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Improving Silat Kick Performance through Muscle Training: Impact on Movement Mechanics and Movement Consistency in South Sulawesi Pencak Silat Athletes

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ABSTRACT

Background: Kick performance in pencak silat is determined by the interaction of muscle explosive power, movement mechanics, and neuromuscular consistency. Athletes from South Sulawesi who compete in national and regional tournaments require evidence-based training protocols to optimize kicking biomechanics. However, scientific research specifically addressing the effect of muscle training programs on kicking mechanics and movement consistency in South Sulawesi pencak silat athletes remains limited. Objectives: This study aimed to analyze the effect of an 8-week structured muscle training program (combining plyometric and resistance training) on kick velocity, angular velocity, impact force, and movement consistency in pencak silat athletes from South Sulawesi. Methods: A pre-experimental one-group pretest-posttest design was employed. Thirty-two male athletes from South Sulawesi's provincial pencak silat contingent (PELATDA Sulawesi Selatan) were selected by purposive sampling. The training program combined progressive plyometric exercises (squat jumps, box jumps, depth jumps) with resistance training (leg press, hamstring curl, hip flexor strengthening) for 8 weeks, 3 sessions per week. Kick biomechanics including kick velocity (m/s), angular velocity of knee joint (°/s), peak impact force (N), and consistency index were measured using 2D kinematic analysis with Kinovea software and a force pad sensor. Data were analyzed using Paired Sample T-Test ($\alpha = 0.05$). Results: Significant improvements were found in kick velocity (pre: 7.84 ± 0.93 m/s → post: 9.47 ± 0.81 m/s; $p = 0.000$), angular velocity (pre: 412.6 ± 38.4 °/s → post: 498.3 ± 32.7 °/s; $p = 0.000$), peak impact force (pre: 1.247 ± 186.4 N → post: 1.534 ± 164.2 N; $p = 0.000$), and consistency index (pre: 72.4 ± 8.1% → post: 84.6 ± 6.3%; $p = 0.001$). Conclusions: A structured 8-week combined plyometric and resistance training program significantly enhances both biomechanical parameters and movement consistency of kicks in South Sulawesi pencak silat athletes, with practical implications for performance coaching and periodization planning.

Keywords: Pencak Silat; Kick Performance; Muscle Training; Biomechanics; Movement Consistency; South Sulawesi Athletes; Plyometric; Kinovea.

INTRODUCTION

Pencak silat is an indigenous cultural heritage and martial art of the archipelago that has been recognized by UNESCO as an Intangible Cultural Heritage in 2019. As an achievement sport, pencak silat demands a complex combination of physical abilities, including speed, explosive strength, agility, balance, and high neuromuscular coordination. Among the various techniques used in the game, kicking is the main attack technique that earns the most points,

considering that the legs have a longer reach and greater potential for force than hand techniques (Bustomi et al., 2020; Dahlan et al., 2025). South Sulawesi Province has consistently been a force for pencak silat at the national level, with its athletes participating in the National Sports Week (PON), POPNAS, and various international championships.

The quality of the kick in pencak silat is determined by three main dimensions: (1) kinematic dimensions which include the linear speed of the legs, the angular speed of the knee and pelvic joints, and the execution time; (2) kinetic dimensions that include peak impact forces and impulses; and (3) the neuromuscular consistency dimension of the athlete's ability to reproduce the same movement pattern repeatedly with minimal deviation. These three dimensions interact with each other and collectively determine the effectiveness of kicks in dynamic match situations (Vagner et al., 2021; Valkonen et al. in encyclopedia.pub, 2023).

The main muscles involved in the execution of the pencak silat kick include: (1) the quadriceps femoris, hamstring, gastrocnemius, and anterior tibialis leg muscles for the extension and flexion phases; (2) pelvic muscles of iliopsoas, gluteus medius and minimus, tensor fasciae latae for swing and rotation phases; and (3) the core muscles transversus abdominis, obliquus internus and externaus as stabilizers and force transfer (Ihsani et al., 2024). The power and explosiveness of these muscles directly determine the amount of speed and force that can be generated in each kick. Research by Saripudin & Kamarudin (2023) confirmed a significant correlation between leg muscle explosiveness ($r = 0.745$) and sickle kick speed in pencak silat athletes.

Structured muscle strength training programs in particular that combine plyometric training and progressive resistance training have been scientifically proven to be effective in improving the biomechanical parameters of kicks. Sudirman et al. (2024) in a comparative study in the journal SPORT TK found that plyometric training was significantly more effective in increasing the explosiveness of sickle kicks compared to conventional exercises. Sudiana et al. (2023) reported that the combination of plyometric stair jump and reaction box jump significantly increased the frequency of straight kicks in pencak silat athletes. Meanwhile, Vagner et al. (2021) in the Archives of Budo showed that a 12-week strength training program significantly improved kinematics and front kick styles in martial arts karate that has similar biomechanical characteristics to pencak silat.

On the other hand, the aspect of consistency of kick movements, namely the ability of athletes to reproduce optimal kinematic patterns repeatedly with minimal variability, is still not receiving much attention in pencak silat research in Indonesia. In fact, consistency of movement is an indicator of neuromuscular maturity and technical reliability that greatly determine the effectiveness of attacks in matches (Jia et al., 2024). A systematic review by Vagner et al. (2023) in PMC showed that elite athletes consistently exhibited higher angular speeds and lower intertrail variability than sub-elite athletes, confirming that consistency and speed are two attributes that develop along with training quality.

Although research on pencak silat kicks has developed rapidly in a national context, scientific studies that simultaneously measure the impact of muscle training programs on multidimensional biomechanical parameters (kinematics, kinetics, consistency) in South Sulawesi silat athletes have never been conducted. This study aims to fill this gap by comprehensively analyzing the impact of an 8-week muscle training program that combines plyometrics and progressive resistance on kick speed, joint angle speed, peak impact force, and consistency of kick motion in South Sulawesi pencak silat athletes.

METHODS

Research Design

This study uses a pre-experimental one-group pretest-posttest design. In this design, one group of athletes received an intervention structured muscle training program, with measurements of the biomechanical parameters of the kick performed before (pre-test) and after (post-test) the 8-week intervention period. Although without a control group, this design was chosen

pragmatically considering the limited number of active PELATDA athletes who met the criteria, with strict internal control through standardization of measurement conditions, instructors, and training environments (Sugiyono, 2019; Arikunto, 2021).

Population, Sample, and Sampling Techniques

The research population is all male pencak silat athletes who are members of the South Sulawesi Pencak Silat Regional Training Center for the preparation of PON 2025, totaling 41 people. The sampling technique used purposive sampling with inclusion criteria: (1) active male athletes of PELATDA South Sulawesi; (2) aged 15–28 years; (3) have at least 2 years of experience in practicing pencak silat; (4) not being in recovery from an injury in the last 3 months; (5) not participating in other structured physical exercise programs in parallel; and (6) be willing to participate in the entire research series. Out of 41 populations, 32 athletes met all the criteria and were sampled. Nine athletes were excluded due to a history of injury (n=5), lack of age (n=2), and refusal to participate (n=2).

Muscle Training Intervention Program

The combination muscle training program is designed and implemented over 8 weeks with a frequency of 3 sessions per week (24 sessions in total), led by a certified physical trainer. Each training session lasts 90 minutes, consisting of: a 15-minute warm-up (jogging + dynamic stretching), a 60-minute core workout, and a 15-minute cool-down. The program is progressively designed in 4 phases.

The plyometric exercises used include squat jump, box jump (30–40 cm), depth jump, and single leg bound were selected based on scientific evidence on their effectiveness in increasing the explosive power of pencak silat leg muscles (Sudiana et al., 2023; Kamarudin et al., 2023). Resistance exercises include leg press, hamstring curl, hip flexor strengthening, and lateral lunge, using progressive loads from 50% to 90% 1RM (Repetition Maximum). Each session is closed with a technical kick drill to integrate the increased strength into the sport's specific movement patterns.

Measurement Instruments and Techniques

Kick biomechanical measurements were carried out using a 2D kinematic analysis system based on Kinovea software (version 0.9.5) with a 240 fps high-speed camera to capture motion details. The variables measured included: (1) linear foot speed (m/s) peak toe speed during kick execution; (2) the angular velocity of the knee and pelvic joints (°/s) was calculated from angular changes per unit of time using Kinovea quadrant analysis; (3) the peak impact force (N) is measured using a calibrated sensor force pad; and (4) the consistency index (%) is calculated as the percentage of similarity in kinematic patterns between three repetitions of kicks using a coefficient of variation (1 - CV × 100%).

Leg muscle strength was measured using the leg press 1RM test and the vertical jump test (Sargent Jump Test). All measurements were taken under the same conditions (indoor field, temperature 22–25°C, morning time), by the same enumerator, and after a 10-minute standardized warm-up.

Data Analysis Techniques

Descriptive analysis (mean, SD, minimum, maximum, percentage increase) is used to describe the distribution of data. The normality test was carried out with the Shapiro-Wilk Test (n=32). Pre-post hypothesis test using Paired Sample T-Test at a significance level of $\alpha = 0.05$. Pearson correlation analysis was used to test the relationship between muscle strength variables and biomechanical parameters. Effect size is calculated using Cohen's d to quantify the practical magnitude of the change. All analyses used SPSS version 26.0 and Microsoft Excel 2021.

RESULTS RESULTS

Characteristics of Research Samples

Table 2 presents the general characteristics of 32 South Sulawesi pencak silat athletes who are the research sample.

Table 1. General Characteristics of the Research Sample (n=32)

Variable	N	Min	Max	Mean ± SD
Age (years)	32	16	27	20.8 ± 3.2
Height (cm)	32	158	181	167.4 ± 5.6
Body Weight (kg)	32	54	79	64.7 ± 7.4
IMT (kg/m²)	32	19.1	27.8	23.1 ± 2.3
Practice Experience (years)	32	2	12	5.8 ± 2.6
Frequency of Exercises (sessions/week)	32	3	5	4.1 ± 0.7
Pre Leg Muscle Strength (kg)	32	62	114	84.6 ± 12.3

Based on Table 1, the sample is dominated by young athletes (average 20.8 ± 3.2 years) with an average training experience of 5.8 ± 2.6 years, indicating that the sample is an athlete with a fairly mature level of coaching. The average frequency of training of 4.1 ± 0.9 sessions per week reflects the high intensity of the PELATDA program. The average BMI of 23.1 kg/m² is within the normal range by Asia-Pacific standards.

Normality Test Results

Table 2. Shapiro-Wilk normality test results

Variabel	N	Say.	a	Remarks
Pre-test Kick Speed	32	0.381	0.05	Normal
Post-test Kick Speed	32	0.412	0.05	Normal
Pre-test Angular Speed	32	0.298	0.05	Normal
Post-test Angular Speed	32	0.354	0.05	Normal
Pre-test Impact Style	32	0.326	0.05	Normal
Post-test Impact Style	32	0.487	0.05	Normal
Pre-test Consistency Index	32	0.271	0.05	Normal
Post-test Consistency Index	32	0.319	0.05	Normal

All study variables had Shapiro-Wilk significance values above $\alpha = 0.05$, confirming that the data were normally distributed so that the Paired Sample T-Test could be used as a hypothesis test.

Changes in Biomechanical Parameters of Pre-Post Intervention Kicks

Table 3 presents the main results of a comparison of biomechanical parameters before and after the 8-week muscle training program.

Table 3. Paired Sample T-Test Results: Biomechanical Parameters of Pre-Post Intervention Kicks (n=32)

Parameter Biomechanics	Pre-test (Mean ± SD)	Post-test (Mean ± SD)	Improvement	Sig. (p)	Ket.
Kick Speed (m/s)	7.84 ± 0.93	9.47 ± 0.81	↑ 20.8%	0.000	Sig.

Knee Angle Speed (°/s)	412.6 ± 38.4	498.3 ± 32.7	↑ 20.7%	0.000	Sig.
Pelvic Angle Velocity (°/s)	386.2 ± 41.3	461.8 ± 35.9	↑ 19.6%	0.000	Sig.
Peak Impact Style (N)	1247 ± 186	1534 ± 164	↑ 23.0%	0.000	Sig.
Kick Execution Time (sec)	0.387 ± 0.041	0.318 ± 0.033	↓ 17.8%	0.000	Sig.
Consistency Index (%)	72.4 ± 8.1	84.6 ± 6.3	↑ 16.9%	0.001	Sig.
Leg Muscle Strength (kg)	84.6 ± 12.3	103.8 ± 11.7	↑ 22.7%	0.000	Sig.

Table 3 shows a significant improvement (p = 0.000 on all variables except the consistency index p = 0.001) on the entire biomechanical parameters of the kick after 8 weeks of the muscle training program. Kick speed increased by 20.8% (7.84 → 9.47 m/s), knee angle speed increased by 20.7% (412.6 → 498.3 °/s), peak impact force increased by 23.0% (1,247 → 1,534 N), execution time decreased by 17.8% (faster), and movement consistency index increased by 16.9% (72.4% → 84.6%). An increase in leg muscle strength by 22.7% is the support for all of these biomechanical adaptations.

Biomechanical Profiles per Kick Type

Table 4 presents a breakdown of the post-test biomechanical parameters based on the four main types of kicks in pencak silat.

Table 4. Post-Test Biomechanical Profile by Kick Type (n=32)

Types of Kicks	. Pre (m/s)	Kec. Post (m/s)	Δ Districts (%)	Post Style (N)	Post Consistency (%)
Sickle Kick	7.62 ± 0.89	9.34 ± 0.77	↑ 22.6%	1.489 ± 158	86.2 ± 5.9
Front Kick (S)	7.91 ± 0.96	9.52 ± 0.83	↑ 20.4%	1.521 ± 171	83.7 ± 6.8
Side Kick (T)	7.84 ± 1.02	9.48 ± 0.88	↑ 20.9%	1.612 ± 177	84.1 ± 6.4
Back Kick	8.13 ± 1.04	9.68 ± 0.91	↑ 19.1%	1.587 ± 168	83.9 ± 7.1

Table 4 shows that all types of kicks experienced an increase in speed above 19%, with the crescent kick recording the highest increase (22.6%). The side kick (T kick) produces the highest post-test impact force (1,612 ± 177 N), consistent with its biomechanical characteristics that utilize full-body rotation to accumulate maximum angular momentum. The post-test consistency index was in the range of 83.7–86.2% across all types of kicks, indicating that the exercise program succeeded in improving neuromuscular reliability evenly.

Correlation of Muscle Strength with Biomechanical Parameters

Table 5 presents the results of the Pearson correlation test between muscle strength variables and post-test kick biomechanical parameters.

Table 5. Pearson's Correlations: Muscle Strength and Biomechanical Parameters of Post-Test Kicks

Independent Variables	r (Kec. Kickangan)	r (Impact Force)	Sig. (p)	Ket.

Leg Muscle Strength (leg press 1RM)	0.748	0.712	0.000	Sig.
Leg Muscle Explosiveness (vertical jump)	0.681	0.653	0.000	Sig.
Knee Joint Angular Speed	0.824	0.791	0.000	Sig.
Angular Velocity of the Pelvic Joint	0.806	0.768	0.000	Sig.
Movement Consistency Index	0.634	0.598	0.000	Sig.
Training Experience (years)	0.512	0.487	0.003	Sig.
Pelvic Flexibility (°)	0.438	0.412	0.012	Sig.

Table 5 shows that the angular speed of the knee joint has the highest correlation with kick speed (r = 0.824), confirming the dominant role of the knee joint as a speed generator in kick execution. Leg muscle strength (leg press 1RM) was strongly correlated with kick speed (r = 0.748) and impact force (r = 0.712). The consistency index correlated positively significantly with kick speed (r = 0.634), indicating that more consistent athletes also tend to have faster consistency and speed developing along with neuromuscular maturity.

DISCUSSION

The Impact of Muscle Training on Kick Impact Speed and Force

The increase in kick speed of 20.8% (from 7.84 to 9.47 m/s, p = 0.000) achieved in this study is strong evidence of the effectiveness of the combination muscle training program on the kinetic performance of pencak silat kicks of South Sulawesi athletes. This increase is consistent with an underlying physiological mechanism: plyometric exercises induce neuromuscular adaptation through increased motor unit recruitment, increased rate of force development (RFD), and optimization of tendon elasticity through stretch-shortening cycles (Markovic & Mikulic, 2010). Progressive resistance training synergistically increases the cross-sectional area (CSA) of Type II muscle fibers and myofibrillar protein synthesis via the mTORC1 pathway (Ruple et al., 2021), so that each contraction results in a greater force.

The increase in peak impact force of 23.0% (from 1,247 N to 1,534 N) has direct relevance to the effectiveness of the attack in the match. In the modern pencak silat scoring system, the quality of technique is judged subjectively by the referee, but a higher impact force when directed with precision has the potential to improve target response and attack validity (Katiandagho & Saiman, 2023). A comparison with Dahlan et al. (2025) who researched a similar program in BKMF Pencak Silat FIKK UNM athletes showed that the consistency of the findings of leg muscle strength training significantly improved kick performance with a t-count value that far exceeded the t-table. The similarity of the sample population (South Sulawesi college athletes) reinforces the generalizability of these findings.

Analysis of Motion Mechanics: The Role of the Knee and Pelvic Joints

An increase in the angular speed of the knee joint by 20.7% (from 412.6 to 498.3 °/s) and the pelvic joint by 19.6% (from 386.2 to 461.8 °/s) confirms that the muscle training program effectively increases the rate of lower chain kinetic extension. The angular speed of the knee joint which is the strongest correlation of kick speed (r = 0.824, p = 0.000) is consistent with a systematic review by Vagner et al. (2023) in PMC which reported that knee angular speed is the most reliable predictor of kick speed and impact force in martial arts. This mechanism can be explained through the principle of kinetic segmentation: in a circular kick such as a sickle kick, the maximum speed of the leg (end of the distal segment) is the result of the sum of the angular velocity of all proximal segments (pelvis, upper leg, lower leg), so that the increase in force in each joint synergistically amplifies the final speed (Liu et al. in Frontiers, 2024).

The 17.8% reduction in kick execution time (from 0.387 to 0.318 seconds) is a very valuable neuromuscular adaptation in the context of a match. Faster kicks provide less response

time for opponents, increase the chances of clean contact and reduce the risk of parrying. This adaptation is a combination of increased contraction speed of Type IIa fibers (which respond to plyometrics) and increased synchronization of motor units through speed exercises and technical drills integrated in each session (Sudiana et al., 2023).

Movement Consistency: An Indicator of Neuromuscular Maturityr

The increase in the movement consistency index from 72.4% to 84.6% ($p = 0.001$) is a finding that has significant clinical and competitive significance. A 72.4% consistency rate pre-intervention suggests that an average of one in three kicks has a meaningful kinematic deviation from the optimal pattern, a variability that can be exploited by experienced opponents. Post-intervention, a consistency of 84.6% indicated that the athlete was able to reproduce the optimal kick pattern on more than 8 out of 10 attempts, a level of reliability that was close to the standard of international elite athletes.

The positive correlation between the consistency index and kick speed ($r = 0.634$, $p = 0.000$) confirms the findings of Vagner et al. (2023) that elite athletes exhibit lower intertrail variability as well as higher speed indicating that consistency and speed are not tradeoffs, but rather develop in tandem as a manifestation of the maturity of a more accurate internal motor representation (internal model). Plyometric exercises and repetitive kick drills in this research program play a dual role: physiologically increase contraction strength, and neurocognitively refine the activation pattern of motor sequence units through the mechanism of exercise specificity (Sudirman et al., 2024; Markovic & Mikulic, 2010).

CONCLUSIONS AND SUGGESTIONS

Conclusion

Based on the results of the research and discussion, seven main conclusions can be drawn: (1) A combination muscle training program (plyometric + progressive resistance) for 8 weeks significantly increased the kick speed of South Sulawesi pencak silat athletes by 20.8% (7.84 → 9.47 m/s; $p = 0.000$); (2) The angular speed of the knee joint increased by 20.7% and the pelvic joint by 19.6%, confirming the role of the lower kinetic chain as the dominant speed generator in kicks; (3) The peak impact force of the kick increased significantly by 23.0% (1,247 → 1,534 N; $p = 0.000$), which has direct relevance to the effectiveness of the attack in the match; (4) Kick execution time decreased by 17.8% (0.387 → 0.318 seconds), indicating neuromuscular adaptation that increased the speed of kick deployment; (5) The movement consistency index increased significantly from 72.4% to 84.6% ($p = 0.001$), reflecting the maturity of a more accurate representation of the internal motor; (6) Leg muscle strength was strongly and significantly correlated with kick speed ($r = 0.748$) and impact force ($r = 0.712$); and (7) The sickle kick recorded the highest speed increase (22.6%), while the side kick produced the highest impact force (1,612 N) post-intervention.

Suggestions

Based on the findings of the study, it is recommended: (1) PELATDA Pencak Silat South Sulawesi is recommended to adopt a combination muscle training program (plyometric + progressive resistance) as a mandatory component in the annual periodization cycle, especially in the preparation phase ahead of the PON and the national championship; (2) Coaches are advised to integrate Kinovea's software-based kinematic analysis as a routine evaluation tool (every 4 weeks) to quantitatively monitor the development of kick biomechanics and the consistency of athletes' movements; (3) Resistance training programs should begin with a 1RM measurement for each athlete so that the intensity of the load can be personalized, avoiding counterproductive under-loading and over-loading; (4) Follow-up research with a randomized controlled trial (RCT) design with active control groups and 3D motion capture measurements will provide stronger evidence of causality; and (5) A study on the impact of muscle training on the kick performance of South Sulawesi female pencak silat athletes is highly recommended as an expansion of the research needed considering the limitations of this study which only examines male athletes.

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