence to exercise programs [8-10]. In modern society, it is unlikely that individuals will ever return to the high average PE levels of the past. In any case, higher

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Citation: André Bento, Armando Raimundo, Luis Carrasco. High-Intensity Interval Training Program in High-School Physical Education Classes for Promoting Fitness in Adolescents: A Randomized Controlled Trial. Journal of Orthopedics and Sports Medicine. 7 (2025): 299-310

Received: June 17, 2025
Accepted: June 26, 2025
Published: July 04, 2025

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DOI:10.26502/josm.511500209

amounts of sedentary behavior are associated with increased adiposity, poorer cardiometabolic health and fitness in children and adolescents, and the World Health Organization (WHO) stated that this population should achieve at least an average of 60 minutes per day of moderate-to-vigorous PE (MVPE) and must limit sedentary time [11]. However the limited number of people willing to engage in MVPE and the high attrition of those who participate [12], the evidence shows high effectiveness of MVPE in reducing mortality, even considering a long lifespan [13].

In addition to the barriers of PA such as lack of time and access, motivation plays a critical role in adolescents' participation in PE. According to the Self-Determination Theory (SDT), motivation can be intrinsic, driven by the inherent pleasure of the activity, or extrinsic, influenced by external outcomes or pressures [14]. Adolescents' motivation to engage in PE can vary significantly based on how the activities are structured and the perceived enjoyment and challenge. Volitional skills, which encompass the capacity to initiate and sustain PA despite external obstacles, are also crucial in predicting engagement in PE [15]. While intense exercise, such as High-Intensity Interval Training (HIIT), may be perceived as challenging, children and adolescents have expressed a clear preference for time efficiency and pleasure, and the "stop-start" nature of HIIT seems to reflect the activities traditionally observed in childhood [2-4]. The impact of varying intensity and activity types on motivation highlights the need for diverse and adaptable PE programs that cater to different preferences and levels of physical fitness [17]. Schools, as structured environments where adolescents spend a significant portion of their time, are uniquely positioned to implement such interventions, promoting not only physical health but also positive attitudes towards lifelong physical activity [18-20].

Therefore, HIIT is presented as a time-efficient alternative to aerobic training [2,16,21,22], as it leverages the number of exercise participants, resulting in improvements in health outcomes, mainly from adolescents [5,23-25]. HIIT encompasses various protocols that can include short, medium, or long periods of intense exercise, interspersed with recovery phases of low-intensity exercise or complete rest [26-28]. The purpose of HIIT is that physiological systems may perform exercises of higher intensity than those achieved during a gradual maximal test [29]. HIIT is a powerful stimulus in improving body composition and preventing cardiometabolic risk in adults [30]. Preliminary studies conducted with adolescents have shown promising results on body composition and cardiometabolic health and more effective and time-efficient interventions for improving blood pressure and aerobic capacity levels [4,7,23,31,32]. According to Bond et al. [33], time spent in high-intensity activities is the most relevant factor in promoting vascular health and autonomic cardiac modulation. No harmful associations in recent studies applying intense efforts are also encouraging [34,35]. Furthermore, adolescents seem to be more enthusiastic about resistance training, whereas aerobic training is found to be boring [36]. Other studies, besides aerobic and resistance training groups, included a variety of activities to enhance motivation and appeal to the interest of older adolescents, improving aspects of adolescents' cardiometabolic health [37], fitness and body composition, despite the lowest dose among groups [5]. Interventions designed to increase MVPE in Physical Education classes (PEC) indicate that programs could increase the proportion of time students spend in higher intensities and reduce sedentary behavior, since motivational climates that emphasize effort and improvement and provide opportunities to demonstrate leadership and make decisions have a positive impact on PA [38].

Adolescents, especially older ones, are underrepresented in studies implemented in the school context [35]. Despite the widespread interest in the advantages that the HIIT methodology reveals, there is a lack of randomized controlled studies investigating the impact on adolescents [2,35], mainly addressing adolescents' environments, such as schools [5,24]. It is known that the school and PEC are privileged spaces and promoters of positive changes for the rest of life [39], in which time-efficient approach interventions have a prominent role. Recently, some studies present HIIT programs targeting school-aged children [40-43], and in a scope of 10 years, we find dozens of works with students aged 10-19 years, but only a few were implemented in the school setting (manly extracurricular activity). Of them, just a few [10,31,40,41,44-47] were implemented in PEC, replacing the entire session with the intervention [10,47]. Most protocols in the literature opted for 1:1 density and SPRINT as modality [32]. Some, recording large effect sizes on CRF [10,47], PA [10], strength, power, and speed [48], needed only six minutes three [10,47] and four times [48] a week, and chose to use all-out bouts instead of a percentage of Maximal Aerobic Speed (MAS). In adults, previous findings suggest that a 2:1 work-to-rest ratio is optimal during HIIT for both men and women [49]. We aim to provide novel HIIT protocols for schools with less volume (only twice a week) and higher density (less rest in each interval), implement PA interventions that retain the health-enhancing effects and satisfy the adolescents' desire for enjoyment and variety. This study aims to investigate whether 16 weeks of HIIT implemented on PEC, compared to 16-weeks of usual PEC, can improve body composition and physical fitness in high-school adolescents, and determine the gender differences among the participants.

Materials and Methods

Study Design

This project was registered on ClinicalTrials.gov (ID:

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DOI:10.26502/josm.511500209

NCT04022642) and approved by the Ethics Committee of the University of Évora (doc. 19017). In all aspects, this trial was conducted according to the Declaration of Helsinki on Human Research. Apart public schools in the city of Beja (Portugal) were invited to participate, but only one consented to participate. Written consent was obtained before participation from the school principal and parents.

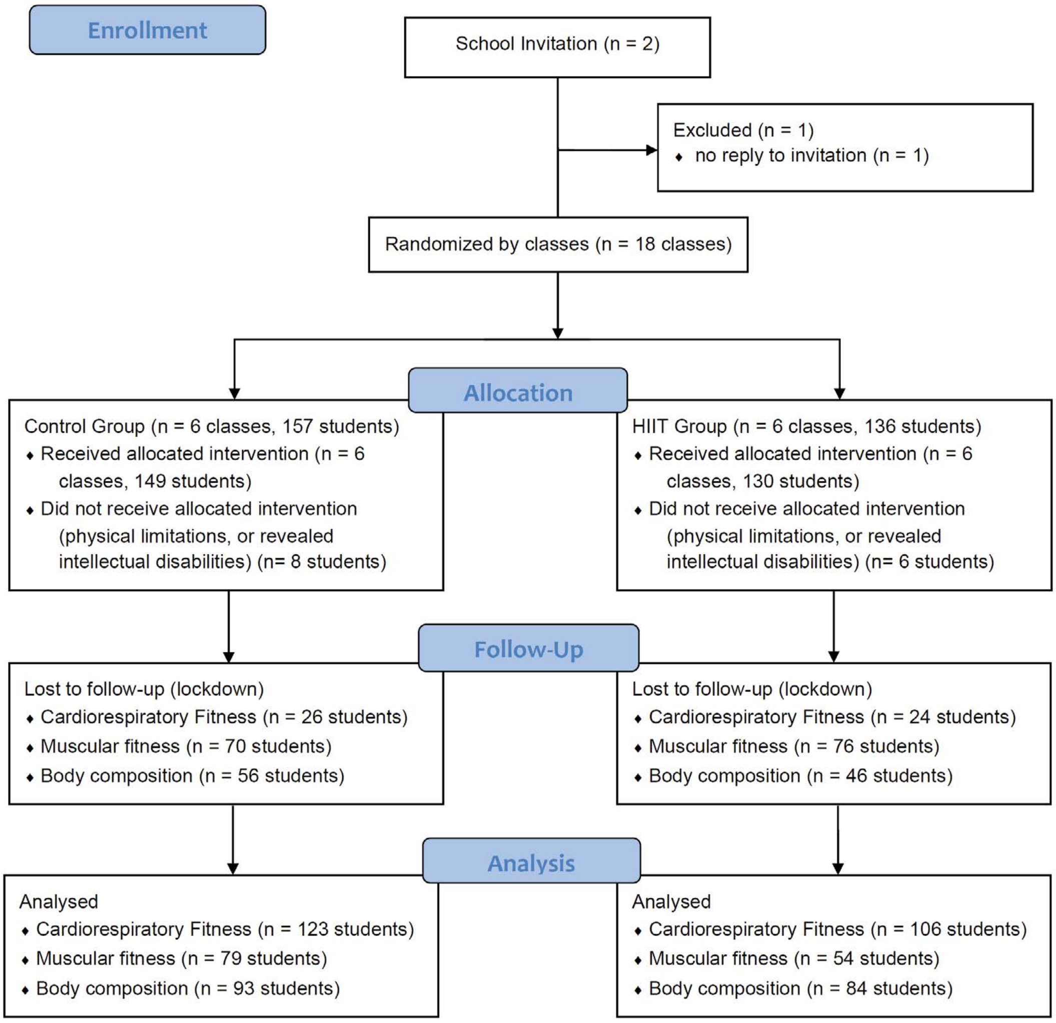

Figure 1: Study design.

Participants

This study was a two-arm randomized controlled trial design with adolescents from the 10th to 12th grades (15-17 years old). Twelve from a total of 18 classes with an average of 25 students each, recruited from a public school (Figure 1), were randomized to either 16 weeks of HIIT (HIIT-G, n = 106 students) implemented on PEC warm-up or a control group (CG, n = 123 students) of usual PEC warm-up. After an invitation, the researchers met with the school principal to provide information on the whole project. After accepting to participate, adolescents and their parents were informed of a detailed description of the scientific background, objectives, and safety.

Randomization

The school principal, as a person independent of the study, concealed participant allocation by shaking a bag with all 18 classes before baseline testing. Due to logistical constraints, the research team only had the availability and means to work with 12 of these classes. Classes were randomized so that two classes from each grade were allocated to the intervention condition and the other two were used as control group. Using this approach, each class had an equal chance of being allocated to the intervention condition while maintaining an appropriate balance of grades across the two conditions. Students were ineligible if they did not provide parental consent to participate, had physical limitations or revealed intellectual disabilities.

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DOI:10.26502/josm.511500209

Sample size

Power calculations were based on the primary outcome of CRF, assessed using the 20-m Progressive Aerobic Cardiovascular Endurance Run (PACER; [50]). To detect a clinically meaningful baseline-adjusted between-group difference of seven laps [35] with 80% power at a 5% significance level, 58 students per treatment group were required (i.e., four classes of 15 students), for a potential drop-out rate of 15% at our primary study end point (i.e., 16 weeks).

On 13 March 2020, the Portuguese Government adopted strict containment measures to avoid the new coronavirus (SARS-CoV-2) spread, and the student population was placed in home confinement, with permission only to leave home for limited and documented purposes (e.g., for health reasons or buying food), and several activities were temporarily prevented, including schools. Many students stayed at home in the first few days of March, even before the formal lockdown, and didn't finish the entire intervention program or post-tests. These global preventive strategies posed unprecedented challenges and obstacles for our research, experiencing lower follow-up rates in the ongoing trial. As a negative consequence of home confinement, we experienced a high number of dropouts in several outcomes (Figure 1).

Intervention program

Throughout the 16-week intervention period, the HIIT-G took part in the regular 90min PEC twice a week, conducted by the schools' PEC teachers following the regular curriculum. The HIIT-G replaced the warm-ups established in the PEC curriculum with the proposed HIIT training sessions. The principal researcher directed and implemented the intervention. After the HIIT sessions, students completed the planned PEC.

The HIIT sessions were applied in the first 10-15 minutes of each PEC and ranged from 8 to 20 all-out bouts intervals, adopting a 2:1 work-to-rest ratio, involving a combination of aerobic and body weight muscle-strengthening exercises, and designed to be fun and engaging, as well as vigorous in nature (Figure 2).

To promote exercise adherence, sessions were designed progressively from four minutes in week zero to 10 minutes in week three using the Tabata et al. [51] protocol (20s intense work, followed by 10s rest). From week four to week seven, the same volume but using 30s-intense work, followed by 15s rest. From weeks nine to 15, sessions were completed in pairs (Figure 3). Participants gave additional elements of choice, such as music, exercises, and workouts.

A cut-point of 90% of HR_{max} was a criterion for satisfactory compliance to high-intensity exercise. HR has become one of the most used outcomes to assess the intensity, and several authors suggest that each interval corresponds to a value equal to or greater than 90%HR_{max} [52,-54]. An optimal stimulus that promotes cardiovascular and peripheral adaptations implies several minutes per session in the so-called *red zone*, which usually means a minimum intensity of 90%VO_{2max} [27]. It is expected that HR reaches maximum values (>90-95% HR_{max})

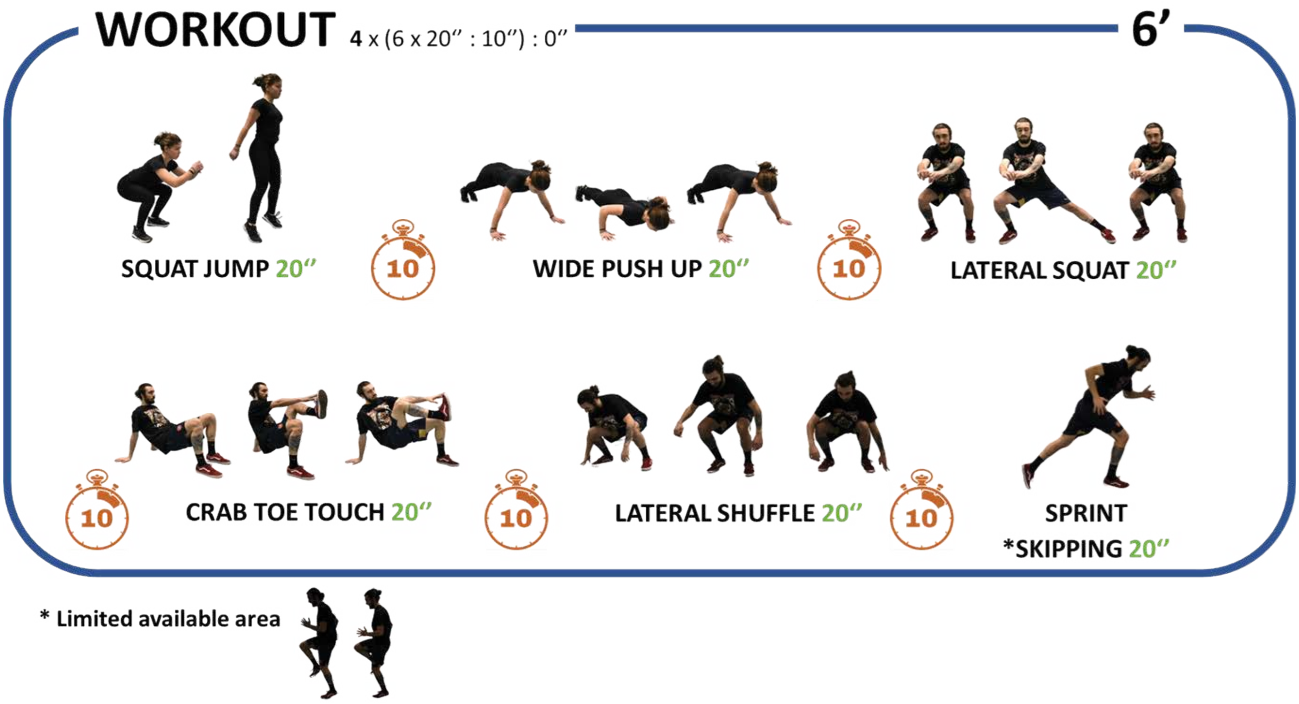

Figure 2: Graphical description of an example session (Figure produced by the author).

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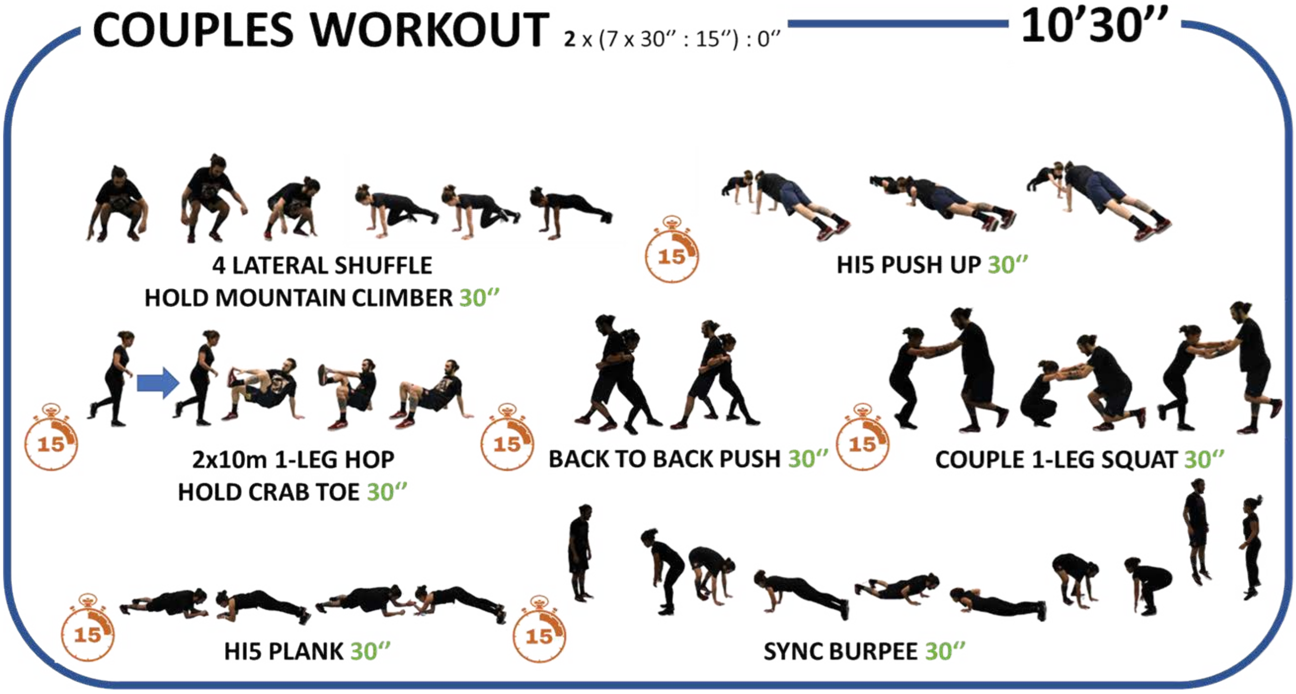

Figure 3: Graphical description of an example session (couples) (Figure produced by the author).

close to the speed/power associated with VO_{2max}, which does not always happen, especially in very short exercises (<30 seconds) [53,54]. It may be related to the known delay in HR response at the beginning of exercise, which is slower than the VO_2 response. During the supervised intervention, and measures, the researchers recorded HR using the Heart Zones Move™ (California, USA) software application which uses a forearm wearable telemetric HR sensor (Scosche Industries, California, USA) to ensure compliance with the exercise stimulus at the predetermined target HR zone. Besides, at the end of each session, rating perceived exertion (RPE) was also measured presenting a visual scale to the students, allowing them to indicate their perceived effort by pointing to the appropriate level on the scale to estimate effort, fatigue, and training load, targeting >17 on the 6–20 Borg scale [55,56].

Throughout the 16-week intervention period, the CG took part in the regular 90min PEC twice a week, conducted by the schools' PEC teachers following the regular curriculum.

Measures

All primary and secondary outcomes were measured at baseline two weeks prior the intervention and after 16 weeks after the HIIT program (Figure 4). CRF was the primary outcome, and secondary outcomes includes muscular fitness and body composition. All assessments were conducted by the Principal Investigator. Anthropometric assessments were conducted sensitively with the presence of a same-sex research staff when possible. The Principal Investigator provided a brief verbal description and demonstration of each fitness test before evaluation. Before the exercise intervention,

Table 1: Training load of HIIT intervention.

		HIIT		
		Total (n =106)	Girls (n =55)	Boys (n =51)
Planned Sessions (n)		26		
Sessions, mean (sd)		12.2 (3.5)	12.2 (3.6)	12.2 (3.4)
Time in seconds >90%HRmáx/session, mean (sd)		179.9 (128.2)§	221.6 (127.8)	132.9 (112.4)
RPE/session, mean (sd)		17.4 (0.7)	17.6 (1.5)	17.4 (0.7)
Abbreviations: HR: heart rate; RPE: rating perceived exertion. Note: Values are presented as mean (SD). § p < 0.001				

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DOI:10.26502/josm.511500209

both group teachers and participants were instructed to follow the regular curriculum and maintain their regular dietary and lifestyle behaviors during the intervention period. The authors evaluated measures and data collection, not blinded for group allocation. Different tests were conducted on different days to ensure sure that all interventions and assessments were implemented in PEC.

Physical fitness assessment

CRF and lower-body strength were assessed using the PACER and horizontal jump tests, respectively [50]. The primary objective of PACER was to execute the greatest quantity of laps while adhering to a specified cadence. An auditory cue was employed to assist the participants in regulating their running velocity throughout the duration of the assessment. The evaluation commences at a cadence of 8.5 km/hr and incrementally escalates by 0.5 km/hr each minute. HR was monitored by telemetric HR during testing. The peak HR recorded during the test was assumed to be representative of maximal HR [57]. The horizontal jump assessment commences from an erect stance with the feet positioned slightly apart and aligned beneath the shoulder width, immediately posterior to a delineated line on the ground. Subsequently, the participant executed a jump with the objective of achieving maximal distance, culminating in a landing with the feet in a unified position. The measurement of interest, specifically the distance from the starting line to the posterior heel of the trailing foot, was meticulously recorded. The optimal performance from two separate attempts was utilized for evaluation purposes.

WEEK	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
TASKS	BASELINE TESTING		4' = 8 x 20'':10''	6' = 12 x 20'':10''	8' = 16 x 20'':10''	10' = 20 x 20'':10''	CANCELED DUE TO SCHOOL ACTIVITIES	CHRISTMAS HOLIDAYS		10' = 14 x 30'':15''		10' COUPLES = 14 x 30'':15''					WINTER BREAK	10' COUPLES = 14 x 30'':15''	POST-TEST	LOCKDOWN

Figure 4: Schedule of assessment and HIIT intervention. (') Total work in minutes, ('':'') ratio ON:OFF in seconds.

Body Composition assessment

Participants' body composition was measured to the nearest 0.1 kg in light sportswear on a bioelectrical impedance scale (Tanita MC -780, Tanita Corporation, Tokyo, Japan), and height was measured to the nearest 1 mm using a portable stadiometer (Seca 213 Portable Height Measuring Rod Stadiometer, Seca GmbH & Co. KG, Hamburg, Germany). Body composition measurements (body fat, lean body mass and basal metabolic rate) were performed by bioelectrical body impedance analysis (BIA). Measurements were performed according to Jackson et al. [58].

Data analysis

All statistical analyses were performed with the Statistical Package for the Social Sciences v.24 (SPSS Inc., Chicago, IL, USA). The normality of data distribution was tested using the Kolmogorov-Smirnov test. When normality was observed, data were checked for significant differences between baseline and post-intervention applying student's t-test for paired samples and for significant differences between the two groups applying student's t-test for unpaired samples. Where the analysis suggested non-normality, simple effects were examined using the non-parametric Wilcoxon's signed ranks test for differences between baseline and post-intervention and the Mann-Whitney U test for significant differences between the two groups and genders.

To estimate effect sizes, Hedge's g was calculated for normally distributed measurements (one of the means from the two distributions is subtracted from the other, and the result is divided by the pooled sample standard deviation) and interpreted as follows: d = 0.2, d = 0.5, and d = 0.8, considered as small, medium, and large effect sizes, respectively [59]. For non-normal distributions, the z value was used to calculate the effect size, such as the r proposed by Cohen [59]; Cohen's guidelines for r are that a large effect is .5, a medium effect is .3, and a small effect is .1. Significance was set at $p < 0.05$.

Results

The mean training load response and volume during HIIT intervention are displayed in Table 1. Descriptive statistics and the effects of the intervention on physical fitness and body composition measures are displayed in Table 2. Due to activities and teaching breaks or climate condition, each class of HIIT-G participated on an average of 16.4 ± 1.3 (63%) of the 26 scheduled exercise sessions. The mean attendance for participants involved in the intervention was 12.2 ± 3.5 (47%). Absences were due to illness, medical appointments, lack of appropriate clothing or work placement attendance and, near the end of the intervention, home confinement.

Post-intervention measures revealed a significant difference between groups in CRF (U = 5313.5; $p < 0.05$; ES = 0.16). Boys in both the HIIT-G and CG showed no significant changes in CRF post-intervention, suggesting that the CRF improvements were largely driven by the female participants, since girls from CG lowered their CRF (Z = -2.1; $p < 0.05$; ES = 0.25) and girls from HIIT-G increased their CRF (t = 2.6; 0.5 to 3.9 95%IC; $p < 0.05$; ES = 0.35), with significant difference between female groups and a medium to large ES (t = -3.6; -5.9 to -1.7 95%IC; $p < 0.001$; ES = 0.65). Within-group analysis indicated a significant increase in muscular fitness for the HIIT-G (t = 3.2; 1.7 to 7.8 95%IC; $p < 0.005$; ES = 0.43), again this improvement was predominantly observed in the female participants, with girls in the HIIT-G showing a significant increase in muscular fitness (t = 2.4;

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0.8 to 9.9 95%IC; $p < 0.05$; ES = 0.45) since boys did not reach significance (t = 2.0; -0.1 to 8.0 95%IC; $p = 0.005$; ES = 0.40). These findings suggest that the HIIT intervention was more effective in improving muscular fitness for girls compared to boys.

There were no significant between-group differences in body composition post-intervention, though all groups and genders showed positive trends. Both HIIT-G and CG groups experienced increases in lean body mass and reductions in body fat percentage. However, while HIIT-G boys showed improvements in lean body mass, they did not achieve a statistically significant reduction in body fat (Z = -1.6; $p = 0.12$; ES = 0.25).

Table 2: Characteristics of physical fitness and body composition variables: Control group and HIIT at baseline and post-intervention.

		Baseline, Mean (SD)			Change to 16 weeks, Mean (95% CI)			Intervention effect					
		Total	Girls	Boys	Total	Girls	Boys	Total	ES	Girls	ES	Boys	ES
Cardiorespiratory Fitness (n)								229		124		105	
PACER (shuttles)	CG (n = 123)	52.6 (24.0)§	36.1 (11.1)	73.7 (19.1)	-1.4 (-3.1 to 0.2)	-1.6 (-2.9 to -0.3)*	-1.2 (-4.7 to 2.3)	.016	0.16	.000	0.65	.830	0.03
	HIIT (n = 106)	50.9 (25.2)§	33.9 (11.2)	69.3 (23.1)	0.0 (-2.2 to 2.3)	2.2 (0.5 to 3.9)*	-2.3 (-6.6 to 2.0)						
Muscular Fitness (n)								133		72		61	
Lower body muscular power (cm)	CG (n = 79)	178.2 (38.5)§	148.8 (16.6)	213.4 (25.4)	2.8 (0.1 to 5.4)	1.1 (-2.7 to 4.9)	4.8 (1 to 8.6)*	.349	0.16	.149	0.35	.751	0.08
	HIIT (n = 54)	162.8 (33.5)§	142.1 (21.9)	186.8 (28.2)	4.7 (1.7 to 7.7)*	5.3 (0.8 to 9.9)*	3.9 (-0.1 to 8)						
Body Composition (n)								177		98		61	
Body Fat (%)	CG (n = 93)	24.6 (8.0)§	29.8 (5.7)	17.4 (4.0)	-0.9 (-1.3 to -0.5)§	-1 (-1.6 to -0.4)*	-0.8 (-1.4 to -0.1)*	.430	0.12	.488	0.14	.735	0.08
	HIIT (n = 84)	24.8 (7.1)§	29.2 (5.8)	19.9 (5.0)	-0.7 (-1.1 to -0.2)*	-0.7 (-1.4 to -0.1)*	-0.6 (-1.3 to 0.1)						
Lean Body Mass (kg)	CG (n = 93)	43.7 (8.7)§	38.3 (4.5)	51.0 (7.6)	1.2 (0.9 to 1.5)§	1.0 (0.7 to 1.4)§	1.4 (0.9 to 1.9)§	.874	0.02	.772	0.03	.778	0.06
	HIIT (n = 84)	44.2 (8.1)§	39.1 (4.8)	49.9 (7.0)	1.2 (0.8 to 1.5)§	0.8 (0.4 to 1.2)§	1.5 (1.0 to 2.1)§						

Abbreviations: PACER Progressive Aerobic Cardiovascular Endurance Run, CG control group, HIIT High-Intensity Interval Training group, CI confidence interval. § $p < 0.001$; * $p < 0.01$;

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The findings from this study highlight that the HIIT intervention had a more pronounced effect on the female participants, both in terms of CRF and muscular fitness improvements. While boys in the HIIT-G showed some gains in fitness and body composition, these changes were not as significant compared to the girls. This gender-specific response to the HIIT protocol suggests that girls may benefit more from this type of high-intensity training, particularly in a school-based setting where time-efficient and engaging exercises are crucial to maintaining motivation and adherence.

Discussion

The aim of this study was to investigate whether 16 weeks of HIIT implemented on PEC, compared to 16 weeks of usual PEC warm-up, can improve physical fitness in high-school adolescents, and determine the gender differences among the participants. The main findings from this study indicate that brief whole-body HIIT (10 min) of an extremely low volume, over 16 weeks (on average, 0.8 sessions per week), can improve CRF and muscular fitness in adolescent girls. Our study registered an increase of 9% in CRF in HITT-G girls and a decrease of 4% in CG girls, representing a medium to large ES (t = -3.6; -5.9 to -1.7 95%IC; $p < .001$; ES = 0.65). Within a 10-year scope, we find dozens of works with students aged 15-17 years, but only a few were implemented in the school setting. Notwithstanding some studies have been implemented in the school setting, only a few were implemented in PEC. Along this line of results [44], at the end of the seventh week, in a similar intervention with only 8 min twice a week, registered an increase of 10% in VO2max to baseline ($p < .001$; ES = 0.33), with only 13 female adolescents distributed by intervention and CG. Also in a seven week intervention [45], but with three sessions/week, using six min SPRINT as modality and only two female adolescents in HIIT-G, researchers observed, compared to CG, a significant increase of seven laps in PACER (p < .005), and a significant decrease in muscular fitness of CG (p < .005). Using three sessions/week for only four weeks [10], this research group replaced the entire PEC session with six min HIIT intervention, with nine female adolescents in HIIT-G, increased CRF 5 ml/kg/min with large ES ($p < .05$, ES = 0.92). Years earlier, the same researchers [47], with seven girls in HIIT-G, reached a large ES in intervention (0.93) due to the significant decrease in CRF of CG (p < .05) in a seven week intervention, three sessions/week. Costigan et al. [34] also did not reach significance in CRF and muscular fitness improvements in an eight week intervention, 10min/session, three sessions/week, with 12 female adolescents distributed in two HIIT-G. An increase in mitochondrial content and induced higher increases in citrate synthase maximal activity [60], type II fiber activation, and adenosine monophosphate-activated protein kinase activity [61] can be some of the physiological mechanisms explaining why HIIT may improve CRF. According to Bond et al. [33], time spent in high-intensity activities is the most important factor in promoting vascular health and autonomic cardiac modulation. Moreover, this could explain the absence of improvements in CRF observed in males. Because this is a high-intensity methodology, it is necessary to regulate the intensity to ensure that subjects hit a high enough threshold in their exercises. The difference in the findings between girls and boys may be a consequence of the higher average intensity, represented as the average time in seconds above 90%HRmax/session, of the girls observed in this study compared with the boys (222s vs 133s, respectively; t = 3.8; 42.0 to 135.5 95%IC; $p < .000$; ES = 0.74). Despite men's ability to produce more power, some studies reveal that women may have a higher resistance to exhaustion and/or better recovery during bouts of repetitive activity [49]. These data support the idea that women may recover faster from high-intensity exercise because they self-select intensities that put their hearts under more pressure. Although VO_2max is frequently used to determine the intensity of HIIT, this method ignores the subjects' anaerobic characteristics, which are critical for HIIT [62]. Likewise, it seems unlikely that teachers would have access to those technologies in PEC real-world contexts. The use of all-out bouts and plyometrics are also simple and effective approaches since some studies that record Large Effect Sizes chose to use all-out bouts instead of a percentage of MAS [10,47,48].

Regarding body composition, in our study, all groups and genders increased their lean body mass and lowered body fat. Alonso-Fernández et al. [44] registered a decrease of 8% in % of body fat to baseline ($p < .001$; ES = 0.58) and an increase of 6% in lean body mass ($p < .001$; ES = 0.15). In Buchan et al. [45] intervention, there were no significant changes in body composition in both groups, and Martin-Smith et al. [10] did not reach significance in the waist and hip circumference. Costigan et al. [34] reduced significantly compared to CG 2 cm in waist circumference ($p < .05$; ES = 0.70). We acknowledge that weight status (underweight, normal weight, overweight, and obese) can influence certain health and fitness outcomes. However, we intentionally included students across this spectrum to reflect the real-world diversity in typical PEC. This decision was made to ensure the generalizability of our findings for PEC teachers, who work with students of various body compositions.

Physical fitness is considered a significant health indicator, as well as a predictor of cardiovascular disease morbidity and mortality [1]. Given the time limits of school curricula, adding a HIIT protocol to the PEC curriculum may help students increase their fitness levels and enhance their health.

Strengths and Limitations

This study has several strengths, including the randomized design, intervention applied to older adolescents,

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objectively and subjectively measured internal load and in a PEC real context, without interfering with other aspects of the curriculum. Adolescents, especially older ones, are underrepresented in studies implemented in the school context [35]. Notwithstanding the fact that some studies have been implemented in the school setting, only a few [10,34,40,41,44-47] were implemented in PEC, some of which replaced the entire session with the intervention [10]. Adjusting exercise intensity using HR has been a valid option, mainly in prolonged and submaximal periods. Few studies have objectively measured internal load by monitoring HR [8,10,35,44,46,63,64] or RPE [44,48]. HR has become one of the most used outcomes to assess intensity. Optimal exercise duration and rest intervals remain ambiguous and dose-response relationships of HIIT volume and intensity are unsettled. On adolescents, despite differences in protocols on intensity like all-out bouts or % of MAS, modality (sprints vs calisthenics), and volume (6min-35min/session), most of them opted for 1:1 density [32]. With this study, the authors aim to provide novel HIIT protocols for schools with less volume (only twice a week) and higher density (less rest in each interval), which include resistance exercises through calisthenic exercises and plyometrics that retain the health-enhancing effects and satisfy the adolescents' desire for enjoyment and variety.

However, some limitations should also be acknowledged, such as the high missing values due to school activities, teaching breaks, weather conditions and lockdown, or the absence of a detailed evaluation to determine intervention fidelity to confirm treatment/protocol adherence. Additionally, the lack of evaluation concerning the sexual maturation of participants renders it ambiguous whether the outcomes of fitness assessments may be influenced by gender-related confounding variables. Due to the negative consequences of home confinement, we experienced a significant number of dropouts in several outcomes, so the primary analysis of the data set was not carried out according to the 'intention to treat' principle. These simple effects were examined either using separate independent repeated measurement analysis, such as t-tests or – where the analysis of the residuals suggested non-normality – using the non-parametric Wilcoxon's signed ranks test. The mean attendance for participants involved in the intervention was 12.2 ± 3.5 (47%) of the 26 scheduled exercise sessions. If there had been a higher participation rate, perhaps the differences between baseline and post-intervention and between groups would have been more pronounced as was noted in other studies [10,34,44,45,47]. One of the gaps in HIIT research is the small number of volunteers and the short duration of interventions so that significant impacts on public health can be inferred [65]. However, in a school context, more than seven weeks can be problematic due to activities and teaching breaks provided for in planning and the school calendar [10]. Although we planned to include a pre- and post-nutrition control and a PA enjoyment scale, home confinement did not allow that assessment.

Conclusions

This study aimed to evaluate the effects of a brief, whole-body HIIT intervention, implemented on PEC, compared to 16 weeks of usual PEC warm-up, on CRF and muscular fitness in high-school adolescents. Our findings indicate that, despite a low average training volume of only 10 minutes per week, the 16-week HIIT program significantly improved CRF and muscular fitness in this population, particularly among girls. These results suggest that brief HIIT sessions can be effectively integrated into PEC without the need for external loads, utilizing simple methods such as all-out bouts and plyometric exercises.

Given the constraints of traditional PEC schedules, including limited time due to activities, teaching breaks, and student absences, this approach can enhance the physical fitness of female students. However, the lack of improvement in CRF among boys indicates a need to explore higher intensity and frequency in HIIT protocols for this group. Future research should focus on dose-response relationships and optimal volume and intensity levels for both healthy and clinical populations to maximize the benefits of HIIT.

Acknowledgments

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

Funding:

This research was funded by the Portuguese national funding agency for science, research, and technology, Fundação para a Ciência e Tecnologia, grant number SFRH/BD/136869/2018

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