https://journal.mutiarahatimoeslem.id/index.php/cores/index
P-ISSN: XXX-XXX E-ISSN: XXX-XXX (Vol. 1 No. 1) 2025
DOI: 10.64131/cores.v1i1.69
Research Article

PLYOMETRIC MODERATE-VOLUME: EFFECT OF BOUNCE DROP JUMP IN DEVELOPING LOWER LIMB POWER OF VOLLEYBALL ATHLETES

Emi Septiani[1]Agus Sulastio[2], Syaifuddin Ali[4]

[12] Physical Education, University of Riau, Indonesia
[3] Physical Education, University of Jakarta, Indonesia

Email author corresponding: emi.septiani1273@student.unri.ac.id

Abstract

Background: Explosive lower limb power is a critical physical component for volleyball performance, particularly in actions requiring repeated vertical jumps such as spiking and blocking. **Aims:** This study aimed to analyze the effects of moderate-volume bounce drop jump training on the improvement of lower limb muscle power in girls volleyball athletes. **Methods:** The study employed an experimental one-group pretest–posttest design involving 14 athletes selected through purposive sampling. Lower limb muscle power was assessed using the vertical jump test. The bounce drop jump training intervention was conducted over 16 sessions, with three sessions per week, applying moderate-volume principles and rest intervals of 3–5 minutes between sets. Data analysis included the Kolmogorov–Smirnov normality test and a paired sample t-test at a significance level of $\alpha = 0.05$. **Result:** The results demonstrated a substantial improvement in vertical jump performance, with mean values increasing from 30.29 cm (pretest) to 41.36 cm (posttest). Isokinetic analysis revealed significant post-intervention increases in absolute peak torque (APT) and average peak torque (AVPT) at both 60°/s and 120°/s ($p < 0.05$). Relative peak torque (RPT) also increased, particularly at 120°/s, reflecting improved force output relative to body mass. Furthermore, reductions in time to peak torque (TPT) suggesting faster force generation and improved neuromuscular efficiency. The normality test indicated that the data were normally distributed. Furthermore, the paired sample t-test revealed a significant difference between pretest and posttest scores ($t = 4.712$; $df = 13$; $p < 0.001$). **Conclusion:** These findings confirm that moderate-volume bounce-drop-jump training significantly enhances lower-limb muscle power in volleyball athletes.

Keywords: *Plyometric, Bounce Drop Jump Moderate Volume, Limb Power, Volleyball*

Introduction

Background of the study: Among the defining characteristics of team sports, volleyball is distinguished by its high demands for explosive locomotor and neuromuscular activities, particularly in the form of repeated vertical jumps during rallies (Barlian & Anpolu, 2021; Jariono et al., 2024). Actions such as spiking, blocking, and jump serving require the ability to generate maximal force within a very short time frame, making lower limb muscle power a critical determinant of performance (Hanafi et al, 2025; Setia Budi, 2021). Therefore, well-developed explosive power capacity is a fundamental prerequisite for volleyball athletes to compete effectively at high levels of game intensity. A growing body of research indicates that physical attributes related to power and jumping ability are significantly associated with performance demands in volleyball matches (Kurnia et al., 2022; Kardiyanto et al, 2022). Athletes with lower levels of lower limb muscle power tend to experience declines in jump height, movement speed, and overall jumping efficiency, especially during phases of play that involve high repetition and intensity (Gaweł et al., 2025; Pinheiro et al., 2020). In contrast, athletes with superior lower-limb

https://journal.mutiarahatimoeslem.id/index.php/cores/index
P-ISSN: XXX-XXX E-ISSN: XXX-XXX (Vol. 1 No. 1) 2025
DOI: 10.64131/cores.v1i1.69
Research Article

power are better able to maintain consistent and effective jumping performance throughout a match, thereby contributing directly to both offensive and defensive success (Adhi et al., 2017; Tirtayasa et al., 2020; Wiratama, 2021).

From a physical conditioning perspective, plyometric training, particularly bounce-drop-jump exercises, is considered a highly relevant method for enhancing lower-limb power because it effectively stimulates the stretch-shortening cycle (Donald A. Chu et al, 2013; Ebben et al., 2024). However, the regulation of training volume remains a critical factor in achieving optimal neuromuscular adaptations while minimising the risk of excessive fatigue and injury. Accordingly, implementing moderate-volume bounce-drop-jump training is a promising and sustainable approach to improving lower-limb muscle power in volleyball athletes (Byrne et al., 2018; Moir et al., 2023; Montoro-Bombú et al., 2023).

Strength and power are fundamental components of physical fitness for volleyball athletes, given their decisive role in sport-specific actions such as repeated vertical jumping, spiking, blocking, jump serving, and rapid explosive movements during rallies (Andrew C. Fry et al., 2025; Petridis et al., 2021). In volleyball, the ability to generate maximal force within a very short time frame is a key determinant of performance, positioning lower limb muscle power as a critical factor influencing competitive success (Dalrymple et al., 2022; Makaruk et al., 2024). Accumulating evidence indicates that lower limb power and jumping capacity are strongly associated with match performance in volleyball (Dallas et al., 2023; Pembayun et al., 2018). Athletes with insufficient lower limb power tend to experience reductions in jump height, movement velocity, and overall jumping efficiency, particularly under conditions of high repetition and match intensity (Grous, 2021; Neill et al., 2025; Ruskin et al, 2021). In contrast, athletes with superior lower-limb power are better able to sustain explosive, stable jumping performance throughout a match, thereby providing a clear competitive advantage in both offensive and defensive phases of play (Adila et al., 2023; Alan Alfiansyah et al., 2020; Kasandrawali, 2022).

From a neuromuscular perspective, lower-limb power in volleyball athletes is primarily influenced by the concentric and eccentric strength capacities of the primary lower-limb muscles, especially the knee and hip extensors and flexors (Du et al., 2025; Gao et al., 2025; P. Wang et al., 2025). Eccentric strength plays a crucial role in landing control and deceleration following jumps, whereas concentric strength directly contributes to the propulsion phase that determines jump height and explosiveness (J. Wang et al., 2025; Yeşilyurt et al., 2025). Plyometric training is widely recognised as an effective conditioning strategy for improving lower-limb power by optimising the stretch–shortening cycle (Pedley et al., 2021; Tumkur AK et al., 2021). However, training volume regulation remains a critical issue, as excessive plyometric loading may lead to neuromuscular fatigue and increased injury risk.

Although plyometric training is effective for developing power and explosive performance, applying plyometrics with uncontrolled volume or intensity may increase the risk of injury while reducing the effectiveness of neuromuscular adaptations (Davies et al., 2021; Xu et al., 2025). Within the framework of neuromechanical development, bounce-drop-jump training is regarded as a specific form of plyometric exercise because it emphasises the ability to rapidly and efficiently direct and utilise ground reaction forces (Falch et al., 2020; Ramirez-Campillo et al., 2020). This exercise promotes optimal neuromuscular responses by rapidly transitioning between eccentric and concentric phases, making it highly relevant for developing explosive power (Lin et al., 2025). Compared with more generalised plyometric exercises, bounce drop jump allows for greater control over movement patterns and the mechanical loads imposed on the body (Dallas et al., 2023; Montoro-Bombú et al., 2023). The implementation of bounce drop jump training with moderate

CORES Coaching Research & Sport Education Studies
https://journal.mutiarahatimoeslem.id/index.php/cores/index
P-ISSN: XXX-XXX E-ISSN: XXX-XXX (Vol. 1 No. 1) 2025
DOI: 10.64131/cores.v1i1.69
Research Article

volume provides a balance between training demands and recovery capacity, thereby enabling progressive and sustainable neuromuscular adaptations (Byrne et al., 2018; Makaruk et al., 2024). This approach not only supports improvements in lower limb muscle power but also contributes to movement efficiency and long-term physical readiness. Accordingly, moderate-volume bounce-drop-jump training can be considered an effective and safe plyometric strategy within power-oriented physical conditioning programs.

Literature review: Plyometric training has been extensively investigated as an effective method for enhancing lower-limb explosive power, owing to its emphasis on rapid stretch–shortening cycle (SSC) actions, which contribute to improved neuromuscular function and the ability to generate force rapidly. (Deng, Yan, et al., 2025) A meta-analysis involving 70 randomised controlled trials with a total of 1,703 trained adult participants reported that plyometric training produced significant positive effects on multiple components of physical performance, including maximal lower-limb strength, reactive strength index (RSI), countermovement jump, and squat jump performance, compared with conventional training or no specific intervention. These findings were further supported by another meta-analysis encompassing 25 studies (19 jump outcomes, 11 sprint outcomes, and 7 lower-limb strength outcomes), which demonstrated that 4–12 weeks of plyometric training resulted in statistically significant performance improvements. The standardized mean difference (SMD) values indicated increases in jump height (SMD = 0.45; 95% CI: 0.16–0.75), reductions in sprint time (SMD = −0.59; 95% CI: −1.01 to −0.17), and improvements in lower-limb strength (SMD = 0.33; 95% CI: 0.03–0.63). This quantitative evidence confirms the consistency of the positive effects of plyometric training on explosive performance in healthy adult populations. (Deng, Li, et al., 2025; Lin et al., 2025) Individual experimental studies also support these findings. For example, a six-week plyometric training program involving 40 male sprinters with a mean age of approximately 20 years demonstrated a highly significant increase in lower-limb power, with mean squat jump power improving by 28.5% ($p < 0.001$). This improvement was accompanied by significant reductions in 30-m sprint time compared with a control group. Similarly, a six-week depth jump training program conducted with 22 male basketball players (mean age 19 years) resulted in significant improvements in lower-limb power, with vertical jump power increasing from 54.05 ± 5.00 to 58.32 ± 4.17 units, corresponding to an approximate 9.56% improvement ($p = 0.00$). In addition, a 27.88% reduction in creatine phosphokinase (CPK) levels was observed, indicating improved muscular adaptation and reduced exercise-induced muscle damage. (Du et al., 2025; J. Wang et al., 2025) Comparable results were reported in a quasi-experimental study involving 15 volleyball athletes, in which plyometric training led to a significant increase in vertical jump performance. Mean jump height increased from 24.53 cm pre-intervention to 29.27 cm post-intervention ($p < 0.05$), with a Cohen's d effect size of 2.43, classified as a large effect. Collectively, these findings further reinforce that plyometric training consistently enhances neuromuscular output and lower-limb power in athletic populations. Although the majority of the literature emphasises the benefits of plyometric training, details in program design, particularly training volume and intensity, are critical determinants of its effectiveness. Several studies indicate that moderate training volumes elicit more optimal performance adaptations than high training volumes. For instance, Villarreal et al. reported that a seven-week drop-jump protocol with approximately 120 jumps per week produced greater improvements in sprint performance and reactive strength than a high-volume protocol with approximately 240 jumps per week. These findings suggest that excessive training volume may diminish the effectiveness of the training stimulus. Therefore, further research is needed to clarify the dose–response relationship in plyometric training, particularly to support moderate-volume

https://journal.mutiarahatimoeslem.id/index.php/cores/index
P-ISSN: XXX-XXX E-ISSN: XXX-XXX (Vol. 1 No. 1) 2025
DOI: 10.64131/cores.v1i1.69
Research Article

approaches that are more practical, safe, and sustainable for physical conditioning programs.

Gap analysis: Numerous studies have demonstrated that plyometric training improves lower-limb muscle power in athletes in team sports. However, most previous studies have remained general in nature, focusing on plyometric training as a broad category without specifically examining particular exercise types such as the bounce drop jump, which has distinctive characteristics in activating the stretch–shortening cycle (SSC) and is highly relevant to the jumping demands of volleyball. In addition, earlier research has often assumed that increasing plyometric training volume leads to greater performance improvements. More recent findings, however, suggest that excessive training volume may induce neuromuscular fatigue and reduce the effectiveness of training adaptations. Despite this evidence, empirical studies that specifically investigate the effects of bounce drop jump training with moderate volume on lower limb muscle power remain limited, particularly among volleyball athletes whose performance relies heavily on explosive vertical movements such as spiking and blocking. Moreover, a large proportion of plyometric training research has been conducted on soccer players or athletes from other team sports, while studies focusing specifically on volleyball club athletes under controlled training conditions are still scarce. This is a critical limitation, as differences in biomechanical demands across sports may lead to different adaptive responses to plyometric training. Therefore, a clear research gap exists regarding the effectiveness of moderate-volume bounce drop jump training as a safe, efficient, and sport-specific method for enhancing lower limb muscle power in volleyball club athletes. This study seeks to address this gap by providing empirical evidence on the impact of moderate-volume bounce drop jump training on lower limb muscle power, thereby contributing to evidence-based plyometric training program design for volleyball performance development.

Rationale of the study: Plyometric training has been widely validated, and numerous research findings indicate that training outcomes are not determined solely by the type of exercise employed, but are also strongly influenced by training volume. Excessive plyometric training volume may lead to the accumulation of neuromuscular fatigue, increase the risk of injury, and reduce the effectiveness of performance adaptations, particularly in athletes with high jump frequencies such as volleyball players. In contrast, moderate training volumes have been shown to elicit more optimal physiological adaptations while maintaining training safety and sustainability. Nevertheless, empirical studies specifically examining bounce-drop-jump training with moderate volume remain relatively limited, especially among club-level volleyball athletes.

Purpose or Hypotheses of the study: The purpose of this study was to determine the effect of moderate-volume bounce drop jump training on lower limb muscle power in volleyball club athletes, as an explosive performance component that is essential for jumping and attacking actions in volleyball.

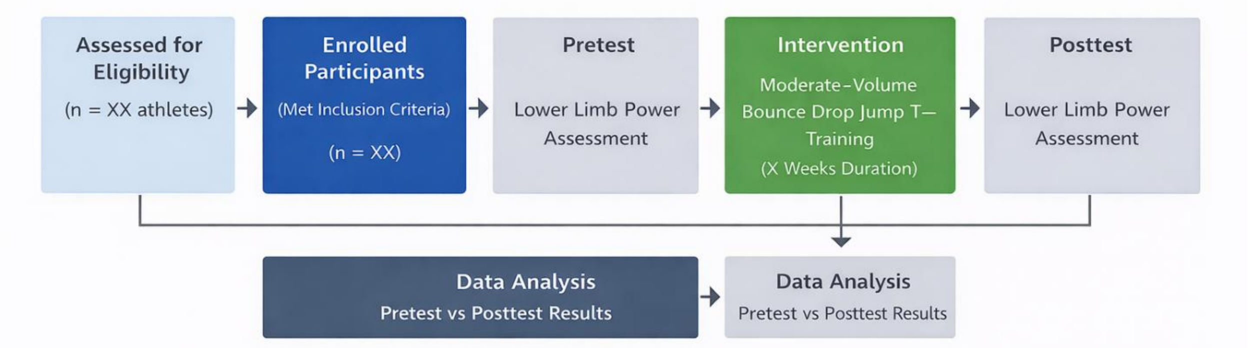
Material & Methods

Research Design: This study was reported in accordance with the principles of the CONSORT statement, adapted for non-randomized and quasi-experimental intervention studies (Krass, 2016). The research employed a one-group pretest–posttest design to evaluate the effects of a moderate-volume bounce-drop-jump training program on lower-limb muscle power in volleyball club athletes (Beni Ahmad Saebani, 2024). Participants were recruited using purposive sampling based on predefined inclusion criteria. All eligible athletes received the same intervention, and outcome measurements were conducted before and after the training program to assess changes attributable to the intervention. All experimental procedures were conducted in accordance with the ethical

CORES Coaching Research & Sport Education Studies
https://journal.mutiarahatimoeslem.id/index.php/cores/index
P-ISSN: XXX-XXX E-ISSN: XXX-XXX (Vol. 1 No. 1) 2025
DOI: 10.64131/cores.v1i1.69
Research Article

standards of human research and the principles outlined in the Declaration of Helsinki. Prior to participation, all athletes were informed about the study objectives, procedures, potential risks, and benefits, and written informed consent was obtained. No changes to the study design or intervention protocol were made after the study commenced. Due to the nature of the study design, randomization and allocation concealment were not applied. However, standardised training protocols, consistent testing procedures, and controlled training conditions were implemented to minimise bias and enhance internal validity.

Figure 1. Research Employed A Single-Group Quasi-Experimental Design



Participant: The study population consisted of all 95 volleyball athletes registered at volleyball Club girls. From this population, 84 athletes were selected as the research sample using a purposive sampling technique, based on predefined inclusion criteria, namely female gender, active participation in regular training sessions, and adequate mastery of fundamental volleyball techniques.

Table 1. Eligibility Criteria Based on the PICOS Framework

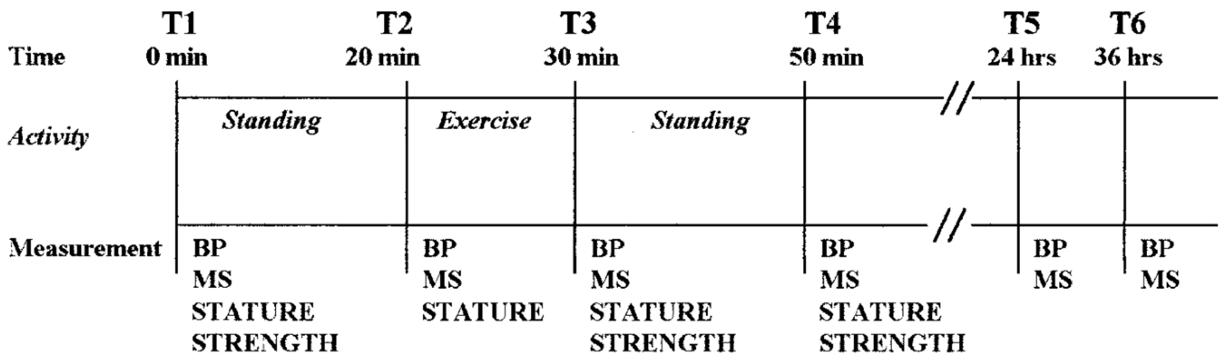
Component	Inclusion Criteria	Exclusion Criteria
Population	Female volleyball athletes registered in Volleyball Club city Pekanbaru, who actively participate in the club's regular training program.	Athletes from outside Volleyball Club in the city Pekanbaru, male athletes, and athletes who do not regularly attend training sessions.
Intervention	A structured and systematic moderate-volume bounce drop jump training program was administered throughout the intervention period.	Athletes engaged in additional training programs outside the study protocol (e.g., intensive resistance training or other plyometric programs).
Comparator	Comparison between pre-intervention (pretest) and post-intervention (posttest) outcomes within the same group.	No between-group comparison, as the study did not include a control group.
Outcome	Lower-limb muscle power, assessed using a valid and reliable physical performance test before and after the intervention.	Outcomes other than lower-limb muscle power; incomplete or missing pretest or posttest data.

https://journal.mutiarahatimoeslem.id/index.php/cores/index
P-ISSN: XXX-XXX E-ISSN: XXX-XXX (Vol. 1 No. 1) 2025
DOI: 10.64131/cores.v1i1.69
Research Article

Study Design	Experimental study using a one-group pretest–posttest design with purposive sampling.	Observational studies, non-experimental designs, or randomized controlled trials with control groups.

Instrument: The instrument used in this study was the vertical jump test to assess lower-limb muscular power. This test demonstrates high criterion validity, with reported correlation coefficients ranging from r = 0.78 to 0.92 when compared with force plate–based measurements and other established lower-body power assessments. Furthermore, the vertical jump test exhibits excellent reliability, as evidenced by test–retest reliability coefficients between r = 0.93 and 0.98 and an intraclass correlation coefficient (ICC) exceeding 0.90, indicating highly consistent and reproducible measurements.
Procedures: Data collection was conducted through three main stages: pretest, intervention, and posttest. During the pretest phase, all athletes performed the vertical jump test to determine baseline lower-limb muscular power. Subsequently, participants underwent a moderate-volume bounce-drop jump training program conducted over 16 training sessions, with three sessions per week. The training protocol was designed according to the stretch–shortening cycle (SSC) principle, with an intensity of 60–80%, consisting of 10–15 sets, 3–5 repetitions per set, and 3–5 minutes of rest between sets. This training configuration was intended to optimize neuromuscular adaptations and explosive power development while minimizing excessive fatigue.
Analysis plan: Data were analyzed using inferential statistics. Prior to hypothesis testing, the Kolmogorov–Smirnov normality test was conducted to examine whether the pretest and posttest data were normally distributed. Subsequently, a paired-samples t-test was used to assess the effect of moderate-volume bounce-drop jump training on lower-limb muscular power. Statistical analyses were performed at a significance level of $\alpha = 0.05$. A result was considered statistically significant when $p < 0.05$, whereas $p \geq 0.05$ indicated no significant effect.

Figure 2. Schematic diagram showing the organization of activity and measurement times.



Results

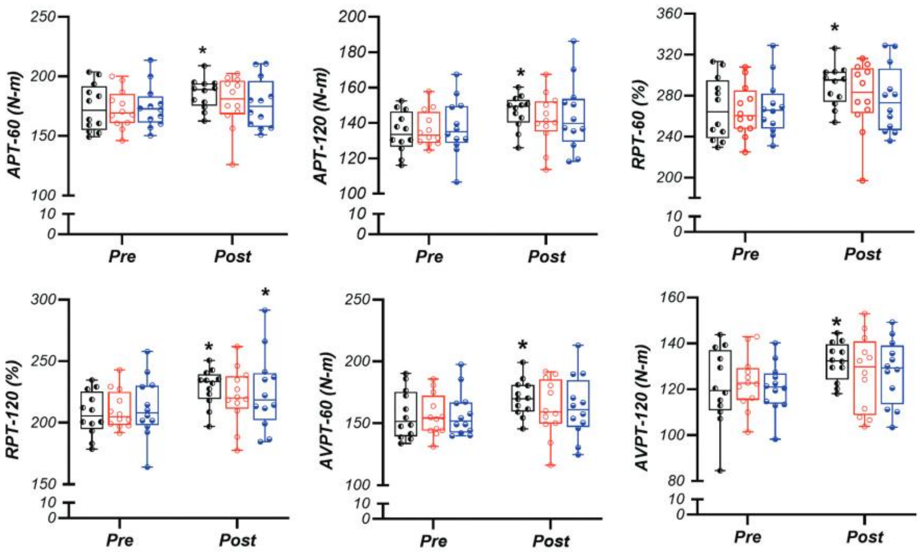
Results: Before the intervention, all participants completed a pretest to assess baseline lower-limb power using the vertical jump test. Participants then undertook an 8-week moderate-volume bounce drop jump training program, conducted three sessions per week, designed according to the overload principle while ensuring sufficient recovery to prevent overtraining. Following the intervention, a posttest using the same vertical jump protocol was administered. Data were

https://journal.mutiarahatimoeslem.id/index.php/cores/index
P-ISSN: XXX-XXX E-ISSN: XXX-XXX (Vol. 1 No. 1) 2025
DOI: 10.64131/cores.v1i1.69
Research Article

analyzed using inferential statistics with SPSS. Before hypothesis testing, data normality was examined using the Kolmogorov–Smirnov test. The effect of the training program was evaluated using a paired-sample t-test with a significance level set at $p < 0.05$.

1. Analized Pretes and Postest Volume Moderat Bounce Drop Jump Training Program

Figure 3. Descrip Parameter t 60°/s and 120°/s. APT



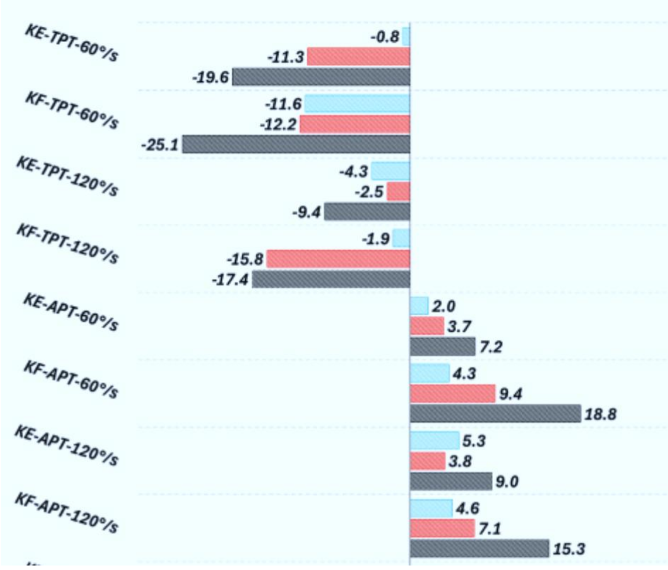
The isokinetic strength parameters of the knee extensors measured at angular velocities of 60°/s and 120°/s demonstrated clear improvements following the intervention period. For consistency and ease of comparison, pretest and posttest values were presented together, allowing direct observation of within-group changes across all measured variables. At 60°/s, a significant increase in absolute peak torque (APT-60) was observed following the intervention ($p < 0.05$), indicating enhanced maximal force-producing capacity of the knee extensors. A similar pattern was found for average peak torque (AVPT-60), suggesting not only greater peak force but also improved torque sustainability throughout the movement range. Although relative peak torque (RPT-60) showed an upward trend post-intervention, the change was more pronounced in participants exposed to plyometric-based training protocols.

At the higher velocity of 120°/s, posttest values showed significant improvements in APT-120 and AVPT-120 ($p < 0.05$), indicating enhanced neuromuscular efficiency and force production during high-speed contractions. Furthermore, relative peak torque (RPT-120) increased significantly from pretest to posttest, indicating improved force output relative to body mass, a critical determinant of performance in explosive sports such as volleyball. Across both testing velocities, reductions in time to peak torque (TPT) were evident in the posttest phase, suggesting faster force generation and improved motor unit recruitment dynamics. Additionally, rate of force development (RFD) exhibited meaningful post-intervention increases, highlighting an enhanced ability to generate force rapidly a key adaptation associated with plyometric-based training stimuli. Overall, the combined presentation of pretest and posttest data illustrates a consistent and systematic enhancement of isokinetic knee extensor strength parameters, particularly in torque-related and explosive force variables. These findings confirm that the applied training stimulus

CORES Coaching Research & Sport Education Studies
https://journal.mutiarahatimoeslem.id/index.php/cores/index
P-ISSN: XXX-XXX E-ISSN: XXX-XXX (Vol. 1 No. 1) 2025
DOI: 10.64131/cores.v1i1.69
Research Article

elicited significant neuromuscular adaptations, optimizing both maximal strength and rapid force production capabilities.

Figure 4. Pre-Test And Post-Test Performance in Groups Vertical Jump



2. Normality Testing Using a Hypothesis Test

Normality testing was conducted on the pretest and posttest data using the Kolmogorov–Smirnov test at a significance level of $\alpha = 0.05$. The Kolmogorov–Smirnov test statistics yielded values of 0.147 for the pretest data and 0.188 for the posttest data. The corresponding significance values (Asymp. Sig. 2-tailed) were 0.200 and 0.197, respectively, both of which exceeded the significance threshold of $\alpha = 0.05$. Based on the decision criteria, both the pretest and posttest data demonstrated significance values greater than 0.05, indicating that the residuals in this study were normally distributed.

Based on the results of the Paired Sample t-test, the mean difference between the pretest and posttest scores was −11.071, with a standard deviation of 8.792 and a standard error of the mean of 2.350. The 95% confidence interval of the difference ranged from −16.148 to −5.995, indicating a substantial difference between the pre-intervention and post-intervention measurements. The t-test yielded a calculated t value of 4.712 with 13 degrees of freedom (df = 13) and a two-tailed significance value (Sig. 2-tailed) of 0.000, which was lower than the significance level of $\alpha = 0.05$. These results indicate a statistically significant difference between the pretest and posttest outcomes. This finding demonstrates that the implemented training program was effective in improving lower limb explosive power, which plays a critical role in jump performance during spiking and blocking actions in volleyball.

Discussion

Bounce drop jump training is one form of plyometric exercise that utilizes the stretch–shortening cycle (SSC) mechanism. This mechanism enables muscles to generate greater force through the utilization of elastic energy during rapid eccentric and concentric phases. Several previous studies have demonstrated that plyometric training can significantly enhance lower limb explosive power

P-ISSN: XXX-XXX E-ISSN: XXX-XXX (Vol. 1 No. 1) 2025
DOI: 10.64131/cores.v1i1.69
Research Article

due to improvements in neuromuscular coordination, muscle contraction velocity, and the efficiency of elastic energy utilization. The findings of the present study are consistent with this theoretical framework, as the observed increase in posttest scores indicates that physiological and neuromuscular adaptations occurred following the completion of the entire training program. The application of a moderate training volume played an important role in maintaining the effectiveness of the program without inducing excessive fatigue or increasing the risk of injury. A moderate volume characterized by 60–80% intensity, controlled repetitions, and adequate rest intervals allowed athletes to perform each repetition with maximal effort. Consequently, the training not only enhanced muscle strength but also improved the athletes' ability to optimize elastic energy utilization and propulsive speed during jumping movements.

Table 2. Evidence From The Literature

Source	Design	Sample	Type of Plyometric Training	Performance Variables	Duration	Intensity & Volume
(Krzysztof Mackala & Marek Fostiak, 2015)	Randomized controlled trials	Mean age: 22.02 years	**Low intensity:** side-to-side ankle hops, standing jump and reach, front cone hops, diagonal cone hops. **Moderate intensity:** lateral jump over barrier, double-leg hops, standing long jump with lateral sprint. **High intensity:** single-leg bounding, lateral single-leg jumps	Physical fitness (aerobic capacity, body composition, flexibility)	6 weeks / 2 sessions per week	Volume: 80–100 jumps (80–100–110–100–100); low to high intensity
(Agusta Simanjuntak et al., 2021)	Randomized controlled trials	Mean age: 17.49 years	**Moderate intensity:** side-to-side ankle hops, front cone hops, stair exercises (40–50 cm). **High intensity:** divided box and hurdles, double-leg hops with force stop, stair exercises (50–60 cm)	Lower limb power and strength, flexibility, speed, long jump	8 weeks / 3 sessions per week	Volume: 80–120 jumps; moderate to high intensity
(Ramirez-Campillo et al., 2018)	Randomized controlled trials	Mean age: 16.89 years	**Moderate volume:** 60 drop jumps/session. **High volume:** 120 drop jumps/session from 20–60 cm boxes	Drop jump, squat jump, countermovement jump, 20 m sprint	7 weeks / 2 sessions per week, 48 h rest	Moderate volume (780 total jumps) and high volume (1,560 total jumps); high intensity
(Ramirez-Campillo et al., 2020)	Randomized controlled trials	Mean age: 22.1 years	**High-intensity:** drop jump (60 drop jumps/session from 20–60 cm boxes)	Drop jump, countermovement jump with arm swing, 20 m sprint, aerobic endurance	6 weeks / 2 sessions per week	Moderate volume (720 total jumps); high intensity
(Chelly et al., 2015)	Randomized controlled trials	Mean age: 14 years	Hurdle jumps and depth jumps	Squat jump, countermovement jump, drop jump, MB5, 40 m sprint	10 weeks	Volume: 40–100 jumps; high intensity
(Maciejczyk et al., 2021)	Non-randomized studies	Mean age: 18.07 years	**High-intensity:** plyometric program (squat jump, countermovement jump, horizontal jump)	Squat jump, standing long jump, standing triple jump, countermovement jump, 60 m sprint, 20 m flying sprint	2 weeks / 3 sessions per week	Volume: 180–255 jumps; high intensity
(Papadakis et al., 2025)	Randomized controlled trials	Mean age: 28.7 years	Weighted static jumps and countermovement jumps with light to heavy loads	Vertical jump, static jump, countermovement jump	8 weeks / 3 sessions per week	Volume: 180–255 jumps; high intensity
(El-Ashker	Randomized	Mean	Dot drill, double-leg jumps, depth	30 m sprint,	8 weeks / 3	Volume: 72–

CORES Coaching Research & Sport Education Studies

https://journal.mutiarahatimoeslem.id/index.php/cores/index
P-ISSN: XXX-XXX E-ISSN: XXX-XXX (Vol. 1 No. 1) 2025
DOI: 10.64131/cores.v1i1.69

Research Article

et al., 2019)	controlled trials	age: 18.24 years	jumps, hurdle hops, box jumps, zig-zag hops	vertical jump, 20 m flying sprint, long jump	sessions per week	120 jumps; moderate to high intensity

The significant improvement in vertical jump performance observed after the moderate-volume bounce drop jump intervention indicates a meaningful enhancement in lower-limb explosive power. This finding suggests that the applied training stimulus was sufficient to induce positive neuromuscular adaptations without imposing excessive mechanical or metabolic stress on the athletes. Given that vertical jump height is widely accepted as a valid indicator of lower-limb power, the observed post-intervention gains provide strong empirical support for the effectiveness of moderate-volume plyometric training in volleyball athletes.

In addition to SSC optimization, the observed performance gains are likely associated with improvements in the rate of force development (RFD). The requirement to produce maximal force in a very short time frame during bounce drop jump exercises enhances neural drive, motor unit recruitment, and firing frequency. These adaptations contribute to faster force generation, which is a key determinant of jump performance, especially when the available time for force production is limited. The increase in vertical jump height following the intervention therefore reflects not only enhanced maximal force capacity but also improved neuromuscular efficiency. Importantly, the use of a moderate training volume appears to be a critical factor in achieving these adaptations. Excessive plyometric volume has been reported to attenuate performance improvements due to accumulated fatigue, whereas moderate-volume protocols provide a more favorable balance between training stimulus and recovery. The training design employed in this study involved three sessions per week with at least 48 hours of recovery likely facilitated optimal adaptation of both SSC efficiency and RFD without inducing overtraining. This finding aligns with contemporary evidence suggesting that moderate-volume plyometric programs are more practical, safe, and sustainable for non-elite or club-level athletes.

The results of the normality test using the Kolmogorov–Smirnov test indicated that both the pretest and posttest data were normally distributed. This was evidenced by significance values of 0.200 for the pretest data and 0.197 for the posttest data, both exceeding the predetermined significance level of $\alpha = 0.05$. These findings confirm that the assumption of normality was satisfied, thereby justifying the use of parametric statistical analysis, specifically the paired sample t-test, to examine the effect of the training intervention. Meeting this assumption strengthens the statistical validity and reliability of the inferential analysis conducted in this study.

The results of the paired sample t-test revealed a statistically significant difference between the pretest and posttest measurements. The mean difference was −11.071, with a standard deviation of 8.792 and a standard error of 2.350. The 95% confidence interval ranged from −16.148 to −5.995, indicating a substantial and consistent improvement following the intervention. Furthermore, the calculated t value of 4.712 with 13 degrees of freedom (df = 13) and a two-tailed significance value of $p = 0.000$ ($p < 0.05$) demonstrates that the observed improvement in posttest scores was statistically significant. These findings confirm that the moderate-volume bounce drop jump training program was effective in enhancing lower limb explosive power, a key physical component underpinning jumping performance during spiking and blocking actions in volleyball.

The findings of this study are consistent with previous research reporting the effectiveness of plyometric training in improving vertical jump performance and lower limb power. A meta-analysis by Markovic (2007) demonstrated that plyometric training programs lasting 6–8 weeks resulted in vertical jump improvements ranging from 4% to 10%, particularly among trained

https://journal.mutiarahatimoeslem.id/index.php/cores/index
P-ISSN: XXX-XXX E-ISSN: XXX-XXX (Vol. 1 No. 1) 2025
DOI: 10.64131/cores.v1i1.69
Research Article

athletes. This aligns with the present study, in which participants were active volleyball athletes engaged in a structured training regimen.

Similarly, (Moir et al., 2023) reported that training interventions emphasizing rapid eccentric–concentric transitions significantly enhanced the rate of force development (RFD), which plays a critical role in explosive movements such as vertical jumping. Improvements in RFD are strongly associated with increased jump height, supporting the posttest gains observed in this study.

Further evidence was provided by (Ramirez-Campillo et al., 2018), who found that plyometric programs employing moderate training volumes and frequencies of two to three sessions per week led to significant improvements in jump performance without inducing excessive neuromuscular fatigue. This supports the training design adopted in the present study, which prioritized an optimal balance between training stimulus and recovery.

In volleyball-specific contexts, (Byrne et al., 2018; Makaruk et al., 2024) demonstrated that drop jump–based plyometric training significantly improved vertical jump performance in volleyball players, attributing these gains primarily to enhanced utilization of the stretch–shortening cycle (SSC). This mechanism is particularly relevant to the bounce drop jump exercises implemented in the present research.

Reported that well-structured plyometric training programs significantly increased lower limb power through improved neuromuscular coordination and SSC efficiency. Such adaptations are highly applicable to volleyball performance, where explosive force production within limited time frames is essential. Finally, (Dalrymple et al., 2022; Moir et al., 2023) highlighted a strong association between vertical jump performance and competitive volleyball skills, particularly spiking and blocking effectiveness.

Therefore, the improvements observed in this study are not only statistically significant but also practically meaningful for volleyball performance. Collectively, these findings reinforce the conclusion that moderate-volume bounce drop jump training is an effective and efficient method for enhancing lower limb explosive power. The combination of normal data distribution, strong statistical significance, and consistency with prior empirical evidence underscores the robustness of the training intervention and its practical relevance for volleyball athletes.

Conclusions

The findings of this research demonstrate that moderate-volume bounce drop jump training significantly improves lower limb explosive power in volleyball athletes, as evidenced by a meaningful difference between pretest and posttest scores based on the paired sample t-test ($t = 4.712$; $df = 13$; $p < 0.05$), indicating that this plyometric training method is effective for enhancing vertical jump performance related to spiking and blocking actions through optimized stretch–shortening cycle utilization and increased rate of force development.

Acknowledgment

The author gratefully acknowledges the contributions of all parties who provided assistance and cooperation, enabling this research to be carried out successfully.

https://journal.mutiarahatimoeslem.id/index.php/cores/index
P-ISSN: XXX-XXX E-ISSN: XXX-XXX (Vol. 1 No. 1) 2025
DOI: 10.64131/cores.v1i1.69
Research Article

Author Contribution Statement

Initial ITQ conceptualized and designed the study, supervised the research process, and revised the manuscript critically. AV conducted data collection, implemented the training intervention, and performed the statistical analysis. AS contributed to data interpretation, literature review, and manuscript drafting. All authors reviewed and approved the final version of the manuscript.

References

Adhi, B. P., Sugiharto, & Soenyoto, T. (2017). Pengaruh Latihan dan kekuatan Otot Tungkai terhadap Power Otot Tungkai. *Journal of Physical Education and Sports*, *6*(1), 7–13. https://journal.unnes.ac.id/sju/index.php/jpes/article/view/17315

Adila, F., Ittaqwa, I., Khozin, M., Fatihin, K., & Purnomo, T. J. (2023). The Effects of Interval Training on The V02max on The Basketball Players. *Journal of Coaching and Sports Science*, *2*(1), 34–40. https://doi.org/10.58524/jcss.v2i1.218

Agusta Simanjuntak, P., Silaban, Z., Adi Lamtama Silaban, P., Karunia One Jaya Gulo, J., Paulina Marpaung, P., Kurniawan, R., & Rahman Marpaung, D. (2021). The Effect of Balance Training on Body Stability in Volleyball Athletes. *Didaktik : Jurnal Ilmiah PGSD FKIP Universitas Mandiri*, *10*(3), 250–258. https://journals.humankinetics.com/view/journals/ijspp/20/7/article-p948.xml

Alan Alfiansyah Putra Karo Karo, Liliana Puspa Sari, & Ratna Dewi. (2020). Pengaruh Latihan Plyometric Terhadap Power Otot Tungkai. *Sains Olahraga : Jurnal Ilmiah Ilmu Keolahragaan*, *4*(2). http://jurnal.unimed.ac.id/2012/index.php/so

Andrew C. Fry, William J. Kraemer, Cheryl A. Weseman, Brian P. Conroy, Scott E. Gordon, Jay R. Hoffman, & Carl M. Maresh. (2025). The Effects of an Off-season Strength and Conditioning Program on Starter and Non-starter in Women's Intercollegiate Volleyball. *Journal of Sport Science Research*, *5*(4), 174–181. https://journals.lww.com/nsca-jscr/abstract/1991/11000/The_Effects_of_an_Off_season_Strength_and.1.aspx

Barlian, E., & Anpolu, D. J. (2021). *The Method of Exercise Play Has an Impact on Under Passing Ability Volleyball Players*. *35*(Icssht 2019), 72–77.

Beni Ahmad Saebani. (2024). *Metode Penelitian* (Tajul Arifin, Ed.; Revisi ke 3). www.pustakasetia.com

Byrne, P. J., Moody, J. A., Cooper, S.-M., Callanan, D., & Kinsella, S. (2018). Potentiating Response to Drop-Jump Protocols on Sprint Acceleration: Drop-Jump Volume and Intrarepetition Recovery Duration. *Journal OfStrength and Conditioning Research*, *34*(3), 717–727. https://journals.lww.com/nsca-jscr/fulltext/2020/03000/potentiating_response_to_drop_jump_protocols_on.15.aspx

Chelly, M. S., Hermassi, S., & Shephard, R. J. (2015). Effects of In-Season Short-term Plyometric Training Program on Sprint and Jump Performance of Young Male Track Athletes. *Journal of Strength and Conditioning Research*, *29*(8), 2128–2136. https://doi.org/10.1519/JSC.0000000000000860

Dallas, G., Dallas, C., Pappas, P., & Paradisis, G. (2023). Acute effect of bounce drop jump and countermovement drop jump with and without additional load on jump performance parameters and reactive strength index on young gymnasts. *Human Movement*, *24*(3), 95–105. https://doi.org/10.5114/hm.2023.125931

Dalrymple, K. J., Davis, S. E., Dwyer, G. B., & Moir, G. L. (2022). Effect Of Static And Dynamic

P-ISSN: XXX-XXX E-ISSN: XXX-XXX (Vol. 1 No. 1) 2025
DOI: 10.64131/cores.v1i1.69
Research Article

Stretching On Vertical Jump Performance In Collegiate Women Volleyball Players. *Journal OfStrength and Conditioning Research*, *24*(1), 149–155. www.nsca-jscr.org

Davies, M. J., Drury, B., Ramirez-Campillo, R., Chaabane, H., & Moran, J. (2021). Effect of Plyometric Training and Biological Maturation on Jump and Change of Direction Ability in Female Youth. *Journal of Strength and Conditioning Research*, *8*(1), 1–8. https://doi.org/10.1519/JSC.0000000000003216

Deng, B., Li, Y., Lin, G., Yan, R., He, J., Li, D., & Sun, J. (2025). Effects of lower limb biomechanical characteristics on jump performance in female volleyball players based on long Stretch–Shortening cycle movements. *Frontiers in Bioengineering and Biotechnology*, *13*. https://doi.org/10.3389/fbioe.2025.1653751

Deng, B., Yan, R., Sui, X., Lin, G., Ding, S., Li, D., & Sun, J. (2025). Effects of unilateral and bilateral complex-contrast training on lower limb strength and jump performance in collegiate female volleyball players. *PLOS One*, *20*(6), e0327237. https://doi.org/10.1371/journal.pone.0327237

Donald A. Chu, P., & Gregory D. Myer, P. (2013). *Plyometric*.

Du, H., Liu, S., Li, M., Zhao, K., Jiang, W., You, T., Wang, Z., Zou, D., Shu, J., & Liu, C. (2025). Effects of Nutritional Supplements on Explosive Lower Limb Performance in Volleyball Players: A Systematic Review and Network Meta-Analysis. *Nutrients*, *17*(23), 3702. https://doi.org/10.3390/nu17233702

Ebben, W. P., Suchomel, T. J., & Garceau, L. R. (2024). The Effect Of Plyometric Training Volume On Jumping Performance. *Https://Www.Researchgate.Net/Publication/264196806*. https://doi.org/10.13140/2.1.1551.4245

El-Ashker, S., Hassan, A., Taiar, R., & Tilp, M. (2019). Long jump training emphasizing plyometric exercises is more effective than traditional long jump training: A randomized controlled trial. *Journal of Human Sport and Exercise*, *14*(1), 215–224. https://doi.org/10.14198/jhse.2019.141.18

Falch, H. N., Rædergård, H. G., & van den Tillaar, R. (2020). Association of strength and plyometric exercises with change of direction performances. *PLOS ONE*, *15*(9), e0238580. https://doi.org/10.1371/journal.pone.0238580

Gao, Y., Yang, Y., Xian, C., & Wang, Z. (2025). Comparative study of functional training and traditional resistance training on lower-limb strength performance in male adolescent volleyball players: a randomized controlled trial. *Frontiers in Physiology*, *16*. https://doi.org/10.3389/fphys.2025.1629055

Gaweł, E., Drozd, M., Maszczyk, A., & Zając, A. (2025). Acute Effects of a Simulated Karate Bout on Muscular Strength Asymmetries of the Lower Limbs in Elite Athletes of Different Age Categories. *Applied Sciences*, *15*(2), 888. https://doi.org/10.3390/app15020888

Grous, F. (2021). *The Relationship between Limb Muscle Power and Backstroke Swimming Ability*. *1*(November), 46–51. https://doi.org/10.31314/gss.v1i2.1066

Hanafi, S., & Rahmi, S. (2025). Analysis of Overhand Serve Ability in Volleyball Game Among Female Players of BKMF Volleyball FIK UNM. *Journal RESPECS (Research Physical Education and Sport*, *7*(1), 51–57. https://doi.org/10.31949/ijsm.v7i1.12994

Jariono, G., Nurhidayat, Indarto, P., Sistiasih, V. S., Nugroho, H., & Maslikah, U. (2024). Physical Activity Training Methods to Improve the Physical Condition of Volleyball Players: A Systematic Review. *Physical Education Theory and Methodology*, *24*(1), 118–129. https://doi.org/10.17309/tmfv.2024.1.15

Kasandrawali. (2022). Pengaruh Latihan Stride Jump Crossover Dan Side Jump Sprint Terhadap

Peningkatan Power Otot Tungkai. *Gelora: Jurnal Pendidikan Olahraga dan Kesehatan IKIP Mataram*, *9*(1). http://e-journal.undikma.ac.id/index.php/gelora

Krass, I. (2016). Quasi experimental designs in pharmacist intervention research. *International Journal of Clinical Pharmacy*, *38*(3), 647–654. https://doi.org/10.1007/s11096-016-0256-y

Krzysztof Mackala, & Marek Fostiak. (2015). Acute Effects Of Plyometric Intervention-Performance Improvement And Related Changes In Sprinting Gait Variability. *J Strength Cond Res*, *29*(7), 1956–1965. www.nsca.com

Kurnia, F., Dewantara, H., Ade, G., & Raya, S. (2022). The Relationship Between Arm Muscle Strength and Lower Passing Ability in Volleyball Game (Study at Bong Volleyball Club, Pasuruan City). *Jurnal Multidisiplin Madani (MUDIMA)*, *2*(1), 359–370. https://journal.yp3a.org/index.php/mudima/index

Lin, G., Deng, B., Li, Y., Yan, R., Li, D., He, J., Zhang, X., & Sun, J. (2025). Less training, better improvement: effects of velocity-based complex training on lower-limb maximal strength and explosive performance in highly-trained volleyball athletes. *BMC Sports Science, Medicine and Rehabilitation*, *17*(1), 312. https://doi.org/10.1186/s13102-025-01364-3

Maciejczyk, M., Błyszczuk, R., Drwal, A., Nowak, B., & Strzała, M. (2021). Effects of Short-Term Plyometric Training on Agility, Jump and Repeated Sprint Performance in Female Soccer Players. *International Journal of Environmental Research and Public Health*, *18*(5), 2274. https://doi.org/10.3390/ijerph18052274

Makaruk, H., Winchester, J. B., Czaplicki, A., Sacewicz, T., Zielin, J., Sadowski, J., Chiu, L., & Sheppard Surfing Australia, J. (2024). Effects of Assisted and Traditional Drop Jumps on Jumping Performance. *International Journal of Sports Science & Coaching*, *9*(5). https://journals.sagepub.com/doi/abs/10.1260/1747-9541.9.5.1217

Moir, G. L., Mergy, D., Witmer, C. A., & Davis, S. E. (2023). The Acute Effects Of Manipulating Volume And Load Of Back Squats On Countermovement Vertical Jump Performance. *Journal of Strength and Conditioning Research*, *25*(6), 1486–1491. www.nsca-jscr.org

Montoro-Bombú, R., Sarmento, H., Buzzichelli, C., Moura, N. A., Gonzáles Badillo, J. J., Santos, A., & Rama, L. (2023). Methodological considerations for determining the volume and intensity of drop jump training. A systematic, critical and prepositive review. *Frontiers in Physiology*, *14*. https://doi.org/10.3389/fphys.2023.1181781

Neill, M. G., Galarneau, J.-M., Kolstad, A. T., Cairns, J., Jordan, M., Smirl, J. D., & Emery, C. A. (2025). Age, power, and sport-related concussion. Is there a tension between sport performance and concussion risk in tackle football? *Journal of Sports Sciences*, *43*(21), 2622–2630. https://doi.org/10.1080/02640414.2025.2548710

Papadakis, Z., Panoutsakopoulos, V., Schwarz, A., & Antonio, J. (2025). Caffeine's influence on vertical jump height: a real-life collegiate student-athlete approach. *Journal of the International Society of Sports Nutrition*, *22*(1). https://doi.org/10.1080/15502783.2025.2501063

Pedley, J. S., DiCesare, C. A., Lloyd, R. S., Oliver, J. L., Ford, K. R., Hewett, T. E., & Myer, G. D. (2021). Maturity alters drop vertical jump landing force-time profiles but not performance outcomes in adolescent females. *Scandinavian Journal of Medicine & Science in Sports*, *31*(11), 2055–2063. https://doi.org/10.1111/sms.14025

Pembayun, D. L., Wiriawan, O., & Setijono, H. (2018). Pengaruh Latihan Jump To Box, Depth Jump dan Single Leg Depth Jump Terhadap Peningkatan Kekuatan Otot Tungkai dan Power Otot Tungkai. *Jurnal SPORTIF : Jurnal Penelitian Pembelajaran*, *4*(1), 87. https://doi.org/10.29407/js_unpgri.v4i1.12006

Petridis, L., Pálinkás, G., Tróznai, Z., Béres, B., & Utczás, K. (2021). Determining strength training needs using the force-velocity profile of elite female handball and volleyball players. *International Journal of Sports Science & Coaching*, *16*(1), 123–130. https://doi.org/10.1177/1747954120964043

Pinheiro, J. S., Monteiro, O. L. S., Pinheiro, C. A. B., Penha, L. M. B., Almeida, M. Q. G., Bassi-Dibai, D., Pires, F. D. O., Cabido, C. E. T., Fidelis-de-Paula-Gomes, C. A., & Dibai-Filho, A. V. (2020). Seated Single-Arm Shot-Put Test to Measure the Functional Performance of the Upper Limbs in Exercise Practitioners With Chronic Shoulder Pain: A Reliability Study. *Journal of Chiropractic Medicine*, *19*(3), 153–158. https://doi.org/10.1016/j.jcm.2020.01.001

Ramirez-Campillo, R., García-Pinillos, F., García-Ramos, A., Yanci, J., Gentil, P., Chaabene, H., & Granacher, U. (2018). Effects of Different Plyometric Training Frequencies on Components of Physical Fitness in Amateur Female Soccer Players. *Frontiers in Physiology*, *9*(JUL). https://doi.org/10.3389/fphys.2018.00934

Ramirez-Campillo, R., Moran, J., Chaabene, H., Granacher, U., Behm, D. G., García-Hermoso, A., & Izquierdo, M. (2020). Methodological characteristics and future directions for plyometric jump training research: A scoping review update. *Scandinavian Journal of Medicine & Science in Sports*, *30*(6), 983–997. https://doi.org/10.1111/sms.13633

Ramirez-Campillo, R., Sanchez-Sanchez, J., Romero-Moraleda, B., Yanci, J., García-Hermoso, A., & Manuel Clemente, F. (2020). Effects of plyometric jump training in female soccer player's vertical jump height: A systematic review with meta-analysis. *Journal of Sports Sciences*, *38*(13), 1475–1487. https://doi.org/10.1080/02640414.2020.1745503

Ruskin, R., & Refiater, U. H. (2021). Relationship between Leg Muscle Strength, Leg Power and Flexibility with Crawl Style Swimming Start. *Gorontalo Sport Science*, *1*(2), 69–75. https://doi.org/10.31314/gss.v1i2.1088

Setia Budi, A. (2021). Effect of Down to Wall Passing Exercises and Pairs On Volleyball Skills on Extracurricular Students at State Junior High School 13 Tanjung Jabung Timur. *Indonesian Journal of Sport Science and Coaching*, *03*(02), 45–52. https://online-journal.unja.ac.id/IJSSC/index

Tirtayasa, P. K. R., Santika, I. G. P. N. A., Subekti, M., Adiatmika, I. P. G., & Festiawan, R. (2020). Barrier Jump Training to Leg Muscle Explosive Power. *Journal of Physical Education, Sport, Health and Recreation*, *9*(3), 173–177.

Tumkur Anil Kumar, N., Oliver, J. L., Lloyd, R. S., Pedley, J. S., & Radnor, J. M. (2021). The Influence of Growth, Maturation and Resistance Training on Muscle-Tendon and Neuromuscular Adaptations: A Narrative Review. *Sports*, *9*(5), 59. https://doi.org/10.3390/sports9050059

Wang, J., Qin, Z., Zhang, Q., & Wang, J. (2025). Lower limb dynamic balance, strength, explosive power, agility, and injuries in volleyball players. *Journal of Orthopaedic Surgery and Research*, *20*(1), 211. https://doi.org/10.1186/s13018-025-05566-w

Wang, P., Qin, Z., & Zhang, M. (2025). Association between pre-season lower limb interlimb asymmetry and non-contact lower limb injuries in elite male volleyball players. *Scientific Reports*, *15*(1), 14481. https://doi.org/10.1038/s41598-025-98158-x

Whinata Kardiyanto, D., & Setiawan, E. (2022). Kekuatan Otot Bahu dan Daya Ledak Otot Lengan: Apakah Memiliki Korelasi dengan Servis Atas Sitting Volleyball. *Jurnal Patriot*, *4*(1). https://doi.org/10.24036/patriot.v%vi%i.821

Wiratama, G. A. (2021). Double Leg Speed Hop and Half Squat Jump Improve Leg Muscle Power.

https://journal.mutiarahatimoeslem.id/index.php/cores/index
P-ISSN: XXX-XXX E-ISSN: XXX-XXX (Vol. 1 No. 1) 2025
DOI: 10.64131/cores.v1i1.69

Research Article

Sport and Fitness Journal, *9*(2), 139. https://doi.org/10.24843/spj.2021.v09.i02.p07

Xu, Z., Sun, J., Gu, J., & Yu, L. (2025). Effects of 8 weeks of combined strength and plyometric training on lower limb vertical stiffness and jump performance in elite long jump athletes. *Frontiers in Physiology*, *16*. https://doi.org/10.3389/fphys.2025.1692254

Yeşilyurt, H., Çabuk, S., İnce, İ., Tortu, E., & Ulupınar, S. (2025). Limb strength asymmetries in elite academy volleyball players: impacts on performance outcomes and insights derived from principal component analysis. *BMC Sports Science, Medicine and Rehabilitation*, *17*(1), 332. https://doi.org/10.1186/s13102-025-01298-w