

The effects of tire-based resistance training on throwing technique performance in adolescent male pencak silat athletes: a pretest-posttest experimental study

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ABSTRACT

Background: Throwing techniques are among the most decisive offensive skills in competitive Pencak Silat because they require efficient coordination of force production and rapid movement execution. Previous studies have primarily investigated the effects of resistance training on kicking performance, while evidence regarding the application of tire-based resistance training to improve throwing technique performance remains limited. This study was conducted to address this gap by evaluating the association between tire-based resistance training and throwing technique performance in adolescent male Pencak Silat athletes. **Purpose:** This study aimed to examine changes in throwing technique performance, measured by execution time, following participation in a four-week tire-based resistance training program among adolescent male Pencak Silat athletes. **Methods:** A quantitative experimental study employing a one group pretest posttest design was conducted with 20 adolescent male athletes selected from Perguruan Pencak Silat Rundayan Merak Emas using saturated sampling procedures. Participants completed a four-week tire-based resistance training program performed three times per week in addition to their regular training activities. Throwing technique performance was assessed before and after the intervention using a standardized performance test, with execution time recorded in seconds using a digital stopwatch. Data were analyzed using descriptive statistics, the Kolmogorov Smirnov normality test, Levene's homogeneity test, paired samples t test, and Cohen's d effect size. **Results:** The mean execution time improved from 6.87 ± 0.49 seconds at pretest to 3.62 ± 0.61 seconds at posttest, representing an average reduction of approximately 3.25 seconds. Statistical analysis demonstrated a significant difference between the two measurements ($t(19) = 3.833$, $p = 0.001$). The calculated Cohen's d of 0.86 indicated a large practical effect, suggesting that the observed improvement was not only statistically significant but also meaningful within the context of competitive throwing performance. **Conclusion:** Participation in the tire-based resistance training program was associated with improved throwing technique performance among adolescent male Pencak Silat athletes. Although the findings provide preliminary support for the application of tire-based resistance training as a practical conditioning strategy, they should be interpreted cautiously because the one group pretest posttest design does not permit definitive causal conclusions. Further controlled studies involving larger and more diverse athlete populations are recommended to confirm and extend these findings.

Keywords: adolescent athletes, functional resistance training, pencak silat, throwing technique performance, tire-based resistance training.

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Introduction

Pencak Silat is an indigenous Indonesian martial art that requires the integration of technical skills, physical fitness, and neuromuscular coordination to achieve optimal performance during competition. Athletes are expected to execute offensive and defensive techniques with high levels of speed, precision, and movement efficiency while responding to rapidly changing situations. Success in competition depends not only on technical mastery but also on the ability to coordinate multiple physical capacities, including

muscular strength, speed, endurance, flexibility, balance, and coordination. Research has shown that these physical components collectively support the quality of movement execution and determine the effectiveness of sport specific techniques performed during combat (Patah et al., 2021). Biomechanical investigations further indicate that efficient Pencak Silat techniques are produced through coordinated interactions among the lower extremities, trunk, and upper limbs, allowing force to be transferred efficiently throughout the body during dynamic movement (Karo et al., 2023). This integrated movement pattern enables athletes to maintain postural stability while generating sufficient force to execute techniques accurately under competitive conditions (Mujiono & Hariono, 2024).

Throwing techniques represent one of the most demanding technical skills in Pencak Silat because their successful execution depends on the athlete's ability to produce force rapidly while maintaining balance throughout the movement sequence. From a biomechanical perspective, throwing actions involve sequential force generation beginning in the lower limbs, continuing through trunk rotation and stabilization, and ending with coordinated upper limb action to destabilize the opponent. This sequence reflects the principle of kinetic chain movement in which each body segment contributes to the efficient transfer of mechanical energy during complex motor tasks (Karo et al., 2023). Effective performance of this movement also depends on physiological adaptations associated with resistance training, including improved motor unit recruitment, greater neuromuscular efficiency, enhanced rate of force development, and increased muscular strength, all of which contribute to the rapid production of force required during explosive sporting actions (Fitri et al., 2023). These physiological characteristics provide an important theoretical basis for developing training interventions intended to improve throwing performance in adolescent Pencak Silat athletes.

Previous studies have consistently reported that resistance training improves physical capacities that support performance in combat sports, particularly muscular strength, explosive power, movement speed, and technical execution. Experimental studies involving Pencak Silat athletes demonstrated that plyometric exercises and resistance based training significantly enhanced lower limb power, resulting in faster and more effective kicking performance (Sudiana et al., 2023). Similar findings were reported by Ilahi et al. (2023), who observed that resistance band training improved front kick speed among adolescent female Pencak Silat athletes, indicating that sport specific resistance exercises can positively influence technical performance. Research conducted by Fitri et al. (2023) also showed that programs emphasizing lower extremity power development contributed to improvements in explosive movement capacity, which is essential for executing dynamic offensive techniques during competition. Complementary evidence was provided by Ihsan et al. (2022), who found that muscular power and flexibility significantly contributed to sickle kick performance among students learning Pencak Silat. These studies collectively demonstrate that improvements in muscular strength and power can facilitate more effective technical execution. Nevertheless, the primary emphasis of previous investigations has remained on kicking performance, while relatively little attention has been directed toward throwing techniques, despite their tactical importance in competitive Pencak Silat.

Current evidence also reveals important methodological limitations that justify further investigation. Most previous intervention studies have evaluated conventional resistance training modalities, including plyometric exercises, resistance bands, and lower limb power programs, with outcome measures focusing primarily on kicking speed or jumping performance (Sudiana et al., 2023). Although these interventions successfully improved selected physical capacities, they did not examine whether functional resistance exercises involving coordinated whole-body movement could enhance throwing technique performance. Research involving tire based resistance training has likewise concentrated on improvements in kicking performance and has not specifically evaluated its influence on throwing techniques, even though both skills require rapid force production, coordinated trunk movement, and efficient kinetic chain activation (Hidayat et al., 2023). Existing findings therefore provide only indirect evidence regarding the potential application of tire-based resistance training for throwing performance because the biomechanical demands of kicking and throwing differ substantially. This limitation indicates that current knowledge remains insufficient to explain whether functional resistance training using tire equipment can effectively improve throwing technique performance among adolescent male Pencak Silat athletes, thereby establishing a clear research gap for the present study.

Tire based resistance training offers a functional approach to strength development because it requires athletes to perform coordinated movements involving the lower limbs, trunk, shoulders, and upper extremities within a single continuous action. Unlike conventional resistance exercises that frequently emphasize isolated muscle groups, tire lifting and flipping demand simultaneous activation of multiple joints and muscle groups while maintaining body stability throughout the movement. This integrated movement pattern resembles the biomechanical characteristics of throwing techniques in Pencak Silat, in which force generated from the lower extremities is transferred through the trunk before being applied through the upper limbs to destabilize an opponent (Karo et al., 2023). Repeated exposure to this type of

movement is expected to stimulate neuromuscular adaptations that improve muscular strength, movement coordination, and the rate of force production required during explosive techniques (Fitri et al., 2023). Previous evidence has also shown that tire based training contributes positively to improvements in kicking performance among Pencak Silat athletes, suggesting that this functional training modality has the potential to enhance sport specific performance beyond conventional resistance exercises (Hidayat et al., 2023). Practical considerations further support the application of tire-based resistance training because tire equipment is inexpensive, durable, widely available, and can be implemented in community-based training environments without requiring specialized strength training facilities.

Current evidence indicates that the application of resistance training in Pencak Silat has predominantly focused on improving kicking performance, lower limb power, or general physical fitness, while empirical evidence concerning throwing technique performance remains limited (Sudiana et al., 2023). Existing studies have also concentrated on conventional resistance training modalities without examining whether functional resistance exercises that closely resemble sport specific movement patterns produce similar or greater improvements in throwing performance (Ilahi et al., 2023). This lack of evidence represents an important gap in the literature because throwing techniques require coordinated force production across the entire kinetic chain rather than isolated muscular strength alone (Karo et al., 2023). The present study addresses this gap by evaluating the effects of tire-based resistance training on throwing technique performance among adolescent male Pencak Silat athletes using a one group pretest posttest experimental design. The training protocol consisted of three sessions per week over four consecutive weeks, a frequency commonly recommended in youth resistance training to provide sufficient neuromuscular stimulus while allowing adequate recovery between training sessions (Fitri et al., 2023). The novelty of this study lies in the application of a functional resistance training modality that closely reflects the movement characteristics of throwing techniques and in its focus on adolescent male Pencak Silat athletes, a population that has received limited attention in previous intervention studies. The findings are expected to enrich the scientific understanding of functional resistance training in combat sports while providing coaches with practical evidence regarding an accessible and cost-effective method for improving throwing technique performance.

Method

This study employed a quantitative experimental approach using a one group pretest posttest design to investigate the effects of tire-based resistance training on throwing technique performance among adolescent male Pencak Silat athletes. This design was selected because it enables researchers to compare participants' performance before and after an intervention within the same group, making it appropriate for evaluating training outcomes in applied sports settings where all athletes receive the same treatment (Kusuma et al., 2023). The design has been widely implemented in field based sports research because it provides a practical framework for assessing training effectiveness when the establishment of a separate control group is constrained by organizational, ethical, or coaching considerations (Agustina et al., 2022). Previous investigations involving athlete development have also demonstrated that this design is capable of capturing performance changes under realistic training conditions while preserving the ecological characteristics of the sporting environment (Rusmi et al., 2023).

The present study recognized that a one group pretest posttest design is susceptible to several threats to internal validity, including history, maturation, testing effects, instrumentation, and regression toward the mean. Several procedural strategies were therefore implemented to reduce these potential sources of bias. The intervention was completed within four consecutive weeks to limit the influence of natural physiological development during adolescence. All participants trained within the same Pencak Silat program under the supervision of the same coaching staff and continued to follow identical routine training schedules throughout the intervention period. The pretest and posttest were administered using identical procedures, testing environments, digital timing equipment, and evaluation criteria to maintain measurement consistency across both assessment sessions. Applying standardized procedures throughout the study was intended to strengthen the credibility of the observed performance changes by reducing procedural variation that could influence the research outcomes (Artanayasa et al., 2023).

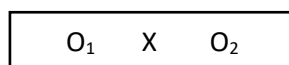


Figure 1. One-Group Pretest-Posttest Design

Notes:

O₁ = Pretest conducted before the intervention to determine participants' baseline throwing technique performance.

X = Tire based resistance training intervention administered three times per week for four

consecutive weeks.

O2 = Posttest conducted after completion of the intervention using the same assessment procedures as the pretest.

Figure 1 illustrates the experimental procedure implemented in the present study. Participants first completed a pretest to establish baseline throwing technique performance. Following the initial assessment, all athletes participated in a four-week tire-based resistance training program conducted three times per week under the supervision of the researchers and the team's coach. After completing the intervention, participants performed the same throwing technique performance test under identical testing conditions. The comparison between pretest and posttest results was used to evaluate changes in throwing technique performance following the intervention.

The target population consisted of 30 adolescent athletes registered at Perguruan Pencak Silat Rundayan Merak Emas. Participant recruitment followed a saturated sampling approach because the accessible population was relatively small and represented the complete group of athletes available during the study period (Sudiadharma et al., 2023). Following the application of the predetermined participant criteria, the final sample comprised 20 adolescent male athletes who completed all stages of the intervention and assessment procedures. Restricting the sample to male athletes was intended to obtain a relatively homogeneous participant group by minimizing physiological variation associated with sex related differences in muscular strength, physical performance, and neuromuscular adaptation. Similar participant selection strategies have been adopted in previous applied sports research involving adolescent athletes when the objective was to evaluate the effectiveness of a specific training intervention under controlled field conditions (Agustina et al., 2022).

All participants were actively involved in routine training activities at Perguruan Pencak Silat Rundayan Merak Emas before and throughout the intervention period. The athletes continued participating in their regular training program while receiving the additional tire-based resistance training prescribed in this study. Maintaining the participants within their usual training environment was intended to preserve the ecological validity of the intervention while ensuring that every athlete experienced comparable coaching supervision and training exposure during the four-week program. Although the participant characteristics limit the generalization of the findings to female athletes or athletes from different competitive levels, the relatively homogeneous sample provided an appropriate basis for evaluating the effectiveness of tire based resistance training within the population examined in the present study (Kusuma et al., 2023).

The intervention consisted of a tire-based resistance training program conducted over four consecutive weeks with three training sessions scheduled each week. All sessions were implemented at Perguruan Pencak Silat Rundayan Merak Emas under the supervision of the researchers in collaboration with the team's coach to ensure that the training procedures were applied consistently throughout the intervention period. The training program was integrated into the athletes' regular Pencak Silat practice rather than replacing their routine activities. Maintaining the existing training schedule allowed participants to continue their normal technical development while receiving the additional resistance training prescribed in this study. This approach was intended to preserve the practical characteristics of the training environment while providing a consistent intervention for every participant.

Tire based resistance training was selected because the movement sequence requires coordinated activation of the lower extremities, trunk, shoulders, and upper limbs within a continuous functional movement. This pattern reflects the biomechanical characteristics of throwing techniques in Pencak Silat, in which force generated from the lower limbs is transferred through the trunk before being applied by the upper extremities during the execution of the technique. Functional resistance exercises involving coordinated whole body movement have been reported to improve muscular strength, movement efficiency, and explosive performance associated with throwing related activities in sport (Martínez-García et al., 2021). Similar observations indicate that resistance training emphasizing coordinated force production contributes positively to technical performance requiring rapid movement execution (Job et al., 2021). Evidence reported by Hadjisavvas et al. (2024) also supports the contribution of resistance training to improvements in sport specific performance through enhanced neuromuscular function and force production. These findings provide the theoretical rationale for applying tire-based resistance training as the intervention examined in the present study.

Throwing technique performance was evaluated through a standardized performance-based assessment administered before and after completion of the intervention program. Each participant performed the designated throwing technique under identical testing conditions, and the execution time required to complete the movement was recorded in seconds using a digital stopwatch. A shorter execution time indicated better throwing technique performance because it reflected greater movement efficiency and faster technical execution. The same testing environment, equipment, evaluators, and assessment

procedures were maintained during both testing sessions to minimize measurement variation and improve the consistency of data collection. Standardized testing procedures have been recommended as an important component of performance evaluation because they reduce instrumentation bias and strengthen the comparability of repeated measurements collected before and after a training intervention (Job et al., 2021).

Data analysis was performed using IBM SPSS Statistics. Descriptive statistics were initially calculated to summarize participant performance before and after the intervention, including the mean, standard deviation, minimum value, and maximum value obtained from the throwing technique performance test. Statistical assumptions were subsequently examined prior to hypothesis testing. Data normality was evaluated using the One Sample Kolmogorov Smirnov test, whereas homogeneity of variance was assessed using Levene's test. The normality analysis produced an Asymp. Sig. value of 0.060, indicating that the distribution satisfied the assumption of normality because the probability value exceeded the predetermined significance level of 0.05. The homogeneity analysis generated a significance value of 0.512, confirming that the data variance was sufficiently homogeneous for subsequent parametric analysis.

Differences between pretest and posttest performance were examined using a paired samples t test because both measurements were obtained from the same participants before and after the intervention. Statistical significance was established at an alpha level of 0.05. The degrees of freedom for the paired samples t test were determined using the formula $df = n - 1$, resulting in 19 degrees of freedom for the twenty participants included in the statistical analysis. The magnitude of the intervention effect was also evaluated using Cohen's d effect size to complement statistical significance with a practical interpretation of the observed performance improvement. The calculated effect size indicated a large practical effect, suggesting that the intervention produced meaningful changes in throwing technique performance beyond statistical significance alone (Martínez-García et al., 2021).

Several procedural considerations were incorporated to strengthen the credibility of the findings despite the limitations associated with a one group experimental design. The intervention was completed within a relatively short training period to reduce potential maturation effects among adolescent athletes. All participants completed the intervention under the supervision of the same coaching staff while continuing identical routine training activities throughout the study. The pretest and posttest were administered using the same testing procedures, digital timing equipment, assessment environment, and evaluators to minimize instrumentation bias and improve measurement consistency. Although the absence of a control group limits the ability to establish causal relationships with complete certainty, the standardized implementation of the intervention and assessment procedures supports a more reliable interpretation of the observed performance changes within the practical context of applied sports training (Agustina et al., 2022).

Results

The descriptive analysis was conducted to provide an overview of participants' throwing technique performance before and after the implementation of the tire-based resistance training program. Execution time served as the primary performance indicator, with lower values representing faster and more efficient completion of the designated throwing technique. A comparison of the pretest and posttest results demonstrated a consistent reduction in execution time following completion of the intervention.

Table 1 presents the individual performance data of the twenty-adolescent male Pencak Silat athletes. Before participating in the intervention, execution times ranged from 6.0 to 7.6 seconds, with an average performance of 6.87 ± 0.49 seconds. Following four weeks of tire-based resistance training, execution times decreased to a range of 2.7 to 4.5 seconds, producing a posttest mean of 3.62 ± 0.61 seconds. These findings indicate an average reduction of approximately 3.25 seconds, suggesting a substantial improvement in the speed of throwing technique execution after completion of the training program.

The individual data also demonstrate that performance improvements were consistently observed across all participants. Every athlete recorded a shorter execution time during the posttest than during the pretest, indicating that the training intervention produced a uniform pattern of improvement rather than changes limited to only a small number of participants. Although differences in individual performance remained after the intervention, the overall reduction in execution time suggests that tire-based resistance training contributed positively to enhancing movement efficiency during throwing technique execution.

Table 1. Pretest and Posttest Throwing Technique Performance

No	Participant	Gender	Body Weight (kg)	Pretest (s)	Posttes (s)	Performance Category
1	P1	M	52	7.2	3	Excellent
2	P2	M	40	7	4.2	Fair
3	P3	M	50	7.5	4.5	Fair
4	P4	M	57	6	2.7	Excellent
5	P5	M	37	7	3.5	Good
6	P6	M	39	7.5	4.4	Fair
7	P7	M	44	6.5	3	Excellent
8	P8	M	67	6.2	3.3	Good
9	P9	M	63	6	2.8	Excellent
10	P10	M	46	6.7	3.6	Good
11	P11	M	42	7.2	4.2	Fair
12	P12	M	79	7.5	4.3	Fair
13	P13	M	45	6.9	3.7	Good
14	P14	M	46	7.2	4.4	Fair
15	P15	M	54	6.5	3.6	Good
16	P16	M	53	6.3	2.9	Excellent
17	P17	M	50	7.1	4	Good
18	P18	M	47	6.8	3.3	Good
19	P19	M	61	7.6	4.2	Fair
20	P20	M	68	6.6	2.8	Excellent
Mean ± SD				6.87 ± 0.49	3.62 ± 0.61	
Minimum				6.0	2.7	
Maximum				7.6	4.5	

Note. Lower execution times indicate better throwing technique performance.

Figure 2 illustrates the comparison between the pretest and posttest execution times recorded for each participant. A consistent reduction in execution time was observed across all twenty athletes following completion of the tire-based resistance training program. The graphical presentation confirms the pattern identified in Table 1, showing that every participant demonstrated improved throwing technique performance after the intervention. Most athletes completed the throwing technique within 2.7 to 4.5 seconds during the posttest, whereas all pretest performances required 6.0 seconds or longer.

The observed reduction in execution time also has practical relevance within the context of competitive Pencak Silat. Competition guidelines generally require throwing techniques to be executed efficiently within a limited time frame, commonly less than five seconds. After completing the intervention, every participant performed the technique within this performance threshold, indicating that the improvement was not only statistically measurable but also meaningful from a practical coaching perspective. Individual differences remained evident, as several athletes continued to require more time than others to complete the technique. Nevertheless, the consistent improvement across all participants suggests that the intervention contributed positively to throwing technique performance under realistic training conditions.

Prior to hypothesis testing, the distribution of the research data was examined to determine whether the assumptions required for parametric statistical analysis had been satisfied. Data normality was evaluated using the One Sample Kolmogorov Smirnov test because the subsequent analysis employed a paired samples t test. A significance value greater than 0.05 indicated that the data did not significantly deviate from a normal distribution and therefore met the normality assumption.

The results of the Kolmogorov Smirnov analysis are presented in Table 2. The analysis produced an Asymp. Sig. (2 tailed) value of 0.060, which exceeded the predetermined significance level of 0.05. These findings indicate that the distribution of the data did not differ significantly from normality and therefore satisfied the statistical assumption required for subsequent parametric analysis. Although the probability value was relatively close to the decision threshold, no evidence was found to suggest a significant violation of the normality assumption within the present sample.

Table 2. Results of the Kolmogorov Smirnov Normality Test

Variable	Statistic	<i>p</i> value	Interpretation
Throwing Technique Performance	0.215	0.060	Normally distributed

Note. Statistical significance was determined at $\alpha = 0.05$. Data were considered normally distributed when $p > 0.05$.

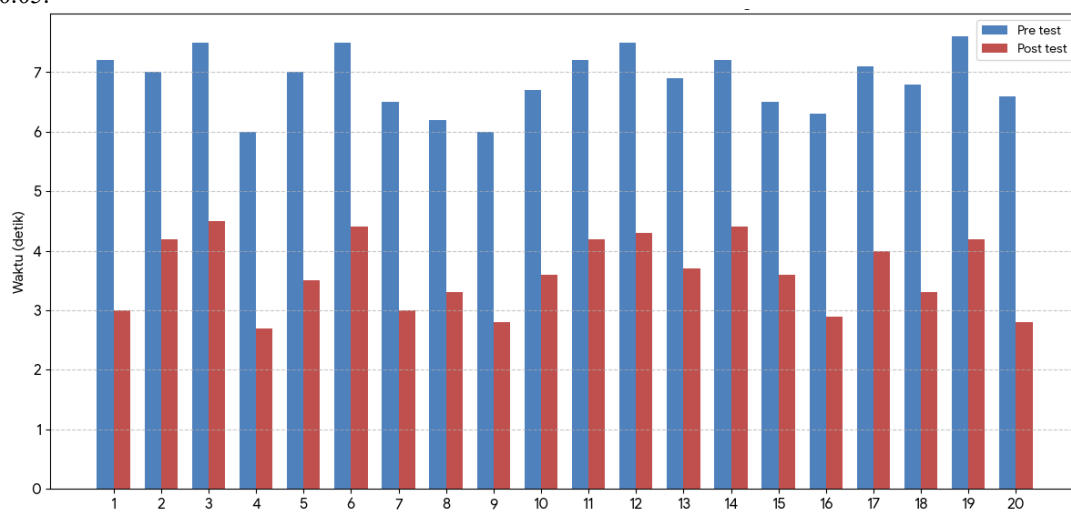


Figure 2. Comparison of Pretest and Posttest Throwing Technique Performance

Homogeneity testing was subsequently conducted to examine whether the variance of the measurement data satisfied the assumptions required for parametric hypothesis testing. Variance homogeneity was assessed using Levene's test, with a significance value greater than 0.05 indicating homogeneous data.

The results presented in Table 3 demonstrate that the significance value obtained from Levene's test was 0.512, exceeding the predetermined alpha level of 0.05. This outcome indicates that the variance of the measurement data was sufficiently homogeneous, supporting the use of parametric statistical procedures for further analysis. Satisfying both the normality and homogeneity assumptions provided an appropriate basis for conducting the paired samples t test to evaluate differences between the pretest and posttest measurements.

Table 3. Results of the Homogeneity Test

Test	Levene Statistic	df1	df2	<i>p</i> value	Interpretation
Based on Median	0.936	5	7	0.512	Homogeneous

Note. Statistical significance was determined at $\alpha = 0.05$. Homogeneity was assumed when $p > 0.05$.

The effectiveness of the tire-based resistance training program was evaluated by comparing participants' throwing technique performance before and after the intervention using a paired samples t test. This statistical procedure was selected because both measurements were obtained from the same participants, allowing the analysis to determine whether the observed changes in execution time were statistically significant.

The descriptive statistics for the paired measurements are presented in Table 4. Before participating in the intervention, the athletes demonstrated a mean execution time of 6.87 ± 0.49 seconds. Following completion of the four-week training program, the mean execution time decreased to 3.62 ± 0.61 seconds.

These descriptive findings indicate an average reduction of approximately 3.25 seconds, suggesting a substantial improvement in throwing technique performance after the intervention.

Table 4. Descriptive Statistics for the Paired Samples Analysis

Variable	n	Mean (s)	SD
Pretest	20	6.87	0.49
Posttest	20	3.62	0.61

The inferential analysis is presented in Table 5. The paired samples t test revealed a statistically significant difference between the pretest and posttest measurements, with $t(19) = 3.833$ and $p = 0.001$. Because the probability value was lower than the predetermined significance level of 0.05, the null hypothesis was rejected and the alternative hypothesis was accepted. These findings indicate that the tire-based resistance training program produced a statistically significant improvement in throwing technique performance among the adolescent male Pencak Silat athletes who participated in this study.

Table 5. Results of the Paired Samples t Test

Variable	Mean Difference (s)	t	df	p	Decision
Pretest vs. Posttest	3.25	3.833	19	0.001	Significant

Statistical significance alone does not fully explain the magnitude of the observed improvement. The practical importance of the intervention was therefore evaluated using Cohen's d effect size. The calculated effect size was approximately 0.86, representing a large practical effect according to conventional interpretation criteria. This finding indicates that the improvement produced by the tire-based resistance training program was not only statistically significant but also substantial from a practical performance perspective.

The reduction in execution time also has meaningful implications for competitive Pencak Silat performance. Before the intervention, all participants required between 6.0 and 7.6 seconds to complete the throwing technique, indicating that none of the athletes achieved the commonly applied competition benchmark of completing the movement within five seconds. Following the intervention, execution times ranged from 2.7 to 4.5 seconds, demonstrating that every participant performed the technique within the expected competitive standard. This improvement suggests that the intervention enhanced not only statistical performance measures but also the athletes' ability to execute throwing techniques more efficiently under conditions that more closely reflect competitive demands.

Although all participants demonstrated improved performance following the intervention, differences in individual execution times remained evident during the posttest assessment. Several athletes completed the throwing technique in less than three seconds, whereas others required more than four seconds. These individual differences indicate that responses to the training program varied among participants, likely reflecting differences in physical characteristics, technical proficiency, and individual adaptation to resistance training. Nevertheless, the consistent reduction in execution time observed across all participants supports the effectiveness of tire-based resistance training as a practical conditioning strategy for improving throwing technique performance in adolescent male Pencak Silat athletes.

Discussion

The present study demonstrated that tire-based resistance training was associated with a significant improvement in throwing technique performance among adolescent male Pencak Silat athletes. The reduction in execution time observed after four weeks of training indicates that the intervention contributed to more efficient movement execution during the designated throwing technique. Although the present study did not directly measure physiological variables such as muscular strength, power, or neuromuscular function, the consistent improvement observed across all participants suggests that repeated functional resistance exercise may have enhanced the athletes' capacity to perform throwing movements more efficiently. These findings should therefore be interpreted as evidence of improved technical performance rather than direct evidence of specific physiological adaptations.

The improvement observed in the present study is consistent with previous investigations reporting positive effects of resistance training on sport specific performance in Pencak Silat. Research conducted by Ilahi et al. (2023) demonstrated that resistance based exercise improved front kick speed among adolescent athletes, indicating that structured resistance training can facilitate more effective execution of technical movements. Similar observations were reported by Sudiana et al. (2023), who found that plyometric training enhanced explosive movement capacity and increased the frequency of effective kicking performance in Pencak Silat athletes. Although these previous studies primarily examined kicking techniques rather than throwing performance, they collectively suggest that resistance-oriented training can

positively influence technical execution through improvements in movement efficiency. The present findings extend this body of evidence by demonstrating that a functional resistance training approach using tire equipment may also support the development of throwing technique performance, an aspect that has received considerably less attention in previous Pencak Silat research.

The findings also correspond with broader evidence reported in resistance training research involving throwing related movements in other sporting disciplines. Martínez García et al. (2021) reported that resistance training programs emphasizing muscular strength and explosive force production improved throwing performance across several overhead sports. Comparable conclusions were presented by Job et al. (2021), who highlighted the contribution of resistance based exercise to improvements in sport specific throwing ability through enhanced movement quality and force application. Hadjisavvas et al. (2024) likewise concluded that progressive resistance training contributes to meaningful improvements in athletic performance when training exercises reflect the movement characteristics required during competition. Although the movement patterns examined in those studies differ from the throwing techniques performed in Pencak Silat, the underlying principle that functional resistance exercise can improve sport specific performance appears to be consistent with the outcomes observed in the present investigation. This comparison suggests that tire-based resistance training may represent a practical variation of functional resistance exercise capable of supporting technical performance in combat sports when integrated into regular training programs.

The performance improvement observed in this study may be interpreted from both physiological and biomechanical perspectives, although these mechanisms were not measured directly. Tire based resistance training requires athletes to coordinate force production across the lower extremities, trunk, and upper limbs while maintaining postural stability throughout the movement sequence. Repeated exposure to this functional movement pattern may enhance intermuscular coordination and movement efficiency, allowing athletes to perform throwing techniques with greater control and reduced execution time. Functional resistance exercises that closely resemble sport specific movement patterns have been reported to facilitate improvements in technical performance by promoting more effective coordination between body segments during dynamic actions. This interpretation is consistent with observations reported by Hadjisavvas et al. (2024), who emphasized that resistance training contributes to improvements in athletic performance when exercise movements correspond closely with the biomechanical demands of the target sport.

Variation in posttest performance among participants also deserves consideration. Although every athlete demonstrated faster execution following the intervention, posttest times remained variable, ranging from 2.7 to 4.5 seconds. These differences suggest that individual responses to the training program were not identical. Several factors may have contributed to this variation, including differences in initial technical proficiency, training experience, body composition, movement coordination, and individual adaptation to repeated resistance exercise. Because these variables were not directly evaluated, the present study cannot determine the relative contribution of each factor to the observed differences in performance. Future investigations incorporating biomechanical analysis and physiological measurements may provide a more comprehensive explanation of the mechanisms underlying individual responses to tire based resistance training.

The findings of this study provide practical implications for coaches and practitioners working with adolescent Pencak Silat athletes. Tire based resistance training appears to represent a practical conditioning method that can be incorporated into regular training programs without requiring expensive resistance training equipment. The intervention was implemented using readily available materials and was integrated into the athletes' existing training schedule, demonstrating that functional resistance exercise can be introduced without substantially altering routine coaching practices. Coaches may therefore consider incorporating tire-based resistance exercises as a complementary component of physical conditioning when the objective is to improve movement efficiency during throwing techniques. At the same time, the selection of tire size, training volume, and exercise intensity should be adjusted according to the athletes' age, physical capacity, and training experience to ensure safe and effective implementation.

Several limitations should be considered when interpreting the findings of the present study. The absence of a control group limits the ability to attribute the observed improvements exclusively to the intervention because other factors associated with routine training may also have influenced performance during the study period. The relatively small sample size and recruitment of participants from a single Pencak Silat school further limit the generalizability of the findings to broader athlete populations. Another limitation is that the study evaluated throwing technique performance solely through execution time without directly assessing physiological variables such as muscular strength, power, or neuromuscular adaptation. Similarly, formal reliability and validity testing of the performance assessment instrument was not conducted. These limitations should be taken into account when interpreting the present findings and provide important considerations for future investigations.

Future research should employ more rigorous experimental designs involving randomized controlled trials or comparison groups to strengthen causal inference regarding the effectiveness of tire-based resistance training. Studies involving larger and more diverse participant populations, including female athletes and athletes representing different competitive levels, would improve the generalizability of the findings. Future investigations are also encouraged to incorporate biomechanical analysis, muscle strength assessment, and neuromuscular performance measurements to clarify the mechanisms responsible for improvements in throwing technique performance. Additional studies comparing tire-based resistance training with conventional resistance exercises such as free weights, resistance bands, or body weight training would further assist coaches in selecting the most appropriate conditioning strategies for different athlete populations.

Conclusion

The findings of the present study indicate that participation in a four-week tire-based resistance training program was associated with improved throwing technique performance among adolescent male Pencak Silat athletes. Participants demonstrated consistently shorter execution times during the posttest assessment compared with the pretest, suggesting that the intervention may contribute to more efficient execution of throwing techniques when incorporated into regular training programs. Although the one group pretest posttest design does not permit definitive causal conclusions, the observed improvement provides preliminary evidence supporting the potential value of tire-based resistance training as a functional conditioning approach for adolescent Pencak Silat athletes.

The practical significance of these findings lies in the accessibility and applicability of the training method. Tire based resistance training can be integrated into routine coaching programs using inexpensive and readily available equipment, making it particularly suitable for community-based clubs and training environments with limited access to conventional resistance training facilities. Coaches considering this approach should adjust the training load and exercise difficulty according to the athletes' age, physical capacity, and technical proficiency to ensure that the exercises remain appropriate and safe for the target population.

Several limitations should be considered when interpreting the findings. The absence of a control group, the relatively small sample size, and the recruitment of participants from a single Pencak Silat school limit the extent to which the results can be generalized to broader athlete populations. In addition, the study involved only adolescent male athletes and evaluated performance using execution time without directly measuring physiological or biomechanical adaptations. These limitations suggest that the present findings should be interpreted within the context of the study design rather than as conclusive evidence applicable to all Pencak Silat athletes.

Future research should employ more rigorous experimental designs involving larger participant samples, comparison groups, and athletes representing different sexes, age categories, and competitive levels. Incorporating physiological, biomechanical, and neuromuscular assessments would also provide a more comprehensive understanding of the mechanisms through which tire based resistance training may influence throwing technique performance. Such investigations would strengthen the evidence base and support the development of more effective sport specific conditioning programs for Pencak Silat athletes.

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Conflicts of Interest

The authors declare that there are no financial, professional, institutional, or personal relationships that could be construed as a potential conflict of interest in relation to this study. The research was conducted independently without any external funding or influence that could affect the interpretation of the results or the objectivity of the manuscript.

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