

# Long-interval training effects on VO<sub>2</sub>max, resting heart rate, and body composition in Pencak Silat athletes aged 16–18 years

Moch Hasan Al as'ary<sup>1ABD</sup>, Adi Pranoto<sup>1ABCD</sup>, Andri Suyoko<sup>1ABDE</sup>, Fansah Adila<sup>2BD</sup>,  
Fuad Noor Heza<sup>1BD</sup>, Yudi Dwi Saputra<sup>1BD</sup>, Andun Sudijandoko<sup>1BD</sup>, Made Pramono<sup>1BD</sup>,  
Nur Ahmad Arief<sup>1BD</sup>, Bekir Erhan Orhan<sup>3ACD</sup>

<sup>1</sup> Department of Sports Coaching Education, Faculty of Sports and Health Sciences, Universitas Negeri Surabaya, Indonesia

<sup>2</sup> Study Program of Sports Coaching Education, Faculty of Teacher Training and Education, Universitas Riau, Indonesia

<sup>3</sup> Faculty of Sports Sciences, Istanbul Aydın University, Turkey

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## Abstract

**Background and Study Aim** Aerobic capacity, cardiac efficiency, and metabolic regulation contribute directly to performance in Pencak Silat. The sport involves intermittent high-intensity actions that place continuous demands on cardiovascular and metabolic systems. Although various conditioning approaches are used in practice, their relative effectiveness in improving responses relevant to Pencak Silat remains a matter of practical interest. This study aimed to evaluate how a structured long-interval training program influences aerobic capacity, heart rate regulation, and body composition indicators in Pencak Silat athletes aged 16–18 years.

**Material and Methods** A quasi-experimental pretest–posttest design with a comparison group was used. Twenty athletes aged 16–18 years were assigned either to an LIT group or to a control group that continued regular training. Aerobic capacity (VO<sub>2</sub>max) was measured with the Multi-Fitness Test (MFT). Resting heart rate, body fat, and visceral fat were assessed using a bioelectrical impedance device. Because the data were not normally distributed, non-parametric tests were applied.

**Results** The LIT program significantly improved VO<sub>2</sub>max ( $p = 0.001$ ) and reduced RHR ( $p = 0.001$ ) compared with the control group. Total and visceral fat also decreased significantly in the LIT group ( $p = 0.001$ ), although the reduction in body fat between groups remained modest. These changes indicate combined cardiovascular and metabolic adaptations in response to long-interval training. The results are consistent with the demands of Pencak Silat, where higher aerobic efficiency and lower central fat support movement economy and technical execution.

**Conclusions** The study indicates that long-interval training can be used as a structured approach to modify aerobic, cardiac, and body composition indicators in trained youth. The findings support the use of interval-based programs in sports with intermittent high-intensity efforts. They may help practitioners choose conditioning methods that match these demands.

**Keywords:** aerobic performance, cardiovascular adaptation, autonomic regulation, metabolic indicators, interval-based conditioning, visceral adiposity

## Introduction

Physical performance in Pencak Silat depends on the interaction between aerobic capacity, heart rate responses, and body composition. The sport involves repeated high-intensity actions that create sustained demands on cardiovascular and metabolic systems. These demands make the regulation of aerobic work, recovery capacity, and central fat distribution an important part of preparation for young athletes. Structured interval-based training is often used to address these requirements because it provides controlled and repeatable physiological stimuli.

These demands highlight the importance of the physiological factors that support sustained work and recovery in combat sports. Athletic performance in Pencak Silat depends not only on technical execution but also on aerobic capacity and body composition [1]. Aerobic capacity and body composition, including visceral fat, influence endurance, energy use, and overall functional readiness in young athletes. Aerobic capacity, commonly assessed through VO<sub>2</sub>max, reflects the efficiency of oxygen delivery during intensive activity [2]. Visceral fat affects physical performance and metabolic status because it is hormonally active and associated with insulin resistance and inflammatory processes [3].

In Pencak Silat, athletes work under varying movement intensities, demanding exchanges,

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and short recovery periods, which increase the importance of aerobic capacity and metabolic efficiency [4]. These features require high aerobic power and effective energy use. The training response in athletes aged 16–18 years is also shaped by ongoing growth, which can influence how they adapt to high-intensity programs, including interval training [5]. Studies in martial arts and related sports have reported that interval training can raise  $VO_2\max$  and affect body fat, but its specific effects on visceral fat in this age group are examined infrequently [6]. Many available studies also focus on general or obese youth populations rather than trained adolescents, which limits sport-specific conclusions.

Beyond aerobic capacity and body composition, heart rate (HR) is a common indicator used in exercise science. HR monitoring offers a simple, non-invasive way to observe cardiovascular strain, exercise intensity, and recovery patterns [7]. In applied sport settings, HR data help estimate training load and guide adjustments to planned sessions [8]. Heart rate variability (HRV), defined as the beat-to-beat fluctuation in HR, is also used to assess autonomic regulation and recovery status [9, 10]. Interpretation of HR during high-intensity or interval training requires caution, because delayed cardiovascular responses and irregular recovery periods can limit its accuracy as a proxy for metabolic load [11]. HR and HRV values therefore need to be interpreted in relation to the structure of the session, recovery duration, and the athlete's fitness level [7].

Long-interval training (LIT) involves high-intensity exercise performed over intervals of two to four minutes with planned recovery periods [12]. Studies comparing high-intensity interval training (HIIT) with continuous exercise report similar effects on body fat, while HIIT often produces greater changes in  $VO_2\max$  or metabolic efficiency [13]. In contrast with short-interval or sprint protocols, LIT provides a steadier aerobic stimulus and enables athletes to spend more time near  $VO_2\max$ . It also supports central cardiovascular adaptations and reflects the intermittent yet sustained effort patterns seen in Pencak Silat. Interval training, including long-interval formats, can reduce total and visceral fat and contribute to favorable body-composition profiles, although the size of these changes varies with the duration and volume of the training program [14, 15].

Analysis of research findings has shown that interval-based methods can influence aerobic capacity, heart rate responses, and body-composition indicators in young athletes. Authors emphasize that the effects of these methods depend on the structure of the training load and on the physiological demands of sports with intermittent high-intensity actions. Researchers also note that adaptations during late adolescence may differ from

those observed in adults, which adds complexity to training design. Together, these considerations highlight the relevance of examining how structured long-interval formats operate under conditions comparable to those encountered in Pencak Silat and create the basis for defining the specific focus of the present study.

These observations also draw attention to how interval-based methods may function in sports with distinct movement structures and recovery patterns. This creates a natural context for considering their relevance in disciplines such as Pencak Silat.

Although interval training has been studied extensively in youth sports populations, its application to adolescent Pencak Silat athletes remains underexplored. The sport's unique combination of sustained striking phases, rapid stance transitions, and short rest intervals presents distinct physiological demands that justify tailored conditioning approaches. This study adapts a long-interval training protocol to address these demands and evaluates its effectiveness in improving aerobic efficiency and fat metabolism in a combat-sport-specific context.

Against this background, the study aimed to evaluate how a structured long-interval training program influences aerobic capacity, heart rate regulation, and body composition indicators in Pencak Silat athletes aged 16–18 years.

## Materials and Methods

### *Participants*

This study used a quasi-experimental pretest-posttest design with a comparison group and involved Pencak Silat athletes aged 16–18 years from East Java, Indonesia. Participants were recruited through convenience sampling from two sports-focused high schools. Twenty eligible athletes were randomly allocated to a long-interval training (LIT) group ( $n = 10$ ) or a comparison group ( $n = 10$ ) using sealed opaque envelopes. An independent researcher generated the random sequence and was not involved in recruitment or data collection. To maintain allocation concealment, the envelopes were sequentially numbered and opened only after completion of baseline assessments. This procedure was applied to reduce selection bias.

All athletes were required to be free from orthopedic injuries or metabolic disorders and to attend at least 90% of the training sessions. Athletes were excluded if they missed more than two sessions, joined additional structured conditioning programs, or sustained injuries that interfered with participation. The study was approved by the Ethics Committee of Universitas Negeri Surabaya. Informed consent was obtained from participants aged 18 years, and parental or guardian consent was obtained for those younger than 18.

*Study Design*

This study consisted of 16 supervised training sessions conducted three times per week. The long-interval training (LIT) protocol was applied only to the experimental group, while the control group continued their regular Pencak Silat training without structured interval work. Attendance was recorded at each session. Researchers also coordinated with the coach to ensure that training performed outside the study followed a lower intensity. Any reports of injury or discomfort were documented, and medical staff provided appropriate care.

VO<sub>2</sub>max was assessed using the Multi-Fitness Test (MFT), a validated field protocol for adolescent athletes. Body fat percentage and visceral fat index were measured with the Xiaomi Smart Scale S400 (Xiaomi Inc., Beijing, China) using bioelectrical impedance analysis (BIA). All measurements were taken at baseline and after the final training session.

To ensure reliability, VO<sub>2</sub>max and BIA assessments were conducted indoors at 22–24°C and 40–60% humidity and at the same time of day. Testing took place in the morning after an 8–10-hour fast. The MFT and the Xiaomi Smart Scale S400 were calibrated according to manufacturer instructions. Participants were asked to avoid strenuous physical activity, caffeine, and large meals for 12 hours before testing. For BIA, they emptied their bladder 30 minutes before measurement and maintained a consistent hydration level. All assessments were performed by the same trained examiner to ensure consistency.

*Training program*

The LIT intervention was structured over six weeks (16 sessions) and used running intervals prescribed according to each participant’s Maximum Aerobic Speed (MAS). MAS was determined with the Multi-Fitness Test (MFT). The final level and duration reached before exhaustion were converted into MAS using the official MFT conversion table, which links the last completed level to the estimated maximal running speed associated with VO<sub>2</sub>max.

This MAS value was then used to individualize training intensity during the intervention.

Each session consisted of 180-second work intervals followed by 180-second active recovery at 40–50% MAS. Training was carried out in four small groups formed according to similar MAS values to ensure suitable pacing. The FITT structure of the program is presented in Table 1.

Across the intervention, intensity increased from 95% to 120% MAS, and training volume rose by adding repetitions and sets from week 3 onward. Recovery pace increased from 40% to 50% MAS in the later weeks. Total session duration ranged from approximately 24 to 36 minutes, excluding warm-up and cool-down. Heart rate was monitored with a Polar H10 device (Polar Electro Oy, Kempele, Finland) to control training intensity and confirm compliance. Heart rate was recorded continuously during each session to verify that participants remained within the planned intensity zones. Compliance was checked by reviewing the heart rate log after each session. Deviations from the target zones were documented and corrected during the following sessions.

All training sessions were conducted on an outdoor running track with a flat synthetic surface to maintain safety and consistency. Environmental conditions were monitored, and training was carried out only at temperatures of 26–30°C and in stable weather. Before each session, participants completed a 10–12-minute warm-up that included light jogging, dynamic stretching, and neuromuscular activation. The same warm-up routine and environmental conditions were used throughout the intervention.

The training structure was adapted to reflect the typical duration and intensity of Pencak Silat match segments, which involve intermittent exertion lasting 2–3 minutes with short active recovery. This alignment ensured that the LIT protocol remained relevant to real competition demands.

*Statistical analysis*

Normality was assessed using the Shapiro–

**Table 1.** Long-Interval Training Program Based on MAS

Week	Intensity (MAS %)	Work:Rest (s:s)	Repetitions (count)	Sets	Frequency (per week)	Goal of Adaptation
1	95	180:180	4	1	3	Aerobic tolerance development
2	100	180:180	4	1	3	Aerobic power activation
3	100	180:180	5	1	3	Increasing time at VO <sub>2</sub> max
4	110	180:180	5	1	3	High-intensity stimulus
5	110	180:180	6	1	3	Aerobic power consolidation
6	120	180:180	6	2	3	Peak intensity and overload

Wilk test. Because several variables did not meet normality assumptions, within-group comparisons were performed using the Wilcoxon signed-rank test, and between-group differences were examined using the Mann-Whitney U test. Exact p-values and effect sizes are reported (two-tailed,  $\alpha = 0.05$ ). Statistical analyses were carried out using IBM SPSS Statistics version 26 (IBM Corp., Armonk, NY, USA).

## Results

The baseline characteristics of the participants showed that the two groups had comparable initial profiles (Table 2). There were no significant differences between the control and treatment groups in age ( $p = 0.445$ ), resting heart rate ( $p = 0.835$ ), systolic blood pressure ( $p = 0.356$ ), diastolic blood pressure ( $p = 0.673$ ), height ( $p = 0.113$ ), weight ( $p = 0.272$ ), BMI ( $p = 0.849$ ), body fat ( $p = 0.992$ ), visceral fat ( $p = 0.425$ ), or baseline  $VO_2\max$  values ( $p = 0.111$ ). These results indicate that baseline characteristics were similar in both groups, with no statistically significant differences.

The pre-post changes in  $VO_2\max$ , resting heart rate, body fat, and visceral fat in the control group are shown in Figure 1.

As shown in Figure 1, no significant pre-post differences were observed in the control group.  $VO_2\max$  remained stable across both measurement points. Resting heart rate followed the same pattern. Body fat percentage and visceral fat levels also stayed within comparable ranges from baseline to post-intervention. Overall, Figure 1 indicates that the control group showed minimal change across all measured indicators.

Meanwhile, the pre-post changes in  $VO_2\max$ , resting heart rate, body fat, and visceral fat in the treatment group are presented in Figure 2.

As shown in Figure 2, the treatment group demonstrated clear pre-post changes across all measured variables.  $VO_2\max$  increased from baseline to post-intervention. Resting heart rate showed a lower post-intervention value compared with

baseline. Body fat and visceral fat also decreased over the same period. Overall, Figure 2 shows a consistent shift in all indicators within the treatment group.

The between-group results for  $VO_2\max$ , resting heart rate, body fat, and visceral fat are summarized in Table 3. As shown in the table, the treatment group demonstrated greater changes than the control group across all primary outcomes.  $VO_2\max$  increased in the treatment group while remaining stable in the control group. Resting heart rate, body fat, and visceral fat decreased more in the treatment group than in the control group. These differences were reflected in statistically significant time  $\times$  group effects for the main variables.

Across the intervention, the treatment group showed clear pre-post changes in  $VO_2\max$ , resting heart rate, body fat, and visceral fat, while the control group remained largely unchanged. Between-group comparisons confirmed that these differences were greater in the treatment group, with statistically significant time  $\times$  group effects across the main outcomes.

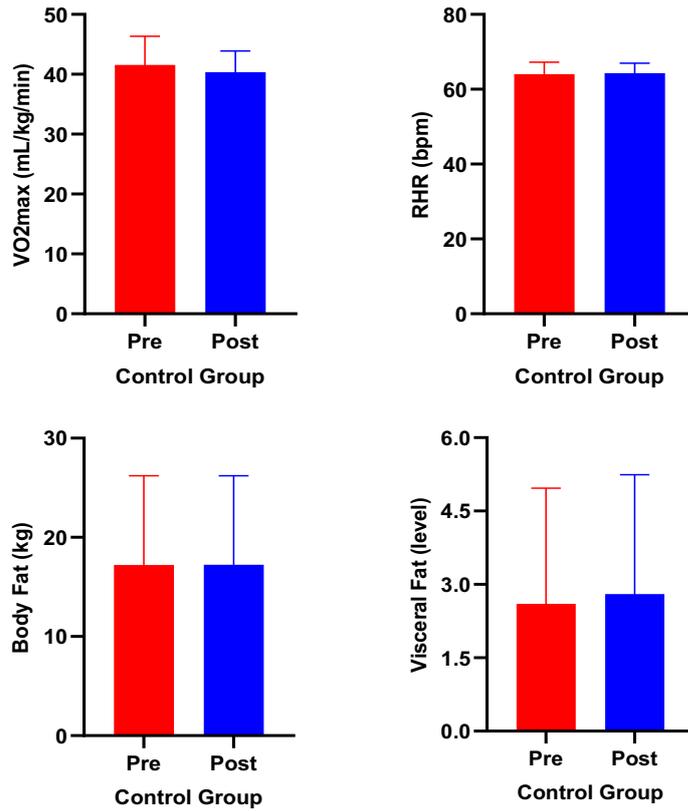
## Discussion

This study aimed to evaluate how a structured long-interval training program influences aerobic capacity, heart rate regulation, and body composition indicators in Pencak Silat athletes aged 16–18 years. The results showed that long-interval training (LIT) increased  $VO_2\max$ , lowered resting heart rate, and reduced both total and visceral fat compared with the control group. These changes indicate that LIT can produce cardiovascular and metabolic adaptations relevant to conditioning in youth combat sport athletes. The increase in  $VO_2\max$  corresponds with studies reporting that interval-based methods lead to larger gains in aerobic fitness than moderate-intensity continuous exercise [16, 17]. HIIT and LIT formats may improve cardiorespiratory function through increases in stroke volume, cardiac output, and peripheral oxygen use [18, 19]. Intervals of 2–4 minutes, as applied in this study, have been associated

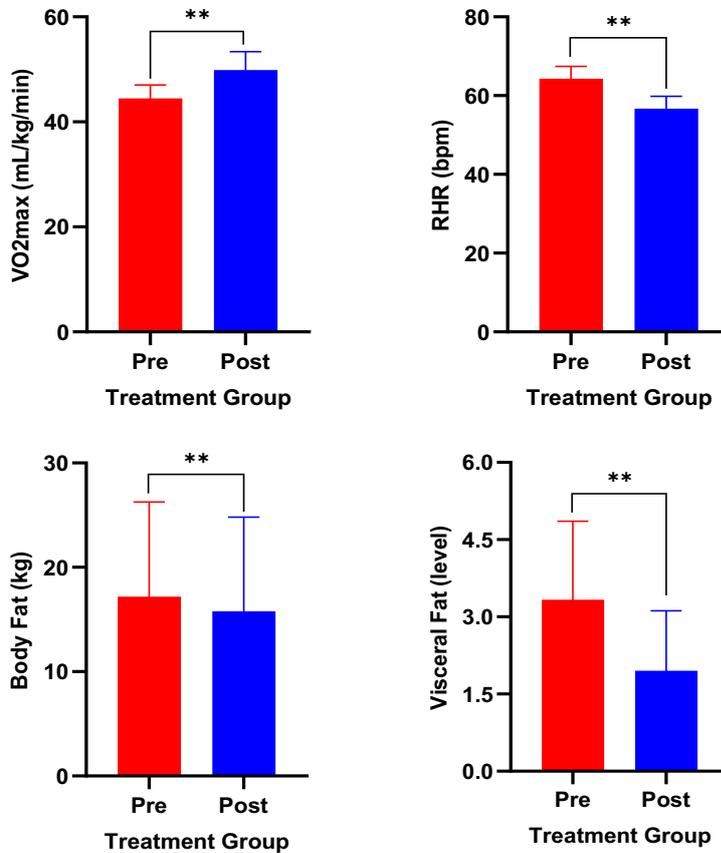
**Table 2.** Baseline characteristics of the study participants

Characteristics	Control (n = 10)	Treatment (n = 10)	p-value
Age (yrs)	16.90 $\pm$ 0.88	16.60 $\pm$ 0.84	0.445
RHR (bpm)	64.00 $\pm$ 3.23	64.30 $\pm$ 3.13	0.835
SBP (mmHg)	116.00 $\pm$ 5.16	118.00 $\pm$ 4.22	0.356
DBP (mmHg)	75.00 $\pm$ 5.27	76.00 $\pm$ 5.16	0.673
Height (m)	1.58 $\pm$ 0.08	1.63 $\pm$ 0.06	0.113
Weight (kg)	52.50 $\pm$ 8.89	56.20 $\pm$ 5.12	0.272
BMI (kg/m <sup>2</sup> )	20.85 $\pm$ 2.09	20.99 $\pm$ 1.13	0.849
Body fat (kg)	17.22 $\pm$ 8.98	17.18 $\pm$ 9.09	0.992
Visceral fat (level)	2.60 $\pm$ 2.37	3.33 $\pm$ 1.53	0.425
$VO_2\max$ (mL/kg/min)	41.56 $\pm$ 4.78	44.48 $\pm$ 2.56	0.111

Note: Data are presented as mean  $\pm$  SD. p-values were obtained using the independent-samples t-test.



**Figure 1.** Pre–post changes in VO<sub>2</sub>max, resting heart rate, body fat, and visceral fat in the control group  
 Note: Data are presented as mean ± SD. p-values were obtained using the paired-samples t-test.



**Figure 2.** Pre–post changes in VO<sub>2</sub>max, resting heart rate, body fat, and visceral fat in the treatment group  
 Note: Data are presented as mean ± SD. p-values were obtained using the paired-samples t-test. (\*\*)  
 Significant at pre (p < 0.001).

**Table 3.** Comparison of pre-, post-, delta, and percentage change values between treatment and control groups

Parameters	Control (n = 10)	Treatment (n = 10)	p-value	ES
Pre-VO <sub>2</sub> max (mL/kg/min)	41.56 ± 4.78	44.48 ± 2.56	0.106	0.762
Pre-RHR (bpm)	64.00 ± 3.23	64.30 ± 3.13	0.835	0.094
Pre-Body Fat (kg)	17.22 ± 8.98	17.18 ± 9.09	0.992	0.004
Pre-Visceral Fat (level)	2.60 ± 2.37	3.33 ± 1.53	0.425	0.366
Post-VO <sub>2</sub> max (mL/kg/min)	40.36 ± 3.56	49.85 ± 3.53**	0.001	2.679
Post-RHR (bpm)	64.30 ± 2.67	56.70 ± 3.13**	0.001	2.613
Post-Body Fat (kg)	17.24 ± 8.98	15.78 ± 9.04	0.721	0.162
Post-Visceral Fat (level)	2.80 ± 2.44	1.95 ± 1.17	0.339	0.444
Δ-VO <sub>2</sub> max (mL/kg/min)	-1.20 ± 3.94	5.37 ± 2.75**	0.001	1.935
Δ-RHR (bpm)	0.30 ± 0.95	-7.60 ± 4.22**	0.001	2.582
Δ-Body Fat (kg)	0.02 ± 0.21	-1.40 ± 0.65**	0.001	2.962
Δ-Visceral Fat (level)	0.20 ± 0.42	-1.38 ± 0.71**	0.001	2.701
Change-VO <sub>2</sub> max (%)	-2.31 ± 8.42	12.14 ± 6.27**	0.001	1.945
Change-RHR (%)	0.52 ± 1.54	-11.65 ± 6.44**	0.001	2.597
Change-Body Fat (%)	0.34 ± 1.73	-9.42 ± 4.73**	0.001	2.738
Change-Visceral Fat (%)	6.67 ± 14.05	-43.37 ± 18.13**	0.001	3.084

Note: Data are presented as mean ± SD. p-values were obtained using the independent-samples t-test. (\*\*) Significant between groups (p < 0.001).

with central adaptations such as improved ventricular compliance and myocardial contractile function [20]. In adolescents, repeated efforts performed at 90–95% HRmax can stimulate mitochondrial development and enhance oxygen transport, contributing to higher aerobic efficiency [21]. For Pencak Silat athletes, these adaptations are relevant because the sport requires repeated high-intensity exchanges, rapid changes of direction, and intermittent striking sequences that rely on sustained aerobic capacity to maintain technical and tactical performance [22]. Evidence from other sports also indicates that long-interval formats can promote stronger cardiovascular and metabolic responses than short-interval protocols due to their longer work durations [4].

In addition to the increase in VO<sub>2</sub>max, this study found a decrease in resting heart rate after six weeks of LIT. A lower resting heart rate reflects greater parasympathetic activity and higher stroke volume, which together indicate improved cardiac function [23, 24]. Comparable responses have been reported in adolescents participating in HIIT or circuit-based programs, where reductions of 5–10 beats per minute suggest increased vagal tone and better recovery capacity [25, 26]. Ingul et al. also showed that aerobic interval training improved left ventricular function and reduced heart rate both at rest and during submaximal workloads in obese adolescents, indicating improved autonomic regulation [20]. Other studies report that interval training can enhance heart rate variability (HRV), supporting more balanced autonomic control and

better recovery in young athletes [24]. For Pencak Silat athletes, improved autonomic regulation may contribute to faster recovery between rounds and help maintain tactical focus during competitions. The combined increase in VO<sub>2</sub>max and reduction in resting heart rate observed in this study reflects adaptations that improve oxygen delivery and reduce the number of cardiac contractions required during rest and exercise. These findings are consistent with the results reported by Eddolls et al. [18] and Ketelhut [23].

This study found reductions in both total and visceral fat following the LIT intervention. These outcomes are consistent with earlier research showing that high-intensity interval training can affect body composition and metabolic health [3, 27]. HIIT and LIT may stimulate fat oxidation through catecholamine-induced lipolysis, elevated post-exercise oxygen consumption (EPOC), and improvements in mitochondrial function [28]. Adolescents may respond well to these mechanisms because of higher metabolic flexibility and hormonal sensitivity during growth [26, 29]. The reduction in visceral fat observed in this study corresponds with reports that intermittent high-intensity exercise can lead to abdominal fat loss more effectively than continuous exercise [30, 31]. Wang et al. and Munhoz da Silveira Campos et al. also showed that interval and combined aerobic-resistance programs can improve abdominal fat distribution and metabolic indicators in youth populations [3, 32]. Meta-analytic findings indicate

that HIIT can reduce total and visceral adiposity to a greater extent than moderate-intensity continuous exercise, particularly in programs lasting more than six weeks [14]. The present study showed that a six-week LIT program produced changes in visceral fat. Similar effects were reported by Francisco [21], who found that training performed near maximal aerobic velocity can influence visceral fat levels. From a sport-specific perspective, reductions in visceral fat may support improvements in agility, mobility, and movement speed in Pencak Silat, where rapid stance transitions and rotational actions are important. The combined changes in  $VO_{2max}$ , resting heart rate, and body composition observed in this study indicate that LIT can influence both cardiovascular function and metabolic regulation in adolescent athletes.

Heart rate responses recorded during the LIT sessions in this study were comparable to those reported in young gymnasts performing high-intensity circuits (83–89% HRmax). This similarity supports the use of HR monitoring as an indicator of internal training load [25]. The consistent HR patterns observed in this study indicate that the prescribed LIT intensity produced the required physiological stress for adaptation. Integrating HR and HRV monitoring into Pencak Silat training can provide coaches with tools to regulate training intensity, recovery, and workload [23]. This study also shows how HR- and HRV-based monitoring can be adapted for martial arts settings and aligned with the tactical and technical demands of Pencak Silat. The combination of reduced resting heart rate, increased  $VO_{2max}$ , and lower adiposity observed in this study reflects improvements in cardiac function, fat metabolism, and insulin sensitivity. These changes may support athletic performance and long-term health in adolescent athletes [29, 31].

While the physiological effects of interval training are well documented, this study provides applied insight into how long-interval training can be adapted for use in combat sport athletes during adolescence. Given the lack of existing data for this specific group, these findings offer practical implications for coaches designing conditioning programs in martial arts disciplines with similar physiological demands.

Despite these findings, several limitations should be considered. The six-week intervention period may have restricted the magnitude of long-term physiological changes. Earlier studies indicate that intervention durations of eight to twelve weeks can lead to wider changes in body composition and autonomic function [18, 21]. Dietary intake was not

monitored, which may have affected the body fat results. The small sample size and the inclusion of only adolescent Pencak Silat athletes from a single competitive level also limit generalizability. Future studies should apply longer intervention periods, include female athletes and different age groups, and incorporate cardiac assessments such as HRV and echocardiography to obtain a clearer understanding of cardiovascular adaptations [20, 24].

From a practical perspective, this study indicates that LIT can be used as a sport-specific conditioning method for adolescent martial artists. Monitoring heart rate responses offers a simple and low-cost approach to managing training intensity and recovery. When combined with appropriate nutrition and progressive training load, long-interval training may help improve cardiovascular function, reduce abdominal fat, and support long-term athlete development in combat sports.

## Conclusions

This study showed that long-interval training (LIT) increased aerobic capacity and reduced resting heart rate in Pencak Silat athletes aged 16–18 years. The lower resting heart rate suggests improvements in cardiac function and autonomic regulation. LIT also produced a reduction in visceral fat, indicating favorable changes in metabolic regulation and body composition. The change in total body fat was not statistically significant, which may reflect the relatively short intervention period or the absence of dietary monitoring.

The outcomes of the study correspond with the physiological demands of Pencak Silat, where repeated high-intensity actions require adequate aerobic capacity and efficient autonomic control. The combined changes in  $VO_{2max}$ , resting heart rate, and visceral fat support the use of LIT as a conditioning method for adolescent martial artists. The findings also illustrate how heart-rate-based indicators can be applied within a combat-sport context to monitor training responses and guide workload regulation.

LIT can therefore be considered a practical component of conditioning programs for adolescent athletes. Future research should extend the duration of interventions, include athletes of different ages and competitive levels, and incorporate cardiac assessments such as heart rate variability and echocardiography to build a clearer understanding of training-induced adaptations in combat sports.

## Conflict of Interest

The authors declare no conflict of interest.

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### Information about the authors:

**Moch Hasan Al as'ary**; <https://orcid.org/0009-0007-7070-7457>; [mochabu.22015@mhs.unesa.ac.id](mailto:mochabu.22015@mhs.unesa.ac.id); Department of Sport Coaching Education, Faculty of Sport and Health Sciences, Universitas Negeri Surabaya; Surabaya, East Java, Indonesia.

**Adi Pranoto**; <https://orcid.org/0000-0003-4080-9245>; [adipranoto@unesa.ac.id](mailto:adipranoto@unesa.ac.id); Department of Sport Coaching Education, Faculty of Sport and Health Sciences, Universitas Negeri Surabaya; Surabaya, East Java, Indonesia.

**Andri Suyoko**; (Corresponding author); <https://orcid.org/0000-0001-6836-8731>; [andrisuyoko@unesa.ac.id](mailto:andrisuyoko@unesa.ac.id); Department of Sport Coaching Education, Faculty of Sport and Health Science, Universitas Negeri Surabaya; Surabaya, East Java, Indonesia.

**Fansah Adila**; <https://orcid.org/0009-0008-3853-3378>; [fansah.adila@lecturer.unri.ac.id](mailto:fansah.adila@lecturer.unri.ac.id); Study Program of Sports Coaching Education, Faculty of Teacher Training and Education, Universitas Riau; Pekanbaru, Indonesia.

**Fuad Noor Heza**; <https://orcid.org/0009-0000-7223-2642>; [fuadheza@unesa.ac.id](mailto:fuadheza@unesa.ac.id); Department of Physical Education, Health and Recreation, Faculty of Sport and Health Science, Universitas Negeri Surabaya; Surabaya, East Java, Indonesia.

**Yudi Dwi Saputra**; <https://orcid.org/0000-0002-5181-7032>; [yudisaputra@unesa.ac.id](mailto:yudisaputra@unesa.ac.id); Department of Sport Science, Faculty of Sport and Health Sciences, Universitas Negeri Surabaya; Surabaya, East Java, Indonesia.

**Andun Sudijandoko**; <https://orcid.org/0009-0000-8548-4988>; [andunsudijandoko@unesa.ac.id](mailto:andunsudijandoko@unesa.ac.id); Department of Sport Science, Faculty of Sport and Health Sciences, Universitas Negeri Surabaya; Surabaya, East Java, Indonesia.

**Made Pramono**; <https://orcid.org/0000-0002-7007-3606>; [madepramono@unesa.ac.id](mailto:madepramono@unesa.ac.id); Department of Sport Science, Faculty of Sport and Health Sciences, Universitas Negeri Surabaya; Surabaya, East Java, Indonesia.

**Nur Ahmad Arief**; <https://orcid.org/0000-0003-3217-7436>; [nurarief@unesa.ac.id](mailto:nurarief@unesa.ac.id); Department of Physical Education, Health and Recreation, Faculty of Sport and Health Science, Universitas Negeri Surabaya; Surabaya, East Java, Indonesia.

**Bekir Erhan Orhan**; <https://orcid.org/0000-0002-3149-6630>; [bekirerhanorhan@aydin.edu.tr](mailto:bekirerhanorhan@aydin.edu.tr); Faculty of Sports Sciences, Istanbul Aydın University; Istanbul, Turkey.

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