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Meta Analysis of the Effect of Plyometric Training on Volleyball Smash Ability

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ABSTRACT

This study aimed to systematically examine the effect of plyometric training on volleyball smash ability through a meta-analytical approach. Plyometric training has been widely applied to enhance explosive power, particularly in sports requiring vertical jumping and rapid force production, such as volleyball. However, empirical findings regarding its effectiveness on smash performance remain inconsistent. Therefore, this study employed a meta-analysis using a descriptive quantitative framework to synthesize empirical evidence and determine the magnitude of the training effect. Research data were obtained from scientific journal articles published between 2016 and 2024. A total of 50 articles were initially identified through systematic searching, of which 8 articles met the predefined inclusion criteria and were eligible for analysis. The selected studies focused on plyometric training interventions and their effects on volleyball smash performance. Data were extracted using a structured coding sheet and analyzed by calculating effect sizes using Cohen's d formula to quantify the magnitude of the intervention effects. The results of the meta-analysis indicate that plyometric training has a positive and statistically significant effect on volleyball smash ability. However, the overall mean effect size was 0.068, which is classified as a small effect. Further subgroup analysis based on educational level revealed meaningful differences in training responsiveness. University-level participants demonstrated a moderate effect size (d = 0.538), whereas high school/vocational school participants showed only a small effect (d = 0.082). These findings suggest that the effectiveness of plyometric training is influenced by factors such as physical maturity, training experience, and physiological readiness. In conclusion, plyometric training contributes positively to the enhancement of volleyball smash performance, yet its impact is limited when applied as a single training modality. Greater effectiveness may be achieved when plyometric exercises are integrated with complementary training approaches tailored to the athletes' developmental level.

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INTRODUCTION

Sports activities play a strategic role in improving the quality of human life, not only in terms of physical health but also mental and social well-being. Sports systematically contribute to increased physical fitness, endurance, emotional stability, and individual

character development (Ikhsanto & Aswara, 2023; Warburton & Bredin, 2017). In the context of competitive sports, the quality of training and the effectiveness of coaching methods are determining factors in achieving optimal athlete performance. One sport with widespread appeal and high participation rates is volleyball, both at the recreational, educational, and competitive levels.

As a team sport, volleyball demands an integration of technical, physical, tactical, and mental abilities. Each player is required to have a good mastery of basic techniques as a foundation for developing advanced skills. Fundamental volleyball techniques include serving, passing, setting, spiking (smashing), and blocking, which are interconnected to form an effective playing system (Raihanati & Wahyudi, 2021; Forthomme et al., 2019). An imbalance in mastery of basic techniques will directly impact the overall effectiveness of a team's play.

Among these techniques, the smash holds a crucial position as the primary scoring weapon. An explosive, accurate, and well-timed smash has proven to be a dominant factor in determining the outcome of a match (Irwanto, 2021; Marcelino et al., 2014). However, the effectiveness of a smash is not solely determined by mastery of the technique but also depends heavily on the athlete's physical capacity, particularly the ability to jump vertically to reach the optimal point of contact. A common problem in volleyball training, particularly at the youth and college levels, is low explosive leg muscle power, which impacts jump height and smash quality.

Several empirical reports indicate that athletes with limited leg explosive power tend to produce less effective smashes, are easily read by opponents, and have a lower chance of success (Salam & Rismayanthi, 2024; Sheppard et al., 2011). This situation emphasizes the need for a specific, systematic, and evidence-based training approach to improve the physical components supporting the smash. Therefore, identifying the most effective training method in improving volleyball smash performance is a relevant and urgent research problem that needs to be studied scientifically.

In the past decade, plyometric training has become one of the most widely used and researched approaches to developing athletes' explosive abilities, particularly in sports that require jumping and rapid movement, such as volleyball, basketball, and athletics (Markovic & Mikulic, 2010; Ramirez-Campillo et al., 2020). Plyometric training is designed to optimize the stretch-shortening cycle in muscles, enabling them to generate maximum force in a short period of time (Pomatahu, 2018; Thaqi et al., 2020).

Experimental research shows that plyometric training significantly improves vertical jump, leg muscle power, and movement speed in volleyball athletes (Haetami & Awanis, 2021; Slimani et al., 2016). Salam and Rismayanthi (2024) reported that improving vertical jump ability through plyometric training positively correlated with improved smash quality, particularly in terms of contact height and angle of attack. Similar findings were also reported by Sheppard et al. (2011) and García-de-Alcaraz et al. (2020), which confirmed that leg explosiveness is a key predictor of attack effectiveness in modern volleyball.

Furthermore, several studies have compared various plyometric methods—such as depth jumps, box jumps, bounding, and hurdle hops—in improving the physical and technical performance of volleyball athletes (Ramirez-Campillo et al., 2015; Stojanović et al., 2017). The

results indicate that training effectiveness is significantly influenced by intensity, volume, and program duration, as well as subject characteristics, such as age, gender, and performance level. However, individual study results often show significant variation in effects, making it difficult to draw strong and consistent general conclusions.

In the methodological realm, the meta-analysis approach is considered the gold standard for systematically and quantitatively synthesizing empirical findings from various primary studies (Anugraheni, 2018; Borenstein et al., 2021). Meta-analysis allows researchers to estimate more stable effect sizes, identify moderator variables, and provide stronger evidence-based recommendations for sports coaching practice.

Although the literature indicates that plyometric training has significant potential for improving the physical components supporting the volleyball smash, existing studies are still dominated by experimental studies with limited sample sizes and varying designs. This variation includes differences in intervention duration, training type, subject characteristics, and measurement instruments for smash and vertical jump performance (Slimani et al., 2016; Stojanović et al., 2017). As a result, research results often show inconsistencies in the reported effect sizes.

Furthermore, most previous meta-analyses have focused on the impact of plyometric training on vertical jump ability or muscle power in general, without specifically linking them to volleyball smash performance (Markovic & Mikulic, 2010; Ramirez-Campillo et al., 2020). Smashing is a complex skill that relies not only on jump height but also on motor coordination, timing, and force transfer to the ball. To date, no meta-analyses have comprehensively synthesized empirical evidence regarding the effect of plyometric training on volleyball smash performance as the primary variable.

The absence of this specific meta-analysis creates a significant research gap, particularly in providing a strong scientific basis for coaches and practitioners to design evidence-based training programs. Without a comprehensive quantitative synthesis, training recommendations tend to be partial and rely on individual, inconsistent findings. Therefore, a meta-analysis is needed that systematically evaluates the effectiveness of plyometric training on volleyball smashing ability, taking into account variations in study designs and characteristics.

Based on the research problems and gaps outlined, the primary objective of this study is to meta-analytically analyze the effect of plyometric training on volleyball smashing ability. Specifically, this study aims to: (1) estimate the magnitude of the effect of plyometric training on volleyball smashing performance based on the results of empirical studies over the past 10 years; (2) identify the consistency and variation of effects across studies; and (3) provide a synthesis of scientific evidence that can be used as a basis for decision-making in planning volleyball training programs.

The novelty of this research lies in its meta-analytic approach, which specifically focuses on volleyball smash performance as the primary variable, rather than simply jumping ability or general leg muscle power. By integrating empirical findings from various reputable studies, this research is expected to provide theoretical contributions to the development of sports coaching science, as well as practical contributions in the form of more targeted, effective, and evidence-based plyometric training recommendations.

METHODS

Research Design and Approach

This study employed a meta-analysis approach with a quantitative descriptive framework, aiming to statistically synthesize the results of previous empirical research on the effect of plyometric training on volleyball smashing ability. Meta-analysis was chosen because of its ability to integrate findings from various similar primary studies, resulting in more stable, objective effect estimates with higher generalizability than single studies (Borenstein et al., 2021; Schmidt & Hunter, 2015). Methodologically, meta-analysis is an advanced form of systematic research review that combines systematic literature search procedures with quantitative statistical analysis of the effect sizes of each study (Higgins et al., 2022). This approach is widely used in sports coaching science to evaluate the effectiveness of training interventions, including plyometric training, because it reduces small sample size bias and study design variation (Markovic & Mikulic, 2010; Ramirez-Campillo et al., 2020). The meta-analysis design chosen for this study was based on the high variation in research results related to plyometric training and volleyball smash performance, both in terms of program duration, training type, and subject characteristics. Therefore, meta-analysis is considered the most appropriate approach for synthesizing robust empirical evidence based on quantitative data (Anugraheni, 2018; Cooper et al., 2019).

Participants and Data Sources

The target population for this study was scientific articles published in Indonesian national journals that examined the effect of plyometric training on volleyball smash performance. Focusing on the Indonesian context was carried out to maintain the homogeneity of the research subjects' characteristics, the sports coaching system, and the relatively uniform coaching curriculum (Sugiyono, 2021). The sampling technique used purposive sampling, which involves selecting samples based on strictly and systematically established inclusion and exclusion criteria. This approach is commonly used in meta-analyses to ensure that only relevant, valid, and methodologically sound studies are analyzed further (Petticrew & Roberts, 2016; Page et al., 2021). Based on the initial identification process, 50 articles relevant to the research topic were identified. After screening and evaluating methodological quality, eight articles met all inclusion criteria and were deemed suitable for analysis in this meta-analysis. This number is considered adequate for a small- to medium-scale meta-analysis focusing on specific intervention variables in sports science (Borenstein et al., 2021).

Research Instruments

The primary instrument used in this study was a data coding sheet. A coding sheet is a standard instrument in meta-analysis, used to extract, organize, and transform raw data from primary studies into a structured, analysis-ready format (Cooper et al., 2019; Lipsey & Wilson, 2001). The data coding sheet in this study contains key information from each article, including: (1) study identity (author, year of publication, and journal); (2) characteristics of the study subjects; (3) study design and type of plyometric training intervention; (4) training duration and frequency; (5) mean and standard deviation values for the pretest and posttest, or experimental and control groups; and (6) volleyball smash performance indicators used. The use of a coding instrument aims to maintain

consistency in the data extraction process, minimize interpretation errors, and increase the reliability of quantitative data synthesis in meta-analysis (Higgins et al., 2022; Valentine et al., 2010). All codified data was then presented in tabular form to facilitate analysis and interpretation.

Data Collection Procedure

The data collection procedure was conducted through a systematic search of scientific articles using national academic digital platforms such as Garuda, SINTA, Google Scholar, and institutional journal portals. The search was conducted using relevant keywords, including plyometric training, volleyball smash, explosive power, and volleyball. The inclusion criteria used in this study included: (1) articles explicitly discussing the effect of plyometric training on volleyball smash ability; (2) articles available in full-text format; (3) research conducted in Indonesia; (4) articles published in journals accredited with at least SINTA 4; and (5) publication period between 2016 and 2024. Exclusion criteria included non-empirical review articles, studies without quantitative data that could calculate effect sizes, and articles with inadequate methodological designs. The article selection procedure was carried out in stages, starting with initial identification, title and abstract screening, full-text evaluation, and determining articles eligible for analysis. This approach is in line with the systematic literature selection guidelines recommended in modern meta-analysis research (Page et al., 2021; Moher et al., 2015).

Data Analysis Techniques

Data analysis in this study was conducted by calculating the effect size for each included study. Effect size is used as the primary indicator to quantitatively and comparatively measure the impact of plyometric training on volleyball smashing ability (Cohen, 1988; Borenstein et al., 2021). The effect size is calculated using Cohen's d formula, namely:

$$d = (M_1 - M_2) / SD\ pooled$$

The use of Cohen's d is considered appropriate because most primary studies use experimental designs with control groups or pretest–posttest designs, and present data in the form of means and standard deviations (Ellis, 2010; Lakens, 2013). Interpretation of effect size values refers to Cohen's criteria: small effect size ($0 < d \leq 0.20$), medium effect size ($0.20 < d \leq 0.50$), and large effect size ($d > 0.80$). This classification is widely used in sports research to assess the practical significance of a training intervention (Hopkins et al., 2009; Batterham & Hopkins, 2006). The results of the effect size analysis from all studies were then synthesized descriptively to illustrate the general trend of the effect of plyometric training on volleyball smash performance.

RESULTS AND DISCUSSION

Result

The analysis was conducted on various articles from national journals published according to established criteria. After a thorough evaluation of the articles, the research findings were categorized and 50 journals were identified for analysis. Through a rigorous data verification process, eight articles met the qualification standards, while 42 others did not meet the inclusion criteria.

Table 1.
Data Distribution by Unit of Analysis

Analysis Category	Educational Levels	Number of Analysis Units
Article Classification	Elementary School	-
	Junior High School	-
	Senior High School/Vocational High School	5
	University	3

Based on the distribution in the table above, there are 8 articles, 3 from tertiary education and 5 from high school/vocational school. All articles implement plyometric training methodology with volleyball smashing ability as the dependent variable.

Table 2.
Descriptive Statistics of Paired Samples

Variabel	N	Mean	Standar Deviasi
Pretest	8	117,5185	296,22607
Posttest	8	139,5363	347,51595

Based on the descriptive statistics presented in Table 2, it appears that the implementation of plyometric training improved volleyball smashing ability, with a mean value transforming from 117.5185 in the baseline condition to 139.5363 in the post-intervention condition.

Table 3.
Results of the Analysis of Plyometric Training Methods on Volleyball Smashing Ability Based on the N-Gain Test

No	Journal Code	Researchers	(*Pretest*)	(*Posttest*)	*N-Gain*	*N-Gain%*
1.	Jurnal Patriot	Dimas Anggara, Alex Aldha Yudi (2019)	4,75	3,33	0,03	3,50%
2.	Jurnal Patriot	Erik Eriyaldi, Masrun (2019)	4,88	3,37	0,04	3,54%
3.	Jurnal Patriot	Siska Madya Oktaviani, Donie (2020)	41,25	6,58	0,11	11,20%
4.	Jurnal Ilmu Keolahragaan	Zuhar Ricky (2020)	14,69	2,74	0,03	3,21%
5.	Jurnal Olahraga	Peneliti Kurniawan, Gilang Ramadan (2016)	850,00	148,97	-0,20	-19,86%
6.	Jurnal Jendela Olahraga	Zuhar Ricky (2020)	14,97	2,28	0,03	2,68%
7.	Jurnal Patriot	Yogi Arizal, Heru Syarli Lesmana (2019)	4,69	4,62	0,05	4,85%
8.	Jurnal Patriot	Saputra, Alex Aldha Yudi (2019)	4,92	4,25	0,04	4,47%

This table shows the results of the N-Gain analysis for each article studied. The majority of articles showed a positive increase with an N-Gain ranging from 0.03 to 0.11, except for one article that showed a negative value (-0.20).

Table 5.
Effect Size by Category

No	Journal Code	Researchers	Effect Size Value	Information
1.	Jurnal Patriot	Dimas Anggara, Alex Aldha Yudi (2019)	0,01	Minor Effect
2.	Jurnal Patriot	Erik Eriyaldi, Masrun (2019)	0,01	Minor Effect

3.	Jurnal Patriot	Siska Madya Oktaviani, Donie (2020)	0,02	Minor Effect
4.	Jurnal Ilmu Keolahragaan	Zuhar Ricky (2020)	0,01	Minor Effect
5.	Jurnal Olahraga	Peneliti Kurniawan, Gilang Ramadan (2016)	0,46	Moderate Effect
6.	Jurnal Jendela Olahraga	Zuhar Ricky (2020)	0,01	Minor Effect
7.	Jurnal Patriot	Yogi Arizal, Heru Syarli Lesmana (2019)	0,01	Minor Effect
8.	Jurnal Patriot	Saputra, Alex Aldha Yudi (2019)	0,01	Minor Effect
Rerata Effect Size Keseluruhan			**0,068**	**Minor Effect**

This table shows the individual effect sizes for each article. Most articles showed small effect sizes (0.01-0.02), with one article showing a medium effect size (0.46). The overall mean showed a small effect size (0.068).

Table 6.
Magnitude of Effect Size by Education Level

No	Educational Levels	Number of Articles	Effect Size	Interpretation
1.	Elementary School	-	-	-
2.	Junior High School	-	-	-
3.	Senior High School/Vocational High School	5	0,082	Minimal Effect
4.	University	3	0,538	Moderate Effect

The results of the effect size calculations indicate that the implementation of the plyometric training model on volleyball smash performance exhibits varying effects across educational levels. At the tertiary level, the effect size was 0.538, classified as a moderate effect. Conversely, at the high school/vocational school level, the effect size was only 0.082, classified as a minimal effect.

The correlation test between pretest and posttest scores yielded a correlation coefficient of 1.000 with a significance level of <0.001. Given that the significance value is <0.05, the results are statistically significant. Therefore, the null hypothesis (H_0) is rejected and the alternative hypothesis (H_1) is accepted, indicating that plyometric training has a significant effect on improving volleyball smash ability.

Discussion

The findings of this meta-analysis consistently confirm that plyometric training positively contributes to improving volleyball smashing ability. The increase in mean scores from the baseline phase (117.52) to the post-intervention phase (139.54) indicates a statistically significant change in performance, as confirmed by a paired-sample t-test with a significance value of $p < 0.05$ ($p = 0.000$). Inferentially, these results support the acceptance of the alternative hypothesis (H_1), which asserts that plyometric training significantly influences volleyball smashing performance. This finding aligns with various experimental studies that place plyometric training as a primary stimulus for improving explosive ability, which directly correlates with smashing effectiveness (Sheppard et al., 2011; Slimani et al., 2016; García-de-Alcaraz et al., 2020).

Biomechanically, the improvement in smashing ability following plyometric training can be explained by optimizing the stretch-shortening cycle (SSC) in the leg muscles.

Plyometric training improves the muscle's ability to efficiently store and release elastic energy, resulting in greater explosive force in a short period of time (Markovic & Mikulic, 2010; Ramirez-Campillo et al., 2020). In the context of volleyball, this mechanism contributes to increased jump height, take-off quality, and stability during the airborne phase, all of which play a crucial role in producing a powerful and effective smash (Forthomme et al., 2019; Wagner et al., 2014).

However, although the improvement in smash performance was statistically significant, the overall mean effect size (d = 0.068) was categorized as minimal. This finding indicates that, in aggregate, the impact of plyometric training on volleyball smashing ability has not demonstrated significant effect strength. This phenomenon is inseparable from the characteristics of meta-analyses, which integrate multiple studies with varying design, training duration, intensity, and subject characteristics (Borenstein et al., 2021; Cooper et al., 2019). This variability has the potential to reduce the magnitude of the aggregate effect, although statistical significance was still achieved.

Further analysis based on educational level stratification revealed more substantive findings. The college group demonstrated an effect size of 0.538 (a moderate effect), while the high school/vocational school group only achieved an effect size of 0.082 (a minimal effect). This disparity indicates that responsiveness to plyometric training is significantly influenced by biological maturity, physical capacity, and training experience. College students generally have more mature muscle strength, neuromuscular coordination, and physiological readiness than high school-aged students (Kumala et al., 2019; Lloyd et al., 2016).

From a long-term athlete development (LTAD) perspective, adolescent athletes are still in a transitional phase of growth, so adaptation to high-intensity training stimuli such as plyometrics is not optimal if not progressively adjusted (Lloyd & Oliver, 2012; Myer et al., 2015). This explains why the effectiveness of plyometric training at the high school/vocational school level tends to be low, especially if the training program is not modified to suit the characteristics of the physical and motor development of the students (Karina Nur Safitri et al., 2024; Faigenbaum et al., 2016).

These findings also confirm that plyometric training applied in isolation is insufficient to produce substantial improvements in smashing ability. Smashing is a complex skill that relies not only on explosive leg power but also involves segmental coordination, core strength, shoulder stability, jump timing, and technical control at ball contact (Wagner et al., 2014; Forthomme et al., 2019). Therefore, the effectiveness of plyometrics will be more optimal when integrated with complementary training modalities, such as specific strength training, smash technique training, and neuromuscular coordination training (Oktariana & Hardiyono, 2020; Stojanović et al., 2017).

In addition to program design factors, variability in training implementation by coaches also contributes to differences in results between studies. Despite using similar plyometric methodology, differences in intensity, load progression, quality of supervision, and athlete adherence to the training program can result in different

outcomes (Evionora et al., 2020; Ramirez-Campillo et al., 2015). This meta-analysis reinforces the view that training success is determined not only by the type of method but also by the quality of implementation and the program's suitability to the athlete's baseline ability.

Although the overall effect size is relatively low, these findings still have practical significance in the context of volleyball coaching. Within the framework of meta-analysis, effect size represents the strength of the influence between variables, not merely statistical significance (Retnawati et al., 2018; Lakens, 2013). Therefore, even if the effect is small, plyometric training still makes a significant contribution to improving smash performance, especially when applied appropriately to a group of athletes with adequate physical preparation.

Overall, the results of this meta-analysis confirm that plyometric training is an important component in developing volleyball smashing skills. However, its effectiveness is highly contextual and depends on educational level, athlete characteristics, and integration with other training methods. These findings add to the empirical evidence in sports coaching science and provide a scientific basis for coaches to design more adaptive, progressive, and evidence-based smash training programs.

CONCLUSION

Based on a meta-analysis of eight scientific articles examining the effect of plyometric training on volleyball smashing ability, it can be concluded that plyometric training consistently contributes positively to improving smashing performance. This improvement is reflected in the comparison of average scores before and after the intervention, as well as statistical significance supporting a meaningful change in performance. Conceptually, these findings support the theory that plyometric training can increase the explosive capacity of leg muscles by optimizing neuromuscular mechanisms, which play a crucial role in the jump and smash execution phases.

However, empirically, the magnitude of the effect of plyometric training in this meta-analysis remains relatively low, with an average effect size of 0.068. This indicates that the application of plyometric training as a single modality is not optimal enough to produce substantial improvements in smashing ability. Variations in training responses were also found based on educational level stratification, with the college group showing a larger, moderate effect magnitude, while the high school/vocational school group tended to show a minimal effect. This difference suggests the influence of physical maturity, training experience, and physiological readiness on the effectiveness of plyometric training.

Overall, this study provides a more comprehensive and evidence-based perspective on the effectiveness of plyometric training in the context of volleyball smash development. The findings of this meta-analysis confirm that plyometric training remains relevant as part of a coaching program, but needs to be integrated with other training modalities, such as specific strength training and technique training, to achieve

optimal results. Therefore, the results of this study not only contribute to the enrichment of the scientific literature on sports coaching but also provide a practical foundation for coaches in designing more effective, adaptive, and evidence-based smash training programs.

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