World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(Research Article)

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Effects of long interval training on muscular endurance and lower limb explosive power in adolescent pencak silat athlete

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World Journal of Advanced Research and Reviews, 2026, 31(01), 552–560

Publication history: Received on 23 May 2026; revised on 07 July 2026; accepted on 09 July 2026

Article DOI: https://doi.org/10.30574/wjarr.2026.31.1.1859

Abstract

This study aimed to evaluate the effectiveness of maximum aerobic speed-based long interval training on muscular endurance and lower-limb explosive power in adolescent Pencak Silat athletes. A quasi-experimental study employing a pretest–posttest control group design was conducted involving 20 adolescent Pencak Silat athletes, who were assigned to either an experimental group (n = 10) or a control group (n = 10). The experimental group completed a six-week long interval training program performed three times per week, whereas the control group continued their regular training routine. The outcome measures included upper-body muscular endurance assessed by the push-up test, abdominal muscular endurance by the sit-up test, back muscular endurance by the back-up test, lower-limb muscular endurance by the wall-sit test, and lower-limb explosive power by the standing broad jump test. Data were analyzed using the Shapiro–Wilk test, Levene's test, paired-samples t-test, and independent-samples t-test, with the significance level set at $p < 0.05$. The results demonstrated that long interval training significantly improved abdominal muscular endurance, back muscular endurance, lower-limb muscular endurance, and lower-limb explosive power ($p < 0.05$), whereas no significant improvement was observed in upper-body muscular endurance ($p > 0.05$). These findings suggest that maximum aerobic speed-based long interval training is an effective training method for enhancing core muscular endurance, lower-limb muscular endurance, and lower-limb explosive power in adolescent Pencak Silat athletes.

Keywords: Long Interval Training; Maximum Aerobic Speed; Pencak Silat; Muscular Endurance; Lower-Limb Explosive Power.

1. Introduction

Pencak silat is a martial art sport that requires the integrated mastery of technical, tactical, psychological, and physical components to achieve optimal competitive performance. The intermittent nature of pencak silat competition requires athletes to perform various high-intensity activities, such as attacking, defending, and changing positions repeatedly throughout the match [1]. Therefore, physical fitness is considered a fundamental component that supports the effective application of techniques and strategies to achieve maximum athletic performance [2]. Various physical fitness components, including strength, endurance, speed, agility, and muscular power, have been reported to play important roles in the performance of combat sport athletes [3].

One of the physical components that plays an important role in pencak silat is strength endurance. Strength endurance is defined as the ability of muscles to sustain contractions or produce force repeatedly over a certain period without a significant decline in performance [4]. This ability is essential for pencak silat athletes because the demands of competition require the repeated execution of offensive and defensive techniques at relatively high intensities [1].

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Adequate strength endurance enables athletes to maintain movement quality, reduce the effects of fatigue, and preserve performance effectiveness throughout the competition.

In addition to muscular endurance, lower limb explosive power is another physical component that significantly determines the performance of pencak silat athletes. Lower limb explosive power contributes to explosive movements such as kicking, jumping, accelerating, and rapidly changing direction during competition [5]. The ability to generate force in a short period is a critical factor supporting the effectiveness of both offensive and defensive actions in combat sports [6]. Athletes with a higher level of lower limb explosive power tend to perform movements that are faster, stronger, and more efficient than those with lower levels of explosive power [7].

One training method that has been widely used to improve athletes' physical performance is long interval training. This training method is a form of interval exercise involving relatively long work periods performed at high intensity, interspersed with structured recovery periods [8]. long interval training has been extensively implemented in various sports because it effectively improves aerobic capacity and enhances athletes' ability to maintain performance during high-intensity activities [9]. In addition to promoting cardiovascular adaptations, interval training can also improve neuromuscular function and metabolic capacity, thereby contributing to overall physical performance enhancement [10]. These adaptations may positively affect the ability to sustain muscular strength and produce explosive movements during sports activities [11].

Although the effectiveness of interval training in improving aerobic capacity has been widely reported, most studies have primarily focused on cardiorespiratory endurance and other aerobic physiological indicators [12]. In combat sports, studies on interval training have also predominantly examined changes in athletes' aerobic and anaerobic capacities rather than muscular endurance and lower limb explosive power [13]. However, both components play crucial roles in supporting the performance of pencak silat athletes during competition. Furthermore, studies specifically investigating the effects of long interval training on muscular endurance and lower limb explosive power in adolescent pencak silat athletes remain limited in the scientific literature [14]. Therefore, further research is needed to provide empirical evidence regarding the effectiveness of this training method on these two physical fitness components.

Based on the aforementioned considerations, this study aimed to analyze the effects of long interval training on muscular endurance and lower limb explosive power in adolescent pencak silat athletes. The findings of this study are expected to contribute to the scientific development of effective training methods for improving the physical performance of adolescent pencak silat athletes.

2. Material and methods

2.1. Study Design

This study employed a quasi-experimental design using a pretest–posttest control group approach to examine the effects of long interval training on muscular endurance and lower limb explosive power in adolescent Pencak Silat athletes. Measurements were conducted before the intervention (pretest) and after the completion of the training program (posttest). Participants were recruited using a purposive sampling technique based on predetermined inclusion criteria, namely: adolescent Pencak Silat athletes aged 16–18 years from East Java, Indonesia. Actively participating in regular training, free from injuries or health conditions that could affect training performance, and willing to participate in all research procedures. A total of 20 adolescent Pencak Silat athletes met the inclusion criteria and were enrolled in this study. Following the baseline assessment, participants were ranked according to their pretest scores and allocated into groups using the ordinal pairing technique to ensure relatively equivalent baseline characteristics between groups. Subsequently, the participants were assigned to an experimental group (n = 10), which received the long interval training program, and a control group (n = 10), which continued their regular training program throughout the study period.

2.2. Study Organisation

The study was conducted over a six-week period and comprised a total of 16 training sessions under the direct supervision of the researchers and coaches. Before the intervention, all participants underwent baseline measurements (pretest) to obtain initial data on muscular endurance and lower limb explosive power. Based on the pretest results, participants were allocated to the experimental and control groups using the ordinal pairing technique to ensure baseline equivalence between groups. The experimental group participated in a long interval training program in addition to their regular pencak silat training, whereas the control group continued their regular training program without any additional structured interval training. The intervention was administered three times per week throughout the study period. All training sessions were conducted according to the predetermined protocol to ensure consistency in the implementation of the training program. Participants adherence to the training program was monitored through attendance records at each session. In addition, the researchers regularly coordinated with the coaches to ensure that training activities outside the research program remained at a controlled intensity and did not influence the intervention outcomes. During the study, any injuries, physical discomfort, or other health-related issues were monitored and managed according to the applicable safety procedures. Upon completion of the intervention, all participants underwent posttest measurements using the same instruments and procedures as those employed during the pretest. The pretest and posttest data were subsequently analyzed to evaluate the effects of the long interval training program on muscular endurance and lower limb explosive power in adolescent pencak silat athletes.

2.3. Testing Prosedures

The Push-Up Test was used to assess upper-body strength endurance. Participants started in a prone position with their hands placed on the floor at shoulder width and their bodies maintained in a straight line from head to heels. Upon the command, participants lowered their bodies until the elbows reached an angle of approximately 90° and then returned to the starting position by fully extending the arms. The test was performed for 60 seconds, and the score was determined by the number of correctly executed repetitions.

The Sit-Up Test was used to assess abdominal muscle strength endurance. Participants started in a supine position with the knees flexed at approximately 90° and the feet flat on the floor. The arms were crossed over the chest throughout the test. Upon the command, participants raised their upper bodies until the elbows touched the thighs or knees and then returned to the starting position until the back touched the mat. The test was performed for 60 seconds, and the score was determined by the total number of repetitions completed according to the prescribed procedure.

The Back-Up Test was used to assess back muscle strength endurance. Participants lay in a prone position with both hands placed behind the head while the legs were stabilized by an assistant. Upon the command, participants repeatedly lifted the trunk through spinal extension and returned to the starting position for 60 seconds. The score was determined by the number of correctly performed repetitions. This test reflects the endurance of the back extensor muscles, which play an important role in maintaining trunk stability.

The Wall Sit Test was used to evaluate lower-limb strength endurance. Participants stood with their backs against a wall and lowered their bodies until the knees formed an angle of approximately 90°, resembling a seated position without a chair. Throughout the test, the back remained in contact with the wall and both feet were maintained in a stable position. The score was determined by the duration for which the participant could maintain the position and was recorded in seconds.

The Standing Broad Jump Test was used to assess lower-limb explosive power. Participants stood behind the starting line with their feet parallel and shoulder-width apart. Before jumping, participants were allowed to swing their arms to generate maximal propulsion. They then jumped forward as far as possible using a two-foot take-off. The jumping distance was measured from the starting line to the nearest point of contact on landing. Each participant was given three attempts with adequate rest between trials, and the longest jump distance was recorded as the final score.

2.4. Training Programme

The long interval training intervention was conducted over six weeks and consisted of 16 supervised training sessions performed three times per week. In addition to the intervention sessions, one session at the beginning of the study was allocated for pre-test assessments and one session at the end of the study was used for post-test assessments, resulting in a total study duration of six weeks. Training intensity was determined based on the participants' maximum aerobic speed obtained during the baseline assessment. To ensure an appropriate training load, participants were grouped according to similar maximum aerobic speed values so that the prescribed exercise intensity could be maintained throughout the intervention. Each training session consisted of 180 s of work intervals interspersed with 180 s of active recovery intervals.

The exercise intensity was progressively increased from 95% of MAS during the first week to 120% of MAS during the sixth week. In addition, the intensity of active recovery was gradually increased from 40% to 50% of MAS to impose greater physiological demands on the cardiovascular and energy metabolic systems. The effective duration of each training session ranged from 24 to 36 min, excluding the warm-up and cool-down periods. The training program was designed to improve aerobic capacity, extend the ability to perform high-intensity exercise, and optimize physiological adaptations that support athletic performance during competition. All training sessions began with a standardized warm-up and ended with a cool-down period. Progressions in exercise intensity, repetitions, and sets were implemented gradually according to the principle of progressive overload to maximize physiological adaptations throughout the six-week training period. The detailed training program is presented in Table 1.

Table 1 Maximum Aerobic Speed-Based Long Interval Training Program

Week	Running Intensity (% MAS)	Recovery Intensity (% MAS)	Interval Duration (Work/Recovery)	Training Volume	Sessions per Week	Expected Adaptation
1	95	40	180 s / 180 s	4 × 1 set	3	Enhancement of aerobic endurance capacity
2	100	40	180 s / 180 s	4 × 1 set	3	Improvement of aerobic power
3	100	45	180 s / 180 s	5 × 1 set	3	Increased exposure to VO_2max intensity
4	110	45	180 s / 180 s	5 × 1 set	3	Greater cardiovascular and metabolic stimulus
5	110	50	180 s / 180 s	6 × 1 set	3	Consolidation of aerobic power adaptations
6	120	50	180 s / 180 s	6 × 2 sets	3	Maximization of training overload and performance adaptation

2.5. Statistical Analysis

Statistical analyses were performed using appropriate statistical software (SPSS version 21). Baseline equivalence between the experimental and control groups was assessed using an independent-samples t-test on the pretest data. After confirming baseline equivalence between groups, within-group comparisons were analyzed using paired-samples t-tests, whereas between-group differences were analyzed using independent-samples t-tests. Statistical significance was set at an alpha level of 0.05 ($p < 0.05$).

3. Results and discussion

Table 2 presents the results of the baseline equivalence test between the experimental and control groups based on pretest scores for all study variables, including push-ups, sit-ups, back-ups, wall-sit, and standing broad jump. The analysis was performed using an independent-samples t-test to ensure that both groups had relatively comparable initial abilities prior to the intervention, thereby allowing any changes observed in the posttest measurements to be attributed to the effects of the implemented training program.

Table 2 Baseline Equivalence Between Control and Experimenta Groups

Parameters	Control (n = 10)	Experimental (n = 10)	p-value
Push Up (reps)	38.2 ± 9.40	43.9 ± 19.19	0.410
Sit Up (reps)	33.9 ± 3.60	33.6 ± 3.13	0.845
Back Up (reps)	52.0 ± 9.32	57.1 ± 9.90	0.251
Wall Sit (s)	192.6 ± 72.26	131.8 ± 58.86	0.054
Standing Broad Jump (cm)	206.7 ± 31.81	178.2 ± 31.30	0.059

Description: Data are presented as mean ± standard deviation (Mean ± SD). P-values were obtained using the independent samples t-test.

The baseline equivalence test revealed no significant differences in any of the pretest variables between the control and experimental groups ($p > 0.05$). These findings indicate that both groups had relatively comparable initial conditions prior to the intervention, suggesting that any changes observed following the training period can be attributed to the effects of the intervention.

Table 3 Comparison of Push-Up, Sit-Up, Back-Up, Wall-Sit, and Standing Broad Jump pre- and post-test in the Control Group

Parameters	Pretest	Postest	p-value
Push Up (reps)	43.9 ± 19.2	48.6 ± 13.9	0.391
Sit Up (reps)	30.7 ± 5.3	31.6 ± 4.5	0.593
Back Up (reps)	57.1 ± 9.9	57.4 ± 8.5	0.824
Wall Sit (s)	131.8 ± 58.9	150.9 ± 58.4	0.252
Standing Broad Jump (cm)	178.2 ± 31.30	179.8 ± 28.28	0.545

Description: Data are presented as mean ± standard deviation (Mean ± SD). The p-values were obtained using the paired-samples t-test.

Based on the statistical analysis, no significant differences were observed between the pre-test and post-test measurements for all variables in the control group ($p > 0.05$). The mean values of push-up, sit-up, back-up, wall-sit, and standing broad jump remained relatively stable throughout the study period. Although slight changes in the mean scores of several variables were observed, these changes did not reach statistical significance. These findings indicate that no meaningful improvements occurred in muscular endurance and lower-limb explosive power among the participants in the control group during the study period. Therefore, in the absence of a specific training intervention, the participants' physical performance remained relatively unchanged. Meanwhile, the results of the pre-test and post-test analyses in the experimental group are presented in Table 4.

Table 4 Comparison of Push-Up, Sit-Up, Back-Up, Wall-Sit, and Standing Broad Jump pre- and post-test in the Experimental Group

Parameters	Pretest	Postest	p-value
Push Up (reps)	43.9 ± 19.2	48.6 ± 13.9	0.391
Sit Up (reps)	30.7 ± 5.3	31.6 ± 4.5	0.593
Back Up (reps)	57.1 ± 9.9	57.4 ± 8.5	0.824
Wall Sit (s)	131.8 ± 58.9	150.9 ± 58.4	0.252
Standing Broad Jump (cm)	178.2 ± 31.30	179.8 ± 28.28	0.545

Description: Data are presented as mean ± standard deviation (Mean ± SD). The p-values were obtained using the paired-samples t-test.

The statistical analysis revealed significant changes between the pre-test and post-test measurements for all variables in the experimental group ($p < 0.05$). The mean push-up score increased from 38.2 ± 9.4 to 46.0 ± 11.3 repetitions ($p = 0.033$), while the mean sit-up score increased from 38.8 ± 6.1 to 43.6 ± 5.4 repetitions ($p = 0.011$). A significant improvement was also observed in back-up performance, which increased from 52.0 ± 9.3 to 61.2 ± 8.7 repetitions ($p = 0.030$). In addition, wall-sit performance significantly improved from 192.6 ± 72.3 to 252.9 ± 42.6 seconds ($p = 0.005$). A significant increase was also found in standing broad jump performance, with the mean score increasing from 206.7 ± 31.81 cm to 228.0 ± 36.46 cm ($p = 0.001$). Overall, these findings indicate that the intervention effectively improved muscular endurance and lower-limb explosive power in the experimental group.

Table 5 Between-group comparison of pre-test, post-test, delta, and change outcomes in the control and experimental groups

Parameters	Experimental (n = 10)	Control (n = 10)	p-value
Δ-Push Up (reps)	7.8 ± 5.6	4.7 ± 8.2	0.319
Δ-Sit Up (reps)	4.8 ± 3.2	0.9 ± 2.8	0.012*
Δ-Back Up (repes)	9.2 ± 8.5	0.3 ± 5.6	0.015*
Δ-Wall Sit (s)	60.3 ± 39.8	19.1 ± 31.4	0.018*
Δ-Standing Broad Jump (cm)	21.3 ± 8.76	1.6 ± 8.04	0.001*
Change-Push Up (reps)	21.6 ± 15.7	10.7 ± 19.2	0.154
Change-Sit Up (reps)	12.6 ± 8.5	3.0 ± 8.9	0.024*
Change-Back Up (reps)	18.1 ± 15.9	0.7 ± 9.8	0.010*
Change-Wall Sit (s)	35.2 ± 24.6	16.0 ± 24.1	0.048*
Change-Standing Broad Jump (cm)	10.27 ± 3.88	1.27 ± 4.41	0.001*

Description: Data are presented as mean ± standard deviation (Mean ± SD). P-values were obtained using the independent-samples t-test.

Table 5 presents the comparison of delta (Δ) values and percentage changes between the control and experimental groups. No significant difference was observed in the delta values for push-up performance between the two groups ($p = 0.319$). However, significant differences were found in the delta values for sit-up ($p = 0.012$), back-up ($p = 0.015$), wall-sit ($p = 0.018$), and standing broad jump ($p = 0.001$), with the experimental group demonstrating greater improvements than the control group. The analysis of percentage changes also revealed no significant difference in push-up performance between the two groups ($p = 0.154$). In contrast, significant differences were observed in sit-up ($p = 0.024$), back-up ($p = 0.010$), wall-sit ($p = 0.048$), and standing broad jump ($p = 0.001$). These findings indicate that the intervention was more effective in improving abdominal muscular endurance, back muscular endurance, lower-body muscular endurance, and lower-limb explosive power compared with the regular training program performed by the control group.

The findings of this study demonstrated that six weeks of long interval training produced positive effects on several components of physical fitness in adolescent pencak silat athletes compared with conventional training. Significant differences were observed in abdominal muscle endurance (sit-up), back muscle endurance (back-up), lower limb muscular endurance (wall-sit), and lower limb explosive power (standing broad jump), whereas no significant difference was found in upper-body muscular endurance (push-up) between the experimental and control groups. These findings suggest that the adaptations induced by long interval training predominantly occurred in the muscle groups receiving the greatest training stimulus. Similarly, [15] reported that high-intensity interval training programs in adolescents improve various components of physical fitness through physiological and neuromuscular adaptations that are specific to the characteristics of the training stimulus.

The improvements in sit-up and back-up performance indicate that long interval training was effective in enhancing core muscular endurance. The core muscles play an essential role in maintaining body stability, preserving posture, and optimizing force transmission during sports movements. These abilities are particularly important in pencak silat, as they contribute to the maintenance of technical performance throughout competition. [16] explained that improvements in core muscle capacity contribute to movement efficiency and enhanced physical performance in adolescent athletes. Furthermore, [17] reported that six weeks of interval training improved muscular endurance by increasing the ability of muscles to resist fatigue during repeated contractions. The improvement in wall-sit performance further suggests that long interval training contributed to enhancing lower limb muscular endurance. These adaptations may have resulted from increases in oxidative capacity, mitochondrial density, and the ability of the muscles to tolerate metabolite accumulation during high-intensity activities. Such peripheral adaptations enable athletes to sustain submaximal contractions for longer durations. [18] stated that interval training enhances muscular work capacity through central and peripheral adaptations that support tolerance to repeated exercise. Similarly, [19] found that interval training in adolescents positively affects several components of physical fitness, including the ability to maintain muscular performance during prolonged activity.

Another important finding of this study was the improvement in standing broad jump performance following the long interval training intervention. This result indicates that long interval training not only enhances aerobic capacity but also improves lower limb explosive power. The improvement in explosive performance is likely attributable to neuromuscular adaptations, including increased motor unit recruitment, improved synchronization of muscle activation, and an enhanced ability to generate force rapidly. [20] reported that high-intensity interval training can improve force production through enhanced neuromuscular efficiency. Likewise, [21] explained that high-intensity training effectively improves the explosive abilities of combat sport athletes by optimizing the quality of muscular contractions required for explosive movements.

Conversely, the absence of significant differences in push-up performance suggests that long interval training did not provide sufficient stimulus to improve upper-body muscular endurance. According to the principle of training specificity, physiological adaptations occur primarily in the muscle groups that are most actively engaged during exercise. During long interval training sessions, the lower limbs and core muscles are more actively involved than the upper extremities, resulting in limited adaptations in upper-body muscular endurance. [22] emphasized that adaptive responses to interval training are strongly influenced by the type of stimulus and the muscle groups receiving the training load. Therefore, improvements in push-up performance may require additional resistance training specifically targeting the arm and shoulder muscles.

From a practical perspective, these findings suggest that long interval training can be implemented as an effective physical conditioning method for adolescent pencak silat athletes. Improvements in core muscular endurance may help athletes maintain stability and technical performance throughout competition. [23] stated that adequate trunk stability contributes to efficient force transfer and greater effectiveness of sports movements. In addition, improvements in lower limb muscular endurance and explosive power may enhance kicking effectiveness, acceleration ability, and the execution of repeated attacks, which are fundamental characteristics of pencak silat performance.

This study also contributes to the scientific literature by providing empirical evidence regarding the effectiveness of maximum aerobic speed -based long interval training in adolescent pencak silat athletes. Previous studies have primarily focused on team sports or non-combat sport populations, and evidence regarding the application of long interval training in adolescent pencak silat athletes remains limited. Therefore, the findings of this study may serve as a basis for developing evidence-based training models aimed at improving the biomotor components required in pencak silat, particularly muscular endurance and lower limb explosive power.

This study has several limitations that should be considered. The relatively small sample size and short intervention period may limit the generalizability of the findings and may not fully reflect the long-term adaptations to Long Interval Training. In addition, external factors such as nutritional intake, physical activity outside the training program, sleep quality, and participant motivation were not strictly controlled and may have influenced the individual responses to training. Furthermore, muscle endurance and lower limb power were assessed only through field-based performance tests, which do not fully explain the underlying physiological adaptations. Therefore, future studies should include larger sample sizes, longer intervention periods, stricter control of external factors, and additional physiological measurements to provide a more comprehensive understanding of the effects of long interval training on muscle endurance and lower limb power in adolescent pencak silat athletes.

4. Conclusion

The findings of this study indicate that six weeks of maximum aerobic speed-based long interval training effectively improved several components of physical fitness in adolescent pencak silat athletes. Significant improvements were observed in abdominal muscle endurance (sit-up), back muscle endurance (back-up), lower limb muscular endurance (wall-sit), and lower limb explosive power (standing broad jump). In contrast, upper-body muscular endurance, as measured by the push-up test, did not show a significant improvement. These findings suggest that the adaptive responses to long interval training follow the principle of training specificity, whereby performance enhancements are more pronounced in muscle groups that receive direct training stimuli. Therefore, long interval training may be considered an effective training method in the physical conditioning programs of adolescent pencak silat athletes, particularly for improving core muscular endurance, lower limb muscular endurance, and lower limb explosive power, all of which are essential for competitive performance. However, if improving upper-body muscular endurance is also a training objective, long interval training should be combined with more specific resistance exercises targeting the upper extremities. Future studies are recommended to involve larger sample sizes, extend the intervention period, and control potential external factors that may influence training adaptations. Furthermore, the inclusion of physiological parameters such as VO_2max, lactate threshold, and neuromuscular indicators should be considered to provide a more comprehensive understanding of the mechanisms underlying adaptations to long interval training in adolescent pencak silat athletes.

Compliance with ethical standards

Acknowledgments

The authors sincerely appreciate the valuable participation and cooperation of the athletes, coaches, and administrators of SMA Negeri Olahraga Jawa Timur throughout this research. The authors also gratefully acknowledge Universitas Negeri Surabaya for its academic guidance and institutional support during the completion of this study.

Disclosure of Conflict of interest

The authors affirm that there are no financial, professional, or personal conflicts of interest that could have influenced the design, conduct, or publication of this research.

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