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Effects of high-intensity interval training (HIIT) on health-related physical fitness in adolescents

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ABSTRACT

Purpose. High-intensity interval training (HIIT) can effectively improve health-related physical fitness as a preventive measure against central obesity risk factors in adolescents. This study aimed to examine the effects of a 12-week HIIT program on health-related physical fitness in adolescents by comparing pre- and post-training measurements.

Methods. The sample consisted of 12 students from Nakhon Phanom University who were enrolled in the applied physical fitness course. The participants, aged 18–20 years, were selected purposively. The training program lasted for 12 weeks, with training sessions conducted 3 times per week (Monday, Wednesday, and Friday) for 80 min per session. The program consisted of running at maximum speed for 40 s, alternating with jogging for 60 s, for 16 rounds on a 400-metre track. The exercise intensity was controlled at 80–90% of the target heart rate, calculated using the Karvonen formula, and the heart rate was monitored with a smartwatch throughout the training.

Results. The results of the study showed that the effects of HIIT on anthropometric variables – body weight, body mass index (BMI), and percentage of fat (%Fat) – were non-significantly decreased ($p > 0.05$), while the maximum oxygen consumption (VO_2max) was significantly increased after 12 weeks of HIIT training compared to baseline ($p < 0.05$). However, the arm and leg muscle strength was not significantly increased compared to baseline after 12 weeks of training ($p > 0.05$).

Conclusions. Twelve weeks of HIIT resulted in physiological adaptations that improved body composition, even though there were no statistically significant changes in overall anthropometric measurements. Cardiorespiratory fitness was significantly enhanced, as shown by increased VO_2max in both male and female participants. These improvements are likely due to multilevel haemodynamic and respiratory adaptations, including an increased heart rate, higher cardiac output, and improved lung ventilation, along with elevated mitochondrial density in muscle cells, which enhances the fat utilisation efficiency. Although high-intensity interval training does not significantly improve muscle strength, it fosters neurological adaptations that enhance motor unit function, muscle coordination, and contraction efficiency, thereby improving overall muscle performance.

Key words: high-intensity interval training, health-related physical fitness

Introduction

Adolescence is a period of rapid physiological changes that affect many aspects of physical development, including physical fitness. Inadequate healthcare during this critical period can lead to chronic health problems in the long term, particularly central obesity and metabolic syndrome, which result from metabolic system abnormalities. These conditions increase the risk of diseases such as obesity, hypertension, hyperglycaemia, and lipid disorders (characterised by high triglycerides and low HDL cholesterol). These health problems are becoming increasingly severe among today's sedentary adolescents. Previous studies have demonstrated that abdominal obesity and metabolic syndrome in adolescents are significant and rapidly growing health concerns worldwide [1]. These conditions result from an excessive accumulation of visceral fat, leading to increased risks of various diseases, including type 2 diabetes, cardiovascular diseases, and hypertension [2]. The primary factors contributing to the development of these conditions in adolescents include lifestyle changes, consumption of high-calorie foods with poor nutritional value, lack of physical activity, and sedentary behaviours [3]. Furthermore, genetic factors play a crucial role in the onset of these conditions, such as

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individual variations in energy metabolism and fat storage [4]. Preventing and managing abdominal obesity from adolescence are therefore paramount in establishing a strong foundation for future health [1, 2]. One promising approach is the promotion of high-intensity interval training (HIIT), which has been proven effective in improving physical fitness and cardiovascular health in a short period [5, 6]. However, designing appropriate HIIT programs tailored to individuals remains challenging due to differences in fitness levels, health backgrounds, and individual responses to exercise [7]. Moreover, studies on the effects of HIIT on adolescent populations are limited. Therefore, this study aimed to analyse the effects of a HIIT program on health-related physical fitness in adolescents. The findings will contribute to the development of effective exercise programs to enhance health and physical fitness, and to the appropriate management of abdominal obesity in adolescents.

Material and methods

Study design

This experimental study employs a controlled design to investigate the effects of HIIT on physical fitness in adolescents. The 12-week intervention involves randomly assigning participants to ensure group equivalence.

Participants

The study included 12 volunteers (3 females, 9 males) aged 18–20 years. The participants met the following inclusion criteria: they were healthy individuals with no history of regular participation in exercise programs, sports, or physical activities. None had cardiovascular or musculoskeletal conditions that could interfere with performing the exercises or testing procedures. All participants provided written informed consent.

Treatment procedures

The HIIT program for Nakhon Phanom University students enrolled in the Applied Physical Fitness Enhancement course spanned 12 weeks, divided into four 3-week phases. Participants engaged in training sessions thrice weekly (Mondays, Wednesdays, and Fridays), each lasting 80 minutes. The regimen, designed to enhance cardiovascular fitness, involved running on a 400-metre track. Each session consisted of 16 repetitions of 3-second maximum-speed sprints followed by 60-second jogging intervals. The exercise intensity was maintained at 80–90% of the target heart rate, determined using the Karvonen formula: Target heart rate = [(220 – age – resting heart rate) × 80–90%] + resting heart rate. Participants were seated for 5 min before measuring their resting heart rate. The participants' heart rates were continuously monitored throughout the sessions using smartwatches. Table 1. Provides a detailed outline of the complete training program.

Table 1. Exercise intervention for high-intensity interval training (HIIT)

Activity	Time (min)	Intensity (%THR)	Intensity of rests
Warm-up	15	55–60%THR	–
Exercise	50	week 1–4 = 80%THR × 4 sets × 4 rep. week 5–8 = 85%THR × 4 sets × 4 rep. week 9–12 = 90%THR × 4 sets × 4 rep.	60 s rest-work at 60–65%THR
Cool-down	15	50–55%THR	–
Total exercise	80	80–90%THR	–

THR – targeted heart rate, rep – repetitions

Measurement

Anthropometric measurements

Anthropometric measurements were taken with subjects wearing sportswear and no shoes. A trained anthropometrist conducted all measurements. Body weight was measured using a digital scale. Height was measured using a wall-mounted stadiometer, with subjects standing erect, their heels, buttocks, and back against the wall, while facing forwards. Body mass index (BMI) was calculated to assess chronic energy deficiency using the formula: BMI = weight (kg) / height^2 (m^2). Body weight and body composition measurements were conducted again at 6 and 12 weeks following the completion of the high-intensity interval training program.

Measuring physical fitness

<u>Body composition</u>

The body fat percentage (%BF) was calculated based on skinfold thicknesses (ST) measured at four sites on the right side of the body: the biceps, triceps, subscapular, and suprailiac regions. Each measurement was

Table 2. Skinfold thickness measurement sites

Skinfold	Measurement site
Biceps	The front of the upper right arm, above the cubital fossa centre, level with the triceps site.
Triceps	Midpoint of the upper right arm back, between the acromion and olecranon processes.
Subscapular	20 mm below the tip of the scapula, 45° angle to the body's lateral side.
Supra-iliac	Midaxillary line, 20 mm above the iliac crest.

taken twice consecutively using a Lange calliper (accurate to 0.1 mm) [8]. The method for measuring subcutaneous fat is illustrated in Table 2. The fat thickness values at four locations (millimetres) were recorded and aggregated to calculate the body fat percentage using the reference table, which is stratified by gender and age.

Muscular strength

Hand Grip Strength Test: A Takei grip strength dynamometer (Japan) was used with the second handle position for all participants. Subjects stood with the shoulder adducted, neutrally rotated, and the elbow fully extended. Force was measured in kilograms/body weight. Strength was calculated as the average of the best results of two exams. Data were recorded as left or right hand, regardless of dominance. The testing order was balanced. The dominant hand was determined by the writing hand [9].

Leg strength test: The leg dynamometer strength test follows a precise protocol to measure lower body strength. Participants stand on the device's platform with the knees bent at 130–140 degrees, feet slightly apart, and back and arms straight. They grip the handle between their knees, adjusting the strap to their height. Participants then exert maximum effort to extend their legs, performing two attempts with a 1-minute rest in between [1, 10]. The highest value in kilograms is recorded and divided by the participant's body weight, yielding a standardised strength measure for accurate comparisons. This procedure ensures precise physical performance assessments.

Cardiorespiratory fitness

The 20-m Multistage Fitness Test (MSFT), is a widely used assessment of cardiovascular fitness and maximal aerobic power. Participants run back and forth along a 20-metre track, synchronising their pace with audio signals. The test begins at 8.5 km/h and increases by 0.5 km/h every minute [11]. Standardised auditory cues are delivered via a notebook computer connected to a Bluetooth speaker. Before the running test, participants listened to an explanation of the test procedures and engaged in a warm-up session. Participants began running upon hearing the start signal. The initial running speed was set at a relatively low pace of 8.5 km/h, with increments of 0.5 km/h introduced progressively. Participants were required to run between two designated lines, changing direction upon hearing a standard beep. Each beep signalled an increase in speed, with the interval between beeps decreasing progressively (one level per minute). If a participant reached the designated line before the beep, they were required to remain stationary until the beep sounded again before proceeding. Conversely, if a participant failed to reach the designated line before the beep, they received an alert and were required to continue running to the line and back to the next line before the subsequent beeps. Failure to comply would result in immediate disqualification, terminating the individual's evaluation. The total number of successful crossings of the finish line was recorded as the primary performance indicator.

Statistical analysis

Statistical analyses were conducted using IBM SPSS version 27.0. Demographic variables (age, height, weight, and BMI) are presented as means ± standard deviations (*SD*). A repeated measures ANOVA compared test results across time points (pre-, mid-, and post-training), with Tukey's HSD test for post-hoc analyses when significant differences were found. A correlation analysis examined the relationships between variables, focusing on HIIT intensity and health-related fitness improvements. Multiple regression analysis predicted fitness outcomes based on training parameters, including duration and intensity.

Results

Anthropometric characteristics of the participants

This study investigated the anthropometric and physiological characteristics of participants in an exercise training program. The cohort comprised 12 volunteers ($n = 12$; 3 females, 9 males). Female participants exhibited mean (± *SD*) values of 20.33 ± 0.58 (std. error = 0.33) years for age, 47.20 ± 4.54 kg (std. error = 2.62) for body mass, 157.33 ± 2.08 cm (std. error = 1.20) for height, and 19.07 ± 1.40 kg/m² (std. error = 0.81) for body mass index (BMI). Male participants showed mean values of 20.44 ± 0.53 years (std. error = 0.81), 64.77 ± 10.15 kg (std. error = 0.38), 173.22 ± 8.32 cm (std. error = 2.77), and 21.51 ± 2.37 kg/m² (std. error = 0.79) for age, body mass, height, and BMI, respectively. The results indicate that the males demonstrated greater weight and height compared to the females, which aligns with typical physical characteristics. The body mass index values for both males and females fell within the normal range (18.5–24.9). Table 3 presents the complete demographic and anthropometric data.

Analysis of the body composition parameters [body mass, body mass index (BMI), and subcutaneous adiposity] after the 12-week HIIT intervention showed no statistically significant reductions ($p > 0.05$), as detailed in Table 4.

Table 5 presents a comparative analysis of the physical fitness parameters before and after a 12-week HIIT intervention. The results indicate increased muscular strength in both the upper and lower extremities among the male and female participants; however, these improvements were not statistically significant ($p > 0.05$).

Table 3. Average values of the anthropometric parameters of the participants

Anthropometric parameters	Experimental group (*n* = 12)					
	females (*n* = 3)			males (*n* = 9)		
	mean	*SD*	std. error	mean	*SD*	std. error
Age (years)	20.33	0.58	0.33	20.44	0.53	0.18
Body mass (kg)	47.20	4.54	2.62	64.77	10.15	3.38
Height (cm)	157.33	2.08	1.20	173.22	8.32	2.77
BMI (kg/m^2)	19.07	1.40	0.81	21.51	2.37	0.79

Table 4. Comparative analysis of anthropometric parameters following 12-week HIIT intervention

Variable	Test			*F*	*p*-value
	baseline	6 weeks	12 weeks		
Females					
body mass (kg)	47.20 ± 4.54	46.47 ± 4.18	46.60 ± 4.68	0.02	0.98
BMI (kg/m^2)	19.07 ± 1.40	18.87 ± 1.27	18.83 ± 1.41	0.03	0.97
fat% (mm)	22.43 ± 3.95	20.93 ± 3.59	20.27 ± 3.84	0.26	0.78
Males					
body mass (kg)	64.77 ± 10.15	63.67 ± 10.34	63.28 ± 10.22	0.05	0.95
BMI (kg/m^2)	21.51 ± 2.37	21.16 ± 2.39	21.03 ± 2.19	0.10	0.90
fat% (mm)	14.54 ± 4.81	14.67 ± 3.94	13.20 ± 4.32	0.31	0.74

BMI – bdy mass index

Table 5. Comparison of physical fitness variables over 12 weeks of training

Variable	Test			*F*	*p*-value
	baseline	6 weeks	12 weeks		
Females					
arm strength (kg/body mass)	0.45 ± 0.07	0.52 ± 0.09	0.53 ± 0.06	1.08	0.40
leg strength (kg/body mass)	1.74 ± 0.38	1.78 ± 0.35	2.08 ± 0.70	0.36	0.72
VO_{2max} (ml/kg/min)	24.67 ± 0.81	25.93 ± 0.93	27.03 ± 0.71	6.25	0.03*
Males					
arm strength (kg/body mass)	0.63 ± 0.08	0.65 ± 0.09	0.69 ± 0.08	1.23	0.31
leg strength (kg/body mass)	2.61 ± 0.35	2.82 ± 0.54	3.06 ± 0.57	1.81	0.19
VO_{2max} (ml/kg/min)	25.92 ± 1.71	27.69 ± 2.72	29.87 ± 2.27	6.80	0.01*

VO_{2max} – maximal oxygen consumption
* $p < 0.05$

Notably, the maximum oxygen consumption (VO_{2max}) showed a significant increase in both the males and females ($p < 0.05$) compared to baseline values.

Discussion

Body composition changes after 12 weeks of HIIT

The 12-week HIIT exercise intervention resulted in reductions in body weight, body mass index, and subcutaneous fat percentage among both the male and female participants, although these changes did not reach statistical significance. The initial reductions may be attributed to glycogen and water store depletion [12]. By week 12, the decline plateaued, likely due to metabolic adaptations, particularly increased mitochondrial density in skeletal muscle, which enhanced fat utilisation for energy production [12, 13]. These physiological adaptations represent beneficial responses to HIIT, notwithstanding the lack of significant changes in the gross anthropometric measurements. The intensity, duration, and rest intervals of training serve as critical determinants of exercise outcomes. The precise manipulation of these variables directly influences both energy expenditure and fat oxidation efficiency. Moreover, HIIT has exhibited superior efficacy in reducing subcutaneous and abdominal adipose tissue compared to other exercise modalities [14]. Consistent with Sarkar et al.'s findings [15], the HIIT intervention yielded significant improvements in body composition parameters, as evidenced by a 7.6% reduction in body fat percentage (BF%). The enhanced skeletal muscle fat oxidation following HIIT exercise can be attributed to increased mitochondrial volume and several metabolic adaptations, including: (1) intra-adipose tissue lipolysis converting triglycerides into fatty acids, (2) cellular fatty acid uptake, (3) intramuscular triglyceride lipolysis, and (4) fatty acid transport into mitochondria [16, 17]. Weston et al. [18] demonstrated that high-intensity intermittent exercise induces greater subcutaneous fat loss than moderate-intensity exercise, even with equivalent total energy expenditure. During short-duration exercises, the maximal energy output primarily stems from creatine phosphate breakdown, with concentrations declining to near zero at the point of fatigue. Creatine phosphate levels typically return to near-baseline values within approximately 4 min of rest after short-duration maximal exercise [14]. HIIT significantly enhances 3-Hydroxyacyl-CoA Dehydrogenase (HADH) enzyme activity. McCartney et al. [19] demonstrated that triglycerides serve as a substrate for energy metabolism during the initial 30 s of repeated high-intensity exercise. This finding supports the hypothesis that intense exercise enhances the body's capacity to utilise fat more efficiently during the post-exercise phase, potentially leading to increased energy expenditure and fat oxidation. Moreover, Musa et al. [20] reported that an 8-week HIIT program significantly increased the HDL-C concentration while reducing the total cholesterol (TC) concentration in healthy individuals.

Physical fitness parameter changes following 12 weeks of HIIT training

Following 12 weeks of HIIT, the increases in arm and leg strength did not reach statistical significance. This outcome can be attributed to HIIT's primary emphasis on cardiovascular endurance enhancement and metabolic adaptations, rather than direct muscle strength development. Research indicates, however, that HIIT induces neurological adaptations that contribute to increased muscle strength, with these improvements stemming predominantly from neural rather than hypertrophic adaptations. The high intensity of HIIT specifically enhances motor unit activation, compelling the nervous system to recruit additional motor units to meet rapidly escalating energy demands. This process accelerates nerve impulse transmission from motor neurons to muscle fibres, yielding stronger and faster muscle contractions [21–23]. HIIT also enhances muscle coordination, particularly in short, repetitive movements, through neurological adaptations that optimise movement efficiency [24, 25]. Furthermore, HIIT induces biochemical and physiological changes within motor units, including increased contractile protein expression and elevated mitochondrial density. These adaptations synergistically enhance muscle performance [26, 27]. The increase in VO_{2max} observed after HIIT among male and female adolescents stems from multiple physiological adaptations, particularly within the cardiovascular system. Buchheit and Laursen [7] demonstrated that HIIT enhances both stroke volume and cardiac output, leading to increased VO_{2max}. Furthermore, HIIT augments the working muscles' capacity to utilise oxygen delivered via the circulatory system. Additionally, an increase in mitochondrial density within muscle cells enhances energy production (ATP) via oxidative phosphorylation. This adaptation improves the body's efficiency at utilising oxygen, leading to greater force production and reduced lactate accumulation during high-intensity exercise. Consequently, these physiological changes contribute to enhanced muscle endurance [28, 29]. Moreover, HIIT is associated with respiratory adaptations. Specifically, it has been shown to improve pulmonary ventilation and gas exchange efficiency, enabling greater oxygen uptake and more effective carbon dioxide elimination [30]. Although HIIT increases VO_{2max} in both men and women, physiological differences may contribute to variations in training outcomes. These differences include hormone levels – particularly oestrogen in women – and body composition, both of which can influence an individual's response to training [31]. After 12 weeks of HIIT, significant improvements in cardiorespiratory fitness were observed, as indicated by the increased VO_{2max} in both the females (27.03 ml/min/kg) and the males (29.87 ml/min/kg). The effects of the HIIT on the VO_{2max} were influenced by both the training intensity and duration. Consistent with the findings of Sarkar et al. [15], HIIT significantly enhanced physical fitness, as measured by VO_{2max}. This improvement was associated with a 19% reduction in mortality risk from cardiovascular disease (CVD) [33]. Recent evidence suggests that both short-term high-intensity interval training (ST-HIIT) and long-term high-intensity interval training (LT-HIIT) enhance VO_{2max} and reduce specific cardiovascular risk factors in overweight and obese populations [33]. Therefore, HIIT represents a promising strategy for mitigating cardiovascular risk.

Conclusions

Twelve weeks of HIIT resulted in physiological adaptations that improved body composition, even though there were no statistically significant changes in the overall anthropometric measurements. Cardiorespiratory fitness was significantly enhanced, as shown by the increased VO_{2max} in both the male and female participants. These improvements are likely due to multilevel haemodynamic and respiratory adaptations, including an increased heart rate, higher cardiac output, and improved lung ventilation, along with elevated mitochondrial density in muscle cells, which enhances fat utilisation efficiency. Although high-intensity interval training does not significantly improve muscle strength, it fosters neurological adaptations that enhance motor unit function, muscle coordination, and contraction efficiency, thereby improving overall muscle performance. The results indicate that HIIT is an effective and time-efficient method for improving health and physical fitness, particularly for individuals aiming to reduce cardiovascular risk factors. Future research should explore the long-term effects of HIIT and develop personalised protocols to optimise health outcomes.

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Ethical approval

The research related to human use complied with all the relevant national regulations and institutional policies, followed the tenets of the Declaration of Helsinki, and was approved by the Human Research Ethics Committee of Nakhon Phanom University (approval No.: HE 3468).

Informed consent

Informed consent was obtained from all individuals included in this study.

Conflict of interest

The authors state no conflict of interest.

Disclosure statement

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