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# Does incorporating high intensity interval training in physical education classes improve fitness outcomes of students? A cluster randomized controlled trial

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ABSTRACT

The aim of this study was to determine the efficacy of a high intensity interval training (HIIT) intervention lasting 12 weeks on fitness (cardiorespiratory fitness, muscular strength, muscular endurance, power, speed, flexibility, and balance) and adiposity of 10- to 15-year-old students implemented during their physical education (PE). The focus of this study was to compare two approaches to increasing fitness level among school-aged children, one approach focusing on regular PE sessions in accordance with the curriculum and another one on regular PE classes augmented by HIIT. A cluster-randomized controlled trial was conducted (February-May 2022, Zagreb, Croatia). The total number of students across both groups was 207. General linear models were used to compare fitness and adiposity changes in both groups based on Eurofit test battery. A significant effect of the HIIT intervention was present for the 20-meter shuttle run test ($p = 0.001$; $d = 0.31$). The effect of the intervention compared to the control was estimated as an additional 181.2 m, 95 %CI (70.4 to 292.0). An additional intention-to-treat (ITT) analysis showed that the effect of the HIIT intervention on 20-meter shuttle run test remained statistically significant ($p = 0.011$), though the magnitude of the estimated effect was reduced from 181.2 m; SE = 55.4 to 119.6 m; SE = 46.4. Whilst it appears HIIT had the opposite of the expected effect on body fat percentiles, the effect on body composition was inconsistent. The intervention is registered at the Australian New Zealand Clinical Trials Registry (ANZCTR) [ACTRN12622000209796].

## 1. Introduction

Physical activity (PA) is vital for optimum human body functioning, while lack of PA causes maladaptation in the human condition which may lead to poorer quality of life (Booth et al., 2008). Prolonged lack of PA is associated with impaired glucose metabolism and cardiometabolic disorders which consequently lead to increases in mortality worldwide (Owen et al., 2010). Three in four adolescents aged 11–17 around the world do not currently meet the global PA recommendations for maintaining optimal health (World Health Organization. Global action plan on physical activity, 2018), putting them at risk for coronary heart disease, metabolic impairments, some types of cancer, and premature death (Lee et al., 2012). Despite available evidence in favour of PA, lack of PA among children and adolescents is extensive and contributes to adverse health outcomes (Hobbs et al., 2015; Hallal et al., 2012).

Widespread lack of PA is associated with declining fitness among children and adolescents (Tomkinson and Olds, 2007), with trends most likely continuing into adulthood (Telama et al., 2014). Several studies demonstrate declining cardiorespiratory fitness (CRF) (Tomkinson et al., 2007 Apr; Dyrstad et al., 2012; Tomkinson et al., 2019), flexibility (Costa et al., 2017), and strength (Masanovic et al., 2020). Nevertheless, poor fitness is a strong predictor for many noncommunicable diseases (NCD) in many countries (Blair et al., 1989; Myers et al., 2002; Mora et al., 2003; Metter et al., 2002). CRF, muscular fitness and speed are all inversely correlated with overall adiposity in children (Ara et al., 2007), with abdominal adiposity also being a strong inverse correlate among adolescents (Ortega et al., 2007). Majority of NCDs start developing during youth (Berenson et al., 1998), emphasizing the need for implementation of more effective solutions to enhance fitness tailored according to needs of children and adolescents.

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High intensity interval training (HIIT) has been shown to be an efficacious and time efficient strategy for enhancing CRF and body composition in adolescents (Costigan et al., 2015). When implemented in physical education (PE), HIIT can create enough time for learning opportunities while stimulating fitness (Dudley et al., 2021). In comparison to low- and moderate-intensity activities, HIIT produces larger improvements of systolic blood pressure and CRF in youth with excess weight (García-Hermoso et al., 2016), emphasizing its effectiveness in increasing CRF (Eddolls et al., 2017). HIIT-based interventions have also reported improvements in body composition among adolescents (Costigan et al., 2015). Furthermore, HIIT stimulates greater neuromuscular and anaerobic development in comparison to other types of exercise (Bauer et al., 2022). These benefits, however, are largely dependent on different types of HIIT designs.

Interventions within PE enable teachers to meet educative and health outcomes simultaneously (Dudley et al., 2021; Dudley et al., 2016). Schools provide a convenient setting for fitness-based interventions as many have the human (peers, parents, and teachers) and built (buildings, equipment, outdoor space) infrastructure for such activities (Chavez and Nam, 2020). Therefore, the aim of this study was to determine the efficacy of a 12-week HIIT program implemented in PE on the health-related fitness and adiposity status of 10- to 15-year-old students.

## 2. Methods

### 2.1. Trial design

Using a cluster-randomized control trial design (pre-test/post-test), classes in one school were randomly allocated to the intervention or the control group using an unbiased coin randomization process by school personnel after baseline data had been collected. In each of grades 5–8, one whole class was allocated to the intervention and the other to the control. The focus of the trial was to compare two approaches to increasing fitness among school-aged children, one focusing on regular PE sessions in accordance with the curriculum, the other on regular PE classes augmented by HIIT. Baseline data were collected the week before the start of the trial and post-test data after the 12-week period. The study design and participant flow chart are shown in Fig. 1.

### 2.2. Participants

Children attending grades 5–8 were recruited for this trial with no exclusion criteria. All children in these classes agreed to participate voluntarily and provided written consent from a parent or a guardian, including a health status report from the family doctor. The trial was carried out with all students irrespective of their abilities in accordance with an intention-to-treat (ITT) principle (McCoy, 2017). Fitness and adiposity outcomes were measured for all children who were present during initial and final measurements, regardless of their overall proportion of participation in the classes. The calculated sample size required for this intervention to detect statistical significance ($p < 0.05$) at $d = 0.3$ between groups was 87 students.

### 2.3. Intervention

The study was performed in Zagreb, Croatia (February-May 2022) according to the Declaration of Helsinki and the procedures were approved by the Ethics Committee of the Faculty of Kinesiology, University of Zagreb (No. 38./2021.). The intervention is registered at the Australian New Zealand Clinical Trials Registry (ANZCTR)

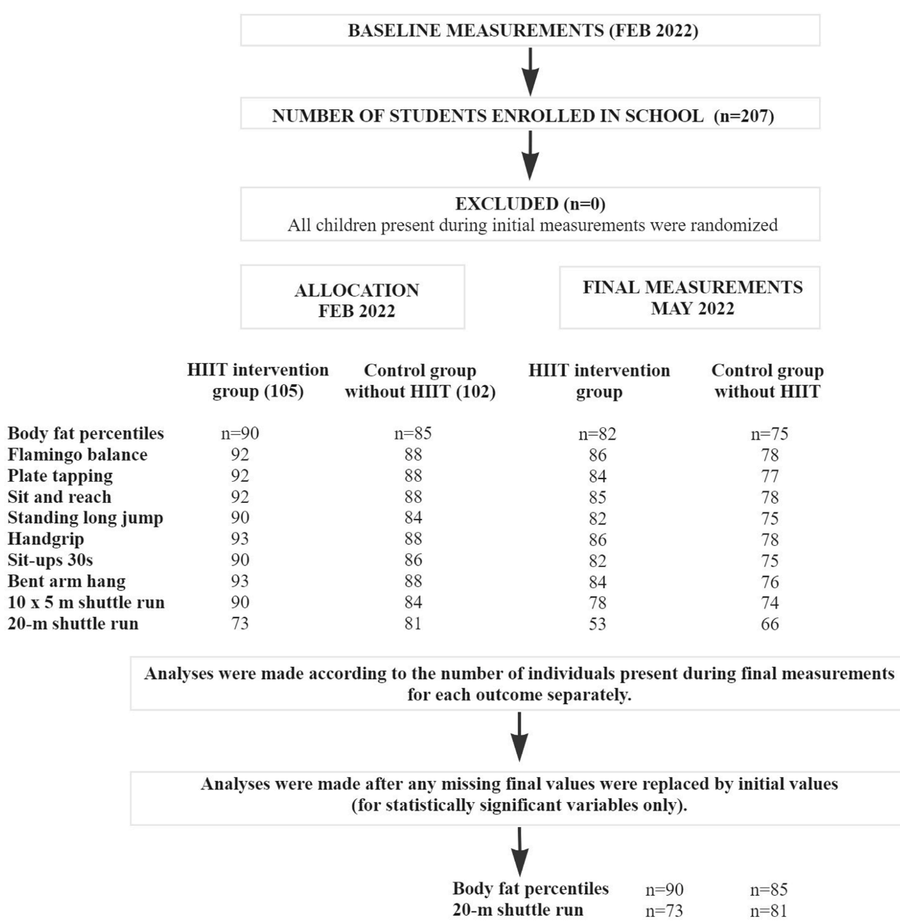


**Fig. 1.** Study design and participant flow chart throughout the study.

[ACTRN12622000209796]. The intervention provided two 10-minutes HIIT sessions per week at the beginning of regular PE classes. The intervention lasted 12 weeks, offering 24 sessions across the whole semester to students involved in the HIIT program. One PE teacher delivered sessions to all participants.

An increase in overall intensity of PA was considered a beneficial approach not only for enhancing fitness, but also as a 'by-product' method for maintaining healthy weight. The HIIT program presented in Table 1 was followed, with almost all children completing the program during each HIIT session. Adherence in terms of frequency and intensity was consistent across all sessions. In a supportive environment following several lockdowns due to the COVID-19 pandemic, all children cooperated with the teacher and were highly motivated to improve their abilities and achieve health benefits.

**Table 1**
Intervention HIIT program.

| Lesson Phase | Example 1 | Example 2 | Example 3 | Example 4 |
|---|---|---|---|---|
| Prep Phase (2 mins) | Jumping Jacks ×10 Running in Place ×10 Rhythmic Jumping ×10 Repeat until time is up | Diamond Jumps ×10 High Knee Runs ×10 Speed Skaters ×10 Repeat until time is up | Power Jumping ×10 Mountain Climbers ×10 Tuck Jumps ×10 Repeat until time is up | Squat Jumps ×10 Burpees ×10 Plank Jacks ×10 Repeat until time is up |
| Passive Recovery Heart rate Check (30 *sec*) | Standing still take pulse (6 s ×10) | Standing still take pulse (6 s ×10) | Standing still take pulse (6 s ×10) | Standing still take pulse (6 s ×10) |
| Work Phase 1 (2 mins) | Push-ups ×10 5 m Shuttle Sprint ×10 Squats ×10 5 m Shuttle Sprint ×10 Repeat until time is up | Chair Triceps Dips ×10 5 m Shuttle Sprint ×10 Reverse Lunge ×10 5 m Shuttle Sprint ×10 Repeat until time is up | Twisting Push-ups ×10 5 m Shuttle Sprint ×10 Plank Leg Raises ×10 5 m Shuttle Sprint ×10 Repeat until time is up | Plank to Push-ups ×10 5 m Shuttle Sprint ×10 V-Sit ×10 5 m Shuttle Sprint ×10 Repeat until time is up |
| Passive Recovery Heart rate Check (30 *sec*) | Standing still take pulse (6 s ×10) | Standing still take pulse (6 s ×10) | Standing still take pulse (6 s ×10) | Standing still take pulse (6 s ×10) |
| Work Phase 2 (2 mins) | Twisting Push-ups ×10 5 m Shuttle Sprint ×10 Plank Leg Raises ×10 5 m Shuttle Sprint ×10 Repeat until time is up | Plank to Push-ups ×10 5 m Shuttle Sprint ×10 V-Sit ×10 5 m Shuttle Sprint ×10 Repeat until time is up | Push-ups ×10 5 m Shuttle Sprint ×10 Squats ×10 5 m Shuttle Sprint ×10 Repeat until time is up | Chair Triceps Dips ×10 5 m Shuttle Sprint ×10 Reverse Lunge ×10 5 m Shuttle Sprint ×10 Repeat until time is up |
| Active Recovery (2 mins) | Dynamic/ static stretching. | Dynamic/ static stretching | Dynamic/ static stretching | Dynamic/ static stretching |
| Body of Lesson | Teacher returns to the normal teaching program for the remaining lesson time | Teacher returns to the normal teaching program for the remaining lesson time | Teacher returns to the normal teaching program for the remaining lesson time | Teacher returns to the normal teaching program for the remaining lesson time |

An example HIIT session comprised: preparation phase (2 min), passive rest (30 s), working phase (2 min), passive rest (30 s), working phase (2 min), and active rest (2 min). Working phases required maximal exertion, and during the following passive rests the heart beat was counted in a standing position for 6 s, subsequently multiplied by 10. Based on this, the load level was monitored. Students had one introductory session to learn how to carry out this self-assessment. If the heart rate (HR) was estimated as low, i.e., below 13 beats in 6 s ($13\times10 = 130$ bpm), children were encouraged to increase the intensity of the exercise during working phases. HR monitors were not used, so no objective measurements of HR were made, which precluded measures of exercise load or intensity. However, by self-assessment children were able to learn to approximately track their own exercise exertion without any necessary equipment, emphasizing the educative component of the intervention which contributed to positive feedback from children.

Regular PE classes were based on the embedded curriculum. An example regular PE class comprised: introductory warm-up (5 min); preparatory exercises (10 min); 'Part A' (15 min), elements specific to the sport of the day; 'Part B' (10 min), a relay game; final part (5 min) including stretching. The intervention group had HIIT instead of the introductory and preparatory sections and continued with Part A after the HIIT was completed.

### 2.4. Measurements

Participants were weighed barefoot wearing light clothes with a pre-calibrated digital scale to the nearest 0.1 kg. Height was taken to the nearest 0.1 cm using an anthropometer (GPM, Siber-Hegner & Co., Zurich, Switzerland). BMI was calculated as body weight in kilograms divided by body height in meters squared (kg/m2) (Garrow and Webster, 1985). Body fat percentage was determined using a Tanita BC-418 Segmental Body Composition Analyzer with correction for light indoor clothing. The student stood barefoot with weight equally distributed between both legs on the analyzer and held a pair of hand-grips, one in each hand (McCarthy et al., 2006).

The Eurofit test battery was used to assess fitness (Adam et al., 1987); it included flamingo balance test, plate tapping test, sit and reach test, standing long jump, handgrip test, sit-ups for 30 s, bent arm hang, 10×5 m shuttle run, and 20-meter shuttle run. The Eurofit test battery has reported acceptable levels of validity and reliability for fitness assessment in adolescents and has been widely used around the world (Ruiz et al., 2016; Council of Europe, 1988; Jürimäe et al., 2007).

### 2.5. Data collection

A circular arrangement was used for fitness and adiposity assessments with the following: height, weight, body fat percentage and Eurofit tests except 20-meter shuttle run test were performed on the same day; children were divided into small subgroups of up to four, and each subgroup started with a different test measurement; after completion of a test, subgroups moved to the next test clockwise. Pre-test instructions were given to children visually without possibility of trying the test before the actual measurement. Children were encouraged and monitored to put maximal effort into each test. The supportive school environment provided additional external motivation for this purpose. The 20-meter shuttle run test was performed separately during the same week but on a different day due to time restriction of 45 min per PE class. For the shuttle run test children were divided into two groups, each consisting of maximum 15 students. All tests were performed during one week or two regular PE classes. Two postgraduate kinesiology students trained to carry out fitness and adiposity measurements were present at each test, both blinded from group allocation; one student performed measurements and the other helped with transitions between tests.

### 2.6. Statistical methods

Independent samples t-tests were used to check the baseline differences in age, height, BMI, and body fat percentage. Body fat percentiles for the sample were calculated based on LMS values reported by a German study (Plachta-Danielzik et al., 2012). Further, BMI percentiles and height percentiles were calculated using World Health Organization LMS values (de Onis et al., 2007). General linear models were used to compare final fitness and adiposity values between intervention and control groups, adjusted for the baseline values of evaluated traits, baseline age, baseline body fat percentile values and sex using Minitab™ statistical software (version 21, Minitab Ltd., https://www.minitab.com) (Minitab, 2021). Changes in BMI values were examined using a Percent over BMI method (BMI50) and the Healthy Fitness Zone continuum (BMI85) which avoid the pattern of a positive mean change in BMI% in children at lower baseline BMI score, and a negative mean change in BMI% in ones at higher baseline BMI score (Peyer et al., 2019).

Using an ITT principle, children randomized before the start of the trial were also included in final analyses regardless of the proportion of their participation in the intervention throughout the 12-week period. In this way, the true efficacy of the intervention implemented within a real-world environment could be assessed. Moreover, additional analyses were carried out to assess the effect of missing data due to absence of children from school during final measurements or their inability or reluctance to perform a specific test. IBM SPSS 28.0. Statistics (https://www.ibm.com/au-en/products/spss-statistics) was used for missing data management. Statistical significance was set at $p < 0.05$.

## 3. Results

### 3.1. Recruitment

The number of children included in the intervention and control groups was 105 (mean age ± SD = 12.1±1.1) and 102 (mean age ± SD = 12.5±1.4). The study experienced a sample decline due to several reasons: absence of children from the school during final measurements, reluctance to perform a specific test, or injury (Fig. 1). This was resolved by accounting for missing data.

### 3.2. Baseline findings

At baseline the intervention group had a similar proportion of boys and girls, whereas the control group had a slightly higher proportion of boys ($p = 0.52$). In girls, the baseline difference in age, height, BMI, and body fat percentage between groups was not statistically significant. In boys, a marginally significant difference between groups was present for age ($p = 0.04$) and BMI ($p = 0.04$), with higher baseline values among controls (Table 2). According to the age and sex-specific BMI cut-off points (Cole et al., 2000); 69.7 % of our sample had normal weight, 23.4 % were overweight and 6.9 % had obesity. Further, for the 20-meter shuttle run test, the HIIT group had a distance much lower than the control group (592.1 m compared to 755. 6 m). Although we adjusted our analysis for age, sex and baseline values, it is still worth noting this occurrence. Possible reasons could be an older control group (although not much older) or a slightly higher proportion of boys in the control group. However, when reanalyzing data, we did not observe any abnormality that would account for this unusual difference.

**Table 2**
Baseline differences in anthropometric values between the intervention and the control group.

| | Intervention (n = 105) | Control (n = 102) | p-value |
|---|---|---|---|
| Age (years) | 12.10 (1.11) | 12.54 (1.35) | 0.010 |
| Height (cm) | 159.44 (8.33) | 161.00 (11.00) | 0.306 |
| BMI (kg/m$^2$) | 20.09 (3.81) | 20.58 (3.77) | 0.393 |
| Body fat (%) | 21.52 (9.52) | 22.14 (9.30) | 0.662 |

Mean (standard deviation); Height – expressed in centimeters; BMI – body mass index – the ratio of body weight in kilograms and body height in meters squared; Body fat – determined using Tanita BC-418 Segmental Body Composition Analyzer.

### 3.3. Post-test findings

The general linear model analyses showed no significant effect of the HIIT intervention for fitness results which required balance, coordination, speed, flexibility, power, static strength, muscular endurance, or non-reactive agility. However, the HIIT intervention significantly improved student performance in the 20-meter shuttle run test with a small to medium effect ($p = 0.001$; $d = 0.31$) when adjusted for baseline age, sex, body fat percentiles and pre-intervention results. The effect of the intervention compared to the control is estimated as an additional 181.2 m, 95 %CI (70.4, 292.0), which translates to nine more sublevels attained by the group having the HIIT program (Table 3). Raw initial and final values for all fitness outcomes are displayed for both groups (Table 4).

The HIIT intervention did not have any significant effect on BMI percentile values, BMI50 nor BMI85 when adjusted for age, sex, centile group, and initial BMI values. However, the group having regular PE classes showed statistically significantly lower body fat percentile values after the 12-week period compared to the intervention group; though significant, the effect was negligible to small ($p = 0.025$; $d = 0.17$). The effect of the regular PE classes compared to HIIT intervention is estimated as 2.76 percentiles, 95 % CI (0.3, 5.1), with lower values among controls. No adverse health outcomes were reported.

### 3.4. Sensitivity analyses

We conducted ITT analyses for the 20-meter shuttle run test and the body fat percentile values, thus increasing the number of cases utilized in each analysis (from n = 119 to n = 154 for the shuttle run, and n = 157 to n = 175 for the body fat percentiles). The effect of the HIIT intervention remained statistically significant for the shuttle run test

**Table 3**
Post-intervention effects on fitness and body composition outcomes.

| TESTS | Change Coef | SE Coef | p-value |
|---|---|---|---|
| Flamingo balance (n) | 0.314 | 0.480 | 0.515 |
| Plate tapping (*sec*) | 0.034 | 0.220 | 0.878 |
| Sit and reach (cm) | −1.286 | 0.742 | 0.085 |
| Standing long jump (cm) | −3.622 | 1.948 | 0.065 |
| Handgrip (kg) | −0.160 | 0.656 | 0.809 |
| Sit-ups 30 s (n) | 0.580 | 0.356 | 0.106 |
| Bent arm hang (*sec*) | 0.712 | 1.918 | 0.711 |
| 10×5 m shuttle run (*sec*) | 0.186 | 0.294 | 0.530 |
| 20-m shuttle run (m) | 181.2 | 55.40 | 0.001 |
| BMI (kg/m$^2$) | 0.225 | 0.117 | 0.056 |
| Body fat (%) | 0.730 | 0.335 | 0.031 |

Coef – Difference in the change coefficient from initial to final between intervention and control (+indicates favor for the intervention group and – indicates favor for the control group); SE Coef – Standard errors; Flamingo balance test – number of touch downs; Plate tapping test – number of seconds for 25 repetitions; Sit and reach test – expressed in centimeters; Standing long jump – expressed in centimeters; Handgrip test – expressed in kilograms; Sit-ups for 30 s –number of repetitions in 30 s; Bent arm hang – expressed in seconds; 10×5 m shuttle run – expressed in seconds; and 20-m shuttle run – expressed in meters. BMI – body mass index – the ratio of body weight in kilograms and body height in meters squared; Body fat – determined using Tanita BC-418 Segmental Body Composition Analyzer. A significant improvement in 20-m shuttle run has been adjusted for age, sex and baseline values.

**Table 4**
Initial and final measurements for the intervention and control group.

| TESTS | Intervention Mean (SD) | Control Mean (SD) | Intervention Mean (SD) | Control Mean (SD) |
|---|---|---|---|---|
| | Initial measurements | | Final measurements | |
| Flamingo balance (n) | 11.45 (7.20) | 10.25 (6.36) | 4.68 (3.51) | 4.29 (3.22) |
| Plate tapping (*sec*) | 11.22 (1.64) | 11.37 (1.93) | 11.40 (2.02) | 11.25 (1.57) |
| Sit and reach (cm) | 5.84 (9.29) | 5.27 (10.07) | 4.79 (9.26) | 5.52 (9.87) |
| Standing long jump (cm) | 167.43 (27.26) | 169.40 (30.94) | 167.30 (28.31) | 173.10 (29.07) |
| Handgrip (kg) | 24.89 (6.07) | 23.41 (8.15) | 30.59 (5.92) | 30.85 (6.81) |
| Sit-ups 30 s (n) | 22.72 (4.18) | 22.05 (3.43) | 21.45 (3.99) | 20.84 (3.61) |
| Bent arm hang (*sec*) | 23.78 (23.82) | 22.05 (21.62) | 24.07 (18.76) | 22.59 (15.45) |
| 10×5 m shuttle run (*sec*) | 22.60 (2.27) | 22.35 (2.85) | 21.78 (2.45) | 21.43 (2.43) |
| 20-m shuttle run (m) | 592.1 (311.5) | 755.6 (389.9) | 906.60 (457.50) | 862.50 (416.10) |

Mean (SD) – mean values and standard deviations for initial and final values for both groups; Flamingo balance test –number of touch downs; Plate tapping test –number of seconds for 25 repetitions; Sit and reach test – expressed in centimeters; Standing long jump – expressed in centimeters; Handgrip test – expressed in kilograms; Sit-ups for 30 s – number of repetitions in 30 s; Bent arm hang – expressed in seconds; 10×5 m shuttle run – expressed in seconds; and 20-m shuttle run – expressed in meters.

(from p = 0.001 to p = 0.011), though the magnitude of the estimated effect was reduced (from 181.2 m; SE = 55.4 to 119.6 m; SE = 46.4 in favor of the experimental group). The anomalous statistical significance of the regular PE on the body fat percentile results was also no longer evident following the ITT analysis (from p = 0.03 to p = 0.086).

We also carried out a complete imputation of missing data for all the outcome variables using the automated multiple imputation method, based on the characteristics of the data available. The completed imputed data set was then used to repeat the previous analyses. Again, the significance of the previous results was maintained, though the magnitude of the effects was reduced. For the shuttle run test, statistical significance changed from p = 0.001 to p = 0.003, and the effect from 181.2 m; SE = 55.4 to 122.9 m; SE = 41.4 in favor of the intervention group. For the body fat percentiles, statistical significance changed from p = 0.025 to p = 0.11, and the effect from 2.76 percentiles; SE = 1.22 to 3.17 percentiles; SE = 1.97, in favor of the control group.

## 4. Discussion

This study investigated the efficacy of a 12-week HIIT intervention on health-related fitness and adiposity in children aged 10–15. Children included in the HIIT intervention significantly improved their performance in the 20-meter shuttle run test; a commonly used test in PE for assessing CRF (Léger et al., 1988). A small to medium effect remains relevant as cardiorespiratory impairment accounts for 31.5 % of all deaths and 45 % of all NCDs-related deaths annually worldwide (GBD, 2013). Our results are consistent with a recently published *meta*-analysis indicating that HIIT has a statistically significant effect on CRF among youth (Solera-Martínez et al., 2021). Also, HIIT outperforms moderate intensity continuous PA for CRF among children and adolescents (Cao et al., 2019), including youth with obesity (Liu et al., 2020). HIIT is also considered a time-efficient strategy, allowing PE teachers to meet health and educative outcomes concurrently, thus increasing the quality of PE (Dudley et al., 2021). Given that our intervention was short in duration, it further highlights the magnitude of the impact HIIT can have on CRF in youth. The sustainability and trajectories of HIIT effects on CRF should be the focus of future research since previous longitudinal studies have shown that the low level of CRF in adults is partly determined by fitness level during youth (Ruiz et al., 2009 Dec). Further, we did not estimate $VO2_{max}$ change from the 20-meter shuttle run results, since many of the equations developed for this purpose for children and adolescents are lacking external validity of estimation when applied to different populations (Ruiz et al., 2009) and lack sufficient sensitivity to detect small changes in CRF in intervention studies of this size (Silva et al., 2012).

This intervention did not show any statistically significant effect on other fitness outcomes including balance, coordination, speed, flexibility, power, static strength, muscular endurance, or non-reactive agility. Although our HIIT protocol did not stimulate the necessary neuromuscular adaptations in children and adolescents for muscular performance (Guy and Micheli, 2001), we did include activities that focused on different muscular groups normally used for strength, speed, power, non-reactive agility, and muscular endurance development. The pervasive lack of specificity in HIIT programs (Costigan et al., 2015) should therefore be resolved in order for HIIT to allow for muscular and cardiorespiratory adaptations simultaneously. A *meta*-analysis focusing on the effects of resistance training in prepubertal and post pubertal healthy children and adolescents found that more exercise sessions per week cause larger strength development with longer interventions being more beneficial than short ones (Behringer et al., 2010). Hence, short-term HIIT interventions with only two 10-minute-long sessions per week within PE may not provide enough stimulus for this broader degree of fitness enhancement. To reach such an efficacy threshold, long-term HIIT interventions appear to be required that have more frequent sessions but are still capable of providing sufficient engagement in PE that will keep youth engaged. Implementation of short and small dose HIIT interventions within PE does not seem to have a demonstrable effect on fitness other than the cardiorespiratory gains. Furthermore, although all students undertook stretching at the end of each HIIT session, no statistically significant effect of the intervention was seen on flexibility. This is consistent with a recent *meta*-analysis which also failed to report effects of HIIT on flexibility (Costigan et al., 2015).

Sensitive periods for developing different motor abilities must also be considered when planning HIIT intervention for different age groups (Van Hooren and Croix, 2020), where this should represent a priority during HIIT implementation. Additionally, adaptations are generally larger for untrained individuals compared to trained ones (Behm et al., 2017). This also highlights the possible impact of children's participation in PA outside the school environment and their PA levels during the Covid-19 pandemic as this intervention was carried out after several lockdowns.

Although the effect was negligible to small, the group having regular PE classes without HIIT showed statistically significantly lower body fat percentile values after 12 weeks compared to the intervention group. This is the opposite of expected, since several studies have indicated significant improvements in body fat % following a 3-month HIIT intervention (Tjønna et al., 2009 Feb; Racil et al., 2016). A recent *meta*-analysis of randomized controlled trials which included youth with obesity found no significant difference between HIIT and moderate intensity continuous exercise on body fat % (Liu et al., 2020). However, our results are supported by a recently published study on adolescent boys with obesity showing that although a 12-week school-based HIIT protocol significantly decreased visceral adiposity, moderate intensity continuous exercise significantly decreased body fat % (Meng et al., 2022). Such inconsistency among different studies is highlighted by a systematic review finding that the effectiveness of HIIT for improving body composition in both children and adolescents remains unclear (Eddolls et al., 2017). Nevertheless, school-based interventions that are fitness-oriented showed larger potential for improving body composition compared to other types of PA interventions (Podnar et al., 2021), where optimal CRF represents a favorable cardiorespiratory predictor regardless of the level of adiposity in youth (Legantis et al., 2012).

We utilized the ITT principle whereby we analyzed data from all individuals regardless of their total participation time during the 12-week period. Excluding individuals who did not follow the planned protocol may introduce unnecessary bias and reduce the accuracy of conclusions about the efficacy of the intervention. Therefore, the ITT method provides a less biased interpretation of the outcomes at the level of adherence in the intervention (McCoy, 2017). The largest drop out was for the 20-meter shuttle run test (Fig. 1). The reason behind this smaller adherence could partly be explained by the fact that the 20-meter shuttle run test was performed separately during the same week but on a different day. Also, it is possible that children were intentionally absent from the final class when this test was conducted because they were aware of the physical exertion it requires. Still, the fact that the efficacy of the intervention was maintained after imputing missing data for the 20-meter shuttle run test, both by using an ITT approach and by using imputation for all missing values, highlights HIIT as useful influence on CRF in children and adolescents. Additionally, after implementing an ITT approach the effect of a regular PE curriculum without HIIT intervention was no longer significant for body fat percentile values implying trivial occurrence.

### *4.1. Strengths and limitations*

This study has many strengths: 1) we conducted a cluster randomized controlled trial providing direct evidence of cause–effect relationships with minimal sampling bias; 2) we included classes from one school where the same PE teacher provided PE lessons across one school year thus bypassing possible hierarchical structures and correlations between different subgroups of classes; 3) we used an ITT principle and analyzed all randomized children; 4) we accounted for missing data due to students' absence during final measurements; 5) a PE specialist delivered the intervention rather than classroom teachers with possibly less expertise in the field; and 6) although the intervention did not show any effect on BMI, we included BMI50 and BMI85 as more appropriate outcomes for monitoring change.

There are also several limitations. First, the lack of objective heart rate assessment prevented precise load monitoring. Further, we did not collect any data on rating of perceived exertion apart from the verbal feedback received from children during the intervention. Second, no information on the eating habits of students included in both groups, nor on the amount of PA outside the intervention, was collected. This was also the case for several other factors that impact fitness and adiposity, such as genetic disparities, epigenetics, endocrine impairments, sleep, infection, and socio-economic determinants (Güngör, 2014). Third, most of the evidence comes from short-term, small-scale HIIT trials like this intervention. However, global low fitness levels during youth require long-lasting scaled-up interventions that are capable of increasing levels of PA in populations across different strata of society (Reis et al., 2016). Fourth, although we used the Tanita analyzer for the purpose of estimating body fat in our sample, inconsistent evidence regarding the validity of this method prevented us from confidently presenting body composition results although these data could have important implications for our lack of body composition findings (Orsso et al., 2020; Lazzer et al., 2003; Elberg et al., 2004; Cleary et al., 2008; Eisenkölbl et al., 2001; Goldfield et al., 2006; Meredith-Jones et al., 2015).

## 5. Conclusions

We found that a 12-week HIIT intervention delivered in regular PE classes was effective for CRF in youth when assessed via 20-meter shuttle run test. This effect occurred with a low dose of HIIT during PE undertaken twice a week with no adverse health outcomes reported. The efficacy of the intervention on CRF was maintained even after using an ITT approach, making our conclusions even stronger. Hence, decision-making institutions and funding bodies should be aware that low CRF is a chronic condition that can be improved even with a short HIIT intervention. However, scaled-up long-term HIIT interventions could represent a better solution for overcoming poor CRF in children and adolescents.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

Data will be made available on request.

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The authors thank the voluntary investigators, children, and parents involved in HIIT intervention. The data that support the findings of this study are available on request from the corresponding author [PJ]. The data are not publicly available due to restrictions related to information that could compromise the privacy of research participants. PJ's work was funded by Croatian Science Foundation, Grant Number DOK-2018-09-8532.

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## Glossary

*BMI:* body mass index
*CRF:* cardiorespiratory fitness
*HIIT:* high intensity interval training
*HR:* heart rate
*ITT:* intention-to-treat
*NCD:* noncommunicable diseases
*PA:* physical activity
*PE:* physical education