PEDAGOGY of Physical Culture and Sports

ORIGINAL ARTICLE

Effects of short-term high-intensity exercise on oxidative stress and antioxidant levels in healthy young males

Slamet Raharjo[1ABDE], Mustika Fitri[2ABD], Mahmud Yunus[1BD], Sandey Tantra Paramitha[2BD], Septian Williyanto[2BD], Nor Eeza Zainal Abidin[3ACD], Raja Mohammed Firhad Raja Azidin[4CD]

Department of Sports Science, Faculty of Sports Science, Universitas Negeri Malang, Malang, Indonesia
Study Program of Sport Science, Faculty of Sport and Health Education, Universitas Pendidikan Indonesia, Bandung, Indonesia
Faculty of Sports and Exercise Science, Universiti Malaya, Kuala Lumpur, 50603, Malaysia
Faculty of Sports Science and Recreation, Universiti Teknologi MARA, Selangor, Malaysia

Authors' Contribution: A – Study design; B – Data collection; C – Statistical analysis; D – Manuscript Preparation; E – Funds Collection

Abstract

Background and Study Aim: High-intensity interval training (HIIT) has become a popular exercise choice for people who have limited time but aim to maximize their workout results. This study aims to compare the impacts of high-intensity running interval training (HIRIT) and high-intensity progressive resistance training (HIPRT) on oxidative stress biomarkers and antioxidant levels in healthy young males.

Material and Methods: The study included 30 healthy male adolescents aged 20–23 years who participated in HIRIT and HIPRT interventions over a four-week period. Data were collected by measuring levels of Malondialdehyde (MDA) and Superoxide Dismutase (SOD) as biomarkers of oxidative stress and antioxidants. These measurements were obtained before and after the intervention using Colorimetric Assay Kits. Data analysis was performed using paired sample t-tests and independent sample t-tests with a significance level set at 5%.

Results: The results showed a significant decrease in MDA levels in both high-intensity training interventions. However, SOD levels increased significantly only in the high-intensity running interval training group ($p \leq 0.05$). Additionally, comparisons between groups revealed a reduction in MDA levels and an increase in SOD levels ($p \leq 0.05$).

Conclusions: These findings suggest that both high-intensity running interval training and high-intensity progressive resistance training, conducted over a four-week period, are effective in reducing oxidative stress. Additionally, both types of training increase antioxidant levels in healthy young men. However, high-intensity running interval training proved to be more effective in reducing MDA levels and increasing SOD levels.

Keywords: antioxidants, oxidative stress, progressive resistance training, running interval training

Introduction

High-intensity interval training (HIIT) has become increasingly popular as an efficient workout option for individuals seeking significant fitness benefits within a limited timeframe. Despite this popularity, identifying the most effective HIIT methods for promoting physiological benefits in young, healthy individuals remains essential and continues to be an important focus in the search for new, optimized training solutions.

In this context, high-intensity interval training (HIIT) has proven to be highly effective for improving cardiovascular fitness and muscle strength within a relatively short period [1]. HIIT consists of short bursts of high-intensity physical activity interspersed with brief recovery phases [2]. This structure not only enhances the efficiency of each session but also enables substantial fitness gains in less time compared to traditional training methods [3]. As a result, HIIT is an appealing option for individuals with limited time who still aim to maximize their fitness outcomes [4].

HIIT operates by pushing the body to reach or approach its maximum capacity during high-intensity intervals, thereby increasing oxygen consumption and boosting metabolism even after the workout ends [5]. This effect, known as excess post-exercise oxygen consumption (EPOC) or the "afterburn effect," enhances calorie burn and metabolic rate post-exercise [6]. While HIIT is well-established in improving physical performance, its impact on oxidative stress, specifically on biomarkers like Superoxide Dismutase (SOD) and Malondialdehyde (MDA), remains a subject of ongoing debate in the scientific community [7]. SOD, a critical antioxidant enzyme, shields the body from oxidative damage induced by reactive oxygen species (ROS), whereas MDA serves as an indicator of lipid peroxidation

doi:10.15561/26649837.2024.0606

and cellular damage [8]. Although numerous studies highlight the fitness benefits of HIIT, the exercise's precise effects on oxidative stress need further exploration, particularly concerning the molecular mechanisms that regulate ROS production and the body's antioxidant response [9].

Oxidative stress occurs when the production of reactive oxygen species (ROS) surpasses the capacity of the body's antioxidant systems to neutralize them [10]. This imbalance can lead to extensive cellular damage, including lipid peroxidation, with Malondialdehyde (MDA) as one of its byproducts [11]. Superoxide Dismutase (SOD), the primary antioxidant enzyme, plays a critical role in neutralizing ROS, particularly superoxide radicals, by converting them into hydrogen peroxide, which is subsequently broken down by other enzymes like catalase [8]. High-intensity exercises, such as HIIT, are known to increase ROS production, primarily due to heightened oxygen consumption during intense phases [12, 13]. However, the long-term effects of HIIT on the body's antioxidant capacity remain incompletely understood.

ROS production during HIIT varies based on the type of exercise performed [14, 15]. In aerobic-based HIIT running, the increase in oxygen consumption within the mitochondria during high-intensity phases leads to elevated ROS production [16]. The body adapts by boosting SOD activity through pathways such as Nrf2 (Nuclear factor erythroid 2-related factor 2) and PGC-1α (Peroxisome proliferator-activated receptor gamma coactivator 1-alpha), which also promote mitochondrial biogenesis [17]. These adaptive pathways enhance the body's overall antioxidant capacity, making HIIT running more effective in stimulating antioxidant responses compared to other training methods [18].

In contrast, HIIT strength training, which emphasizes resistance and muscle strength, causes more pronounced mechanical damage to muscle fibers [19], resulting in localized ROS production in the affected areas [17, 20-21]. This can lead to lipid peroxidation, with MDA serving as a marker of cellular damage [22]. Although the body responds by increasing SOD activity [23-24], this response typically occurs more slowly compared to HIIT running, as the body prioritizes muscle tissue repair [25]. Consequently, MDA levels tend to be higher in the early stages of HIIT strength training, especially before full physiological adaptation has taken place [16, 26].

Although HIIT is widely recognized as an effective method for improving cardiovascular fitness and muscle strength, debate persists regarding its effects on oxidative stress and the body's antioxidant balance [1, 7]. Some studies indicate that HIIT running is particularly effective at enhancing antioxidant enzymes like SOD, which help protect the body from oxidative damage induced by ROS [12, 16, 27, 28, 29]. In contrast, HIIT strength training often leads to elevated MDA levels due to increased muscle damage, suggesting a higher risk of cellular damage during the initial phases of training [30, 31, 32, 33]. This ongoing debate raises important questions about which type of HIIT is more advantageous for managing oxidative stress and whether the short-term risk of cellular damage is balanced by the body's long-term antioxidant adaptation.

This study aims to compare the impacts of high-intensity running interval training (HIRIT) and high-intensity progressive resistance training (HIPRT) on oxidative stress biomarkers and antioxidant levels in healthy young males.

Materials and Methods

Participants

This study used a true experimental design with a pretest-posttest control group structure. A total of 30 healthy males, aged 20–23 years, were recruited from university students in Malang and assigned to either high-intensity running interval training (HIRIT) or high-intensity progressive resistance training (HIPRT). The control group (CNTLR) did not receive any training intervention. Before the study began, all participants were informed verbally and in writing about the research procedures, and they provided consent to participate by signing an informed consent form. All study procedures were approved by the Ethics Committee of Universitas Negeri Malang [No.4.07.2/UN32.14.2.8/LT/2024], and the study adhered to the principles of the Declaration of Helsinki regarding ethical conduct in research involving human subjects.

Research design

High-intensity training programs

The high-intensity running interval training (HIRIT) and high-intensity progressive resistance training (HIPRT) programs were implemented and supervised by professionals from the Department of Sports Science, Faculty of Sports Science, Universitas Negeri Malang. Participants were randomly assigned to one of three groups: a control group without intervention (n = 10), a high-intensity running interval training group (n = 10), and a high-intensity progressive resistance training group (n = 10). The HIRIT intervention consisted of sessions lasting 30–60 minutes, with participants performing 4–6 sets of 10–12 repetitions and taking active rest breaks of 30–60 seconds between sets. The HIPRT intervention was performed at an intensity of 80–90% of one repetition maximum (1RM), also in 4–6 sets of 10–12 repetitions, with active rest periods of 30–60 seconds between sets. Both training programs were conducted three times a week over a four-week period.

Data collection

Data were collected by drawing 4 ml of blood from the cubital vein before and after the intervention to assess serum SOD and MDA levels. MDA levels were measured using Human Colorimetric Assay Kits (TBA Method) (Cat. No.: E-BC-K025-M; Malondialdehyde (MDA); Elabscience Biotechnology Inc., Houston, TX, USA), while SOD levels were measured with Human Colorimetric Assay Kits (Cat. No.: E-BC-K019-S; SOD; Elabscience Biotechnology Inc., Houston, TX, USA). Additionally, participants' age, height, body weight, body mass index (BMI), systolic and diastolic blood pressure, resting heart rate, oxygen saturation, and body temperature were evaluated before the intervention.

Statistical analysis

Data analysis included a normality test using the Shapiro-Wilk test to assess the normal distribution of the data, and homogeneity was evaluated with Levene's Test. Data that were normally distributed with homogeneous variances were analyzed using parametric tests, specifically one-way ANOVA, followed by Tukey's HSD post-hoc test at a 5% significance level. All statistical analyses were conducted using SPSS version 23.

Results

The results showed no significant differences in the characteristics of the research subjects among the three groups, as detailed in Table 1. All characteristic parameters of the research subjects showed no significant differences ($p \geqslant 0.05$). Changes in SOD and MDA levels, which represent oxidative stress and antioxidant biomarkers, were analyzed between pre-training and post-training in each group: control (CNTLR), high-intensity running interval training (HIRIT), and high-intensity progressive resistance training (HIPRT). These results are presented in Figures 1 and 2.

The results showed a significant decrease in MDA levels between pre-training and post-training in the HIRIT group (255.00 ± 77.42 to 141.50 ± 49.66 nmol/mL, p = 0.000) and in the HIPRT group (257.75 ± 28.98 to 166.50 ± 16.29 nmol/mL, p = 0.000). In contrast, no significant change in MDA levels was observed in the CNTLR group (273.50 ± 165.45 to 271.25 ± 128.17 nmol/mL, p = 0.953) (Figure 1).

SOD levels increased significantly between pre-training and post-training in the HIRIT group (75.19 ± 9.83 to 86.15 ± 5.99 nmol/mL, p = 0.015). However, no significant changes in SOD levels were observed in the CNTLR group (76.69 ± 9.94 to 75.59 ± 6.31 U/mL, p = 0.816) or the HIPRT group (75.38 ± 3.38 to 78.43 ± 8.72 nmol/mL, p = 0.273) (Figure 2).

Comparisons of SOD and MDA levels between the groups are presented in Figures 3 and 4.

Discussion

This study aimed to compare the effects of high-intensity running interval training (HIRIT) and high-intensity progressive resistance training (HIPRT) on oxidative stress biomarkers and antioxidant levels in healthy young males. The results show that both types of training effectively reduced oxidative stress and increased antioxidant activity in healthy adolescents. HIRIT proved to be more effective in increasing Superoxide Dismutase (SOD) levels. This enzyme plays a critical role as an antioxidant. HIRIT also reduced Malondialdehyde (MDA) levels, which is a marker of lipid peroxidation and cellular damage. In contrast, HIPRT caused a larger increase in MDA levels. This suggests greater cellular damage during the early adaptation phase of resistance training.

These findings align with the literature, which suggests that aerobic-based exercises, such as HIIT running, are more effective in enhancing the body's antioxidant activity compared to resistance training. Powers et al. [15] demonstrated that aerobic exercise increases SOD levels through molecular adaptation pathways. This includes the activation of Nrf2, a key regulator of antioxidant gene expression. During aerobic exercise, increased oxygen consumption in the mitochondria elevates the production of

Table 1. General characteristics of the research subjects

Parameters	Groups (Mean ± Std. Deviation)			p-value
	CNTLR (n=10)	HIRIT (n=10)	HIPRT (n=10)	
RHR (bpm)	71.60±4.86	70.20±4.76	69.30±5.25	0.585
SpO_2 (%)	97.90±0.99	97.50±1.08	97.80±1.14	0.689
SBP (mmHg)	118.60±2.55	118.10±4.79	116.00±4.29	0.319
DBP (mmHg)	76.00±3.77	75.50±7.71	71.60±6.12	0.227
BT (°C)	36.40±0.22	36.30±0.19	36.26±0.21	0.303
BW (kg)	65.65±11.55	59.90±8.83	58.20±3.39	0.148
BH (m)	1.69±0.07	1.66±0.03	1.68±0.06	0.492
BMI (kg/m^2)	22.89±3.21	21.66±2.79	20.61±0.87	0.146
Age (years)	19.50±2.27	19.20±0.92	18.20±0.63	0.842

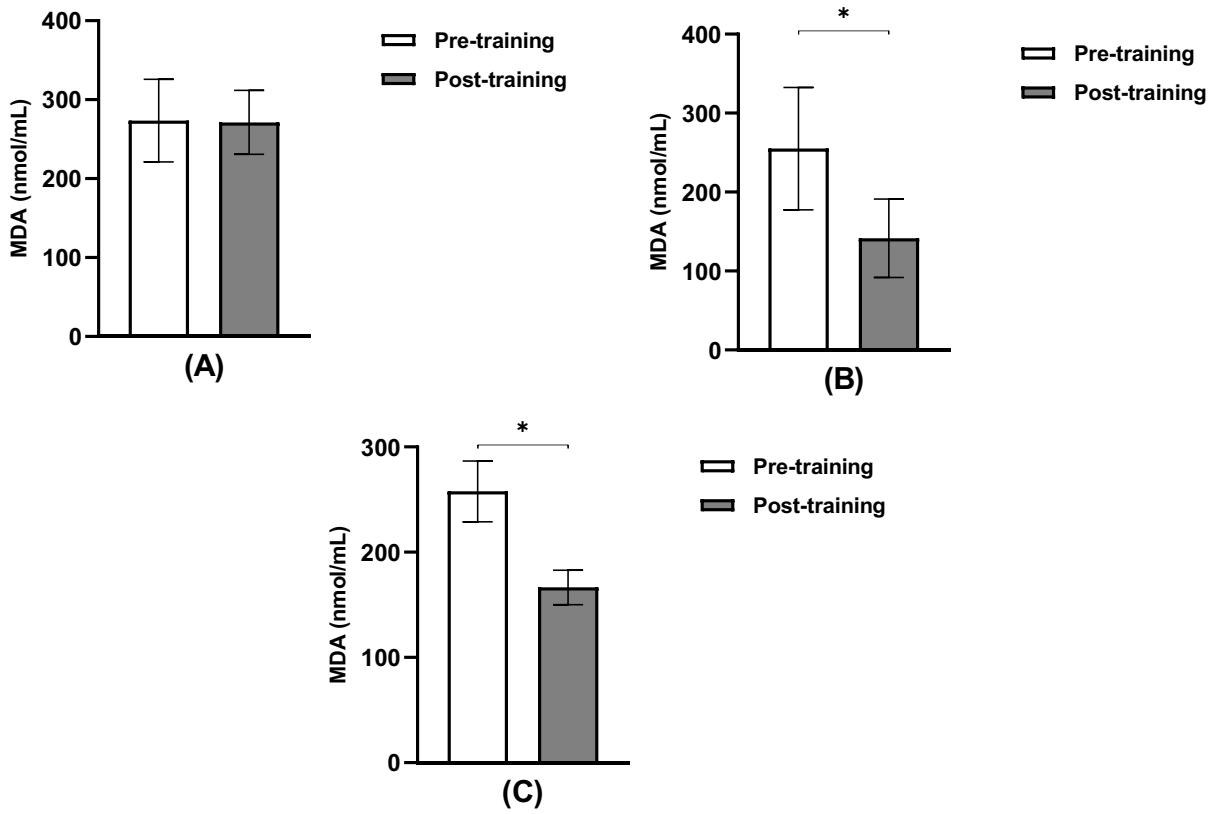

Figure 1. Differences in MDA levels between pre-training and post-training in the three groups.
Note. (*) Indicates a significant difference from pre-training ($p \leqslant 0.05$). (A) Control group (CNTLR), (B) High-intensity running interval training group (HIRIT), (C) High-intensity progressive resistance training group (HIPRT).

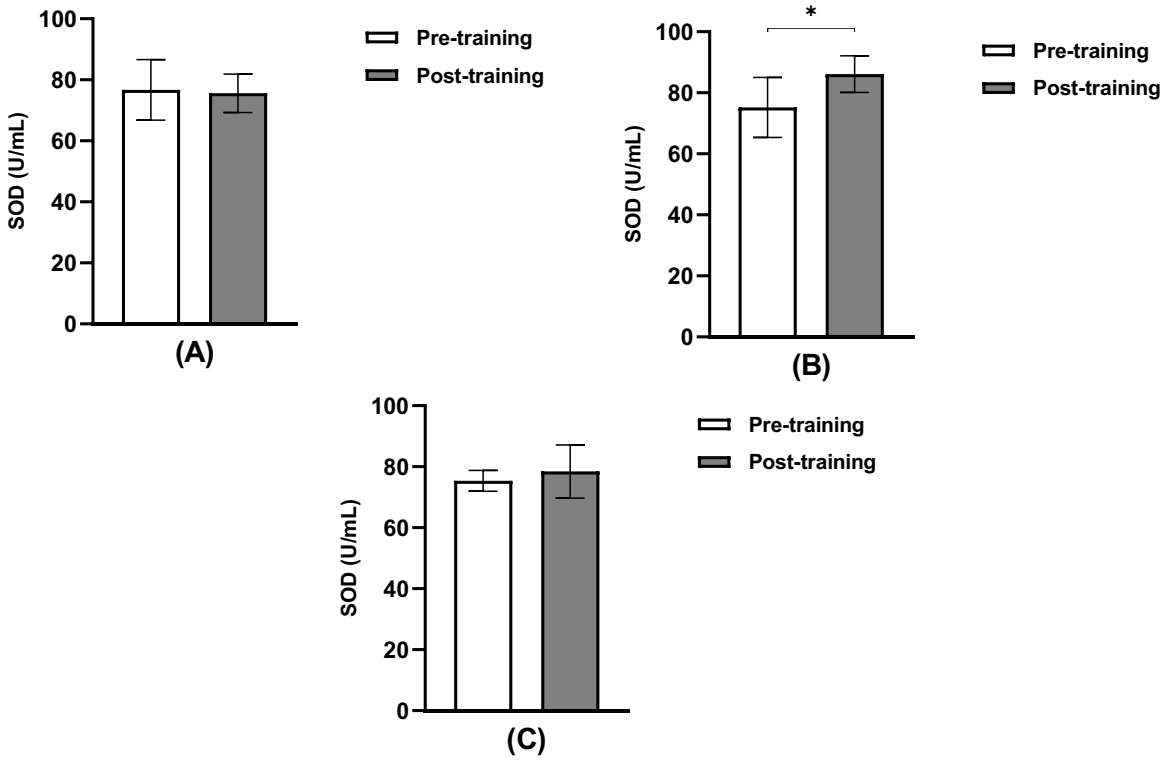

Figure 2. Differences in SOD levels between pre-training and post-training in the three groups.
Note. (*) Indicates a significant difference from pre-training ($p \leqslant 0.05$). (A) Control group (CNTLR), (B) High-intensity running interval training group (HIRIT), (C) High-intensity progressive resistance training group (HIPRT).

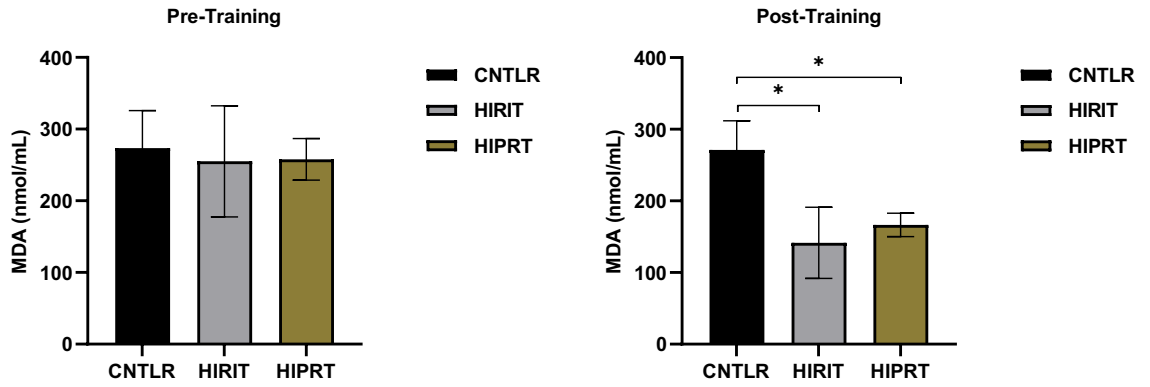

Figure 3. Differences in average MDA levels (nmol/mL) between groups.
Note. (*) Indicates a significant difference from the control group (CNTLR) ($p \leqslant 0.05$).

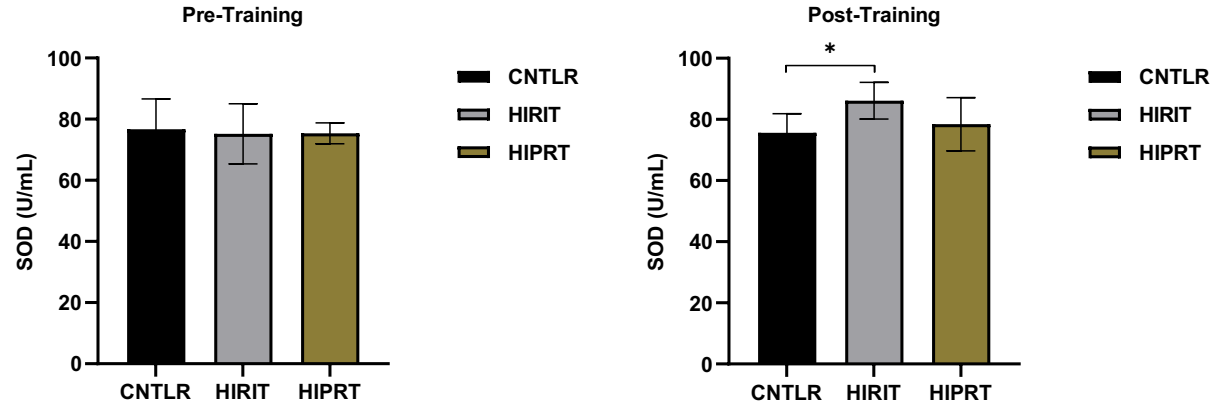

Figure 4. Differences in average SOD levels (U/mL) between groups.
Note. (*) Indicates a significant difference from the control group (CNTLR) ($p \leqslant 0.05$).

Reactive Oxygen Species (ROS). This rise in ROS stimulates the production of antioxidant enzymes, such as SOD, to neutralize free radicals [16]. This mechanism explains why aerobic exercise can more effectively and rapidly reduce oxidative stress.

On the other hand, HIIT strength training tends to increase MDA levels. This marker of lipid peroxidation reflects mechanical muscle damage. Research by Damas et al. [31] showed that resistance training, particularly during the early adaptation phase, causes significant muscle damage. This damage triggers the release of Reactive Oxygen Species (ROS) in the affected tissues. Our findings are consistent with this, as HIIT strength training led to a greater increase in MDA, especially during the early phase of training. Although some studies suggest that resistance training can enhance antioxidant capacity over the long term [30, 31, 32, 33, 34], the relatively short duration of our study may not have been sufficient to capture this adaptation in HIIT strength training.

These results highlight the distinct physiological mechanisms by which the two types of exercise manage oxidative stress. HIIT running increases oxygen consumption, leading to elevated ROS production in the mitochondria [35]. This rise in ROS stimulates the expression of antioxidant enzymes via the Nrf2 pathway. Nrf2 binds to the Antioxidant Response Element (ARE) on the promoter regions of antioxidant genes, including SOD [36]. Increased SOD activity neutralizes superoxide radicals, which could otherwise cause cellular damage. Furthermore, HIIT running activates the PGC-1α pathway. This activation supports mitochondrial biogenesis and enhances cellular respiration efficiency, ultimately reducing overall ROS production [37, 38].

In contrast, HIIT strength training induces higher oxidative stress due to mechanical muscle damage [39, 40]. The intense eccentric contractions during resistance training led to localized ROS production from enzymes such as NADPH oxidase and xanthine oxidase. This exacerbates oxidative damage in the affected tissues [39, 41]. Additionally, the release of pro-inflammatory cytokines like TNF-α and IL-6 prolongs oxidative stress. These cytokines activate the NF-κB inflammatory pathway [42], further contributing to the increase in MDA levels [43]. Although SOD activity increases in response to HIIT strength training, this response is often delayed. The body prioritizes repairing muscle damage before fully engaging its antioxidant defenses [30, 31, 44].

The practical implications of these findings suggest that HIIT running is better suited for individuals aiming to quickly reduce oxidative

stress and enhance antioxidant capacity in the short term. HIIT running-based exercise programs are particularly recommended for those focused on oxidative stress management, such as endurance athletes or individuals seeking to maintain cardiovascular health. In contrast, HIIT strength training provides significant benefits for increasing strength and promoting muscle hypertrophy. However, it is important to account for the elevated oxidative stress during the early adaptation phase. A cautious approach should be taken, emphasizing optimal muscle recovery strategies to minimize excessive oxidative damage.

Study Limitations

First, the four-week intervention period may not have been sufficient to observe long-term adaptations. This is particularly relevant for HIIT strength training, where increases in antioxidant capacity might require more time to develop. Second, the sample consisted exclusively of healthy adolescent males. As a result, the findings may not be generalizable to other populations, such as females, adults, or individuals with specific health conditions. Finally, external factors such as diet and prior fitness levels were not measured. These variables could have influenced the participants' responses to the exercise interventions.

Directions for Future Research

Further research is needed to evaluate the long-term effects of both types of exercise on antioxidant capacity and oxidative stress. Studies with longer intervention durations could offer deeper insights into how antioxidant adaptations develop in HIIT strength training, particularly after the initial muscle damage adaptation phase. Future research should also include a more diverse population, incorporating females and individuals across a broader age range. This would help determine whether the observed results are consistent across different demographic groups. Additionally, factors such as diet, exercise intensity, and lifestyle habits should be taken into account. This would provide a more comprehensive understanding of how these variables influence the balance between oxidative stress and antioxidant capacity.

Conclusions

Based on the study results, both high-intensity running interval training and high-intensity progressive resistance training, conducted over four weeks, were effective in reducing oxidative stress and increasing antioxidant activity in healthy adolescent males. However, high-intensity running interval training demonstrated greater effectiveness. It more significantly reduced Malondialdehyde (MDA) levels, a marker of cellular damage caused by lipid peroxidation, and increased Superoxide Dismutase (SOD) levels, a key antioxidant enzyme, compared to high-intensity progressive resistance training. These findings suggest that high-intensity running interval training is better suited for managing oxidative stress in healthy adolescent males, although both training methods offer notable benefits.

Funding

This research was supported by research funds from the Collaboration of Educational Institutions for Indonesian State Education Personnel No:5.4.28/UN32.14.1/LT/2024.

Conflict of interest

The authors declare that we all have no conflicts of interest.

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Information about the authors:

Slamet Raharjo; (Corresponding author); https://orcid.org/0000-0002-0708-867X; slamet.raharjo.fik@um.ac.id; Department of Sports Science, Faculty of Sports Science, State University of Malang; Malang, Indonesia.

Mustika Fitri; https://orcid.org/0000-0003-1733-9820; mustikafitri@upi.edu; Study Program of Sport Science, Faculty of Sport and Health Education, Universitas Pendidikan Indonesia; Bandung, Indonesia.

Mahmud Yunus; https://orcid.org/0000-0002-9611-8921; mahmud.yunus.fik@um.ac.id; Department of Sports Science, Faculty of Sports Science, State University of Malang; Malang, Indonesia.

Sandey T. Paramitha; https://orcid.org/0000-0002-7256-6711; sandeytantra18@upi.edu; Study Program of Sport Science, Faculty of Sport and Health Education, Universitas Pendidikan Indonesia; Bandung, Indonesia.

Septian Williyanto; https://orcid.org/0000-0002-5713-2448; septianwilliyanto@upi.edu; Study Program of Sport Science, Faculty of Sport and Health Education, Universitas Pendidikan Indonesia; Bandung, Indonesia.

Nor Eeza Zainal Abidin; https://orcid.org/0000-0002-6320-5519; eezazainal@um.edu.my; Faculty of Sports and Exercise Science, Universiti Malaya; Kuala Lumpur, Malaysia.

Raja Mohammed Firhad Raja Azidin; https://orcid.org/0000-0003-4770-2870; firhad@uitm.edu.my; Faculty of Sports Science and Recreation, Universiti Teknologi MARA; Shah Alam, Malaysia.

Cite this article as:

Raharjo S, Fitri M, Yunus M, Paramitha ST, Williyanto S, Abidin NEZ, Azidin RMFR. Effects of short-term high-intensity exercise on oxidative stress and antioxidant levels in healthy young males. *Pedagogy of Physical Culture and Sports,* 2024;28(6):516–524.
https://doi.org/10.15561/26649837.2024.0606

Received: 21.10.2024
Accepted: 29.11.2024; Published: 30.12.2024