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THE CONTRIBUTION OF EXPLOSIVE POWER OF ARM MUSCLES AND EXPLOSIVE POWER OF LEG MUSCLES TO THE ACCURACY OF SMASHES OF MEN'S VOLLEYBALL ATHLETES FROM THE MANGGILANG CLUB

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Abstract

Smash accuracy is one of the main indicators of successful attacks in volleyball. Successful smashing is not only determined by technical mastery but also influenced by physical condition, particularly arm and leg muscle explosiveness. Although both physical components are believed to play a crucial role in smash performance, empirical evidence regarding their individual contributions, or their simultaneous contribution to smash accuracy in club-level volleyball athletes, is limited. This study aims to analyze the contribution of arm and leg muscle explosiveness, both partially and simultaneously, to smash accuracy in male volleyball athletes from the Manggilang Club. This study used a quantitative research design with a correlational approach. The sample consisted of 16 male volleyball athletes aged 19-24 who actively participated in the training program at the Manggilang Club and were selected using a purposive sampling technique. Arm muscle explosiveness was measured using the One-Hand Medicine Ball Throw Test, leg muscle explosiveness was measured using the Vertical Jump Test, and smash accuracy was measured using the Volleyball Smash Accuracy Test. Prior to hypothesis testing, normality was tested using the Liliefors test. The relationship analysis used Pearson Product-Moment correlation, while the joint contribution of the two independent variables was analyzed using multiple correlation at a 5% significance level. The results showed that arm muscle explosiveness had a positive and significant relationship with smash accuracy ($r = 0.558$; $p < 0.05$), contributing 31.1%. Leg muscle explosiveness also had a positive and significant relationship with smash accuracy ($r = 0.536$; $p < 0.05$), contributing 28.7%. Simultaneously, arm muscle explosiveness and leg muscle explosiveness had a strong and significant relationship with smash accuracy ($R = 0.733$; $p < 0.05$), contributing 53.7% of the variation in athletes' smash accuracy. Arm muscle explosiveness and leg muscle explosiveness are components of physical condition that contribute significantly to smash accuracy in men's volleyball athletes. The better the explosive ability in these two muscle groups, the higher the level of smash accuracy an athlete can achieve. The results of this study provide a scientific basis for coaches to design training programs that integrate the development of explosive arm and leg muscle power through exercises such as medicine ball throws, plyometric training, and vertical jump exercises. This training approach is expected to improve smash accuracy, attack effectiveness, and athlete performance in match situations.

Keywords: Arm Muscle Explosive Power; Leg Muscle Explosive Power; Smash Accuracy

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INTRODUCTION

Volleyball is a team sport that demands the integration of technical skills, tactics, physical fitness, and quick decision-making in dynamic game situations. At the competitive level, a team's success is largely determined by the effectiveness of its attacks, particularly through the smash technique, as this technique is the primary means of gaining points and putting pressure on the opponent (Marques et al., 2008); (Santoso & Setiabudi, 2019). A smash is a complex movement that involves the coordination of the entire kinetic chain of the body, starting from the initial phase, push-off, flight phase, arm swing, to contact and meeting the ball. Therefore, the quality of a smash is influenced not only by technical mastery but also by the athlete's biomotor abilities, particularly the explosive power of the neck and arm muscles (Singh, 2026); (Nasuka et al., 2020). Volleyball is a popular and competitive team sport (Irwanto, 2021). Volleyball is a highly popular sport that serves as a source of achievement and national pride. In this game, the ability to execute a smash stands out as the most crucial fundamental technique. A sharp, well-placed smash not only penetrates the opponent's defensive block but also dictates the flow of the match and secures victory for the team.

Biomechanically, a smash is an explosive movement that requires efficient energy transfer from the lower extremities to the trunk and then to the upper extremities. Kinetic chain theory explains that the force generated by the leg muscles is transmitted through the pelvis and trunk to the shoulders, arms, and hands, resulting in high hitting speed and optimal accuracy (Ellenbecker & Aoki, 2020); (Santoso & Setiabudi, 2019). The effectiveness of this energy transfer is highly dependent on the athlete's ability to generate maximum force in a short period of time, known as explosive power. Explosive power is the result of the interaction between muscle strength and contraction speed, which determines the ability to generate large forces in a short period of time (Cormie et al., 2011); (Isabella & Bakti, 2021). In the context of volleyball, this ability influences jump height, arm swing speed, ball speed, and smash direction accuracy (Lidor & Ziv, 2010). The smash is a key technique in volleyball (Sahabuddin dkk., 2022). The smash is a crucial stroke (Azzaria dkk., 2023). Smashing is the primary technique for attacking and scoring points, so a successful smash is crucial to the outcome of a match (Sambono dkk., 2025). Smashing is a fundamental technique that is crucial to all fundamental techniques in volleyball. A good smash allows a team to score points in a match. Without an effective smash, it is impossible for a team to win a competition. Smashing plays a crucial role because without a well-targeted smash, the game will not run smoothly and will be less enjoyable (Akhmady & Adam, 2025). The goal of a powerful smash is to defeat the opponent (Tongge dkk., 2024).

Leg muscle explosiveness plays a crucial role in generating a high vertical jump, enabling athletes to make contact with the ball at the highest point. The higher the contact point, the greater the chance of generating a sharp angle of attack and the less likely it is to be blocked by an opponent (Fuchs et al., 2019); (Sheppard et al., 2008); (Tilp, 2017). Furthermore, leg muscle explosiveness contributes to body stability during the flight phase and landing efficiency, enabling athletes to maintain performance throughout the match (Lidor & Ziv, 2010); (Zhiyong et al., 2026). Meanwhile, arm muscle explosiveness determines the speed of the arm swing and the magnitude of the impulse applied to the ball upon contact. A fast and explosive arm swing results in higher ball speeds while improving the athlete's ability to control the direction of the shot, aiming for areas difficult for opponents to reach

(Singh, 2026); (Nasuka et al., 2020). The success of a smash depends not only on technique but also on physical condition, especially the explosive power of the arm and leg muscles (Oktavia dkk., 2025). Muscle explosive power is one of the most important biomotor components in sports, especially volleyball, because it determines how hard a person can hit, push, lift, and so on (Tongge dkk., 2024). Leg muscle explosive power is very important for smashes in volleyball (Widodo & Fadloli, 2025). Leg muscle explosive power is the ability of the muscles to overcome the load with a high speed of leg muscle contraction, this element is the ability of strength and speed when performing a high jump to reach a thrown ball (Ardila & Alficandra, 2025). Leg muscle explosive power not only determines the height of the athlete's jump, but also affects reaction speed, stability upon landing, and energy efficiency during matches that last for a relatively long duration (M.Rozi dkk., 2025). The ability of leg muscle explosiveness plays a major role in smashing, because the push based on the legs and swing of the arms can increase the jump. In addition to leg muscles, arm muscles also greatly influence the success of the smash. Arm muscle explosiveness is fundamentally useful for producing powerful shots (Syukur dkk., 2019). Arm muscle explosiveness is a crucial factor because it determines how hard the ball can be thrown and directed toward the opponent's area (Saputra dkk., 2025). Equally important is arm muscle explosiveness just before a smash. A full-force arm swing and precise impact on the ball make it difficult for the opponent to return it effectively.

Various studies have demonstrated that muscular explosive power is a key determinant of volleyball performance. Research by (Fuchs et al., 2019),shows that vertical jump ability is closely related to ball contact height and spike velocity. Other studies report that plyometric training can improve lower extremity explosive power, thus positively impacting spike and blocking performance (Ramirez-campillo et al., 2021); (Silva et al., 2019). Furthermore, increased arm muscle strength and explosive power have been shown to contribute to increased ball velocity and attack effectiveness (Sheppard et al., 2008); (Santoso & Setiabudi, 2019). These research findings demonstrate that physical ability is closely related to technical performance in volleyball. However, most international research focuses on the relationship between explosive power and jump height, spike velocity, movement biomechanics, or training program effectiveness, while research specifically examining smash accuracy as the dependent variable is relatively limited. Furthermore, most studies only analyze leg or arm muscle explosiveness separately, thus failing to provide a comprehensive picture of the simultaneous contribution of these two components to smash accuracy. Research on club-level volleyball athletes, particularly in Indonesia, is also still dominated by descriptive approaches, resulting in limited use of multivariate analysis models. This situation indicates a research gap that needs to be addressed through research that integrates these two biomotor variables.

Based on this gap, the novelty of this study lies in analyzing the simultaneous contribution of arm and leg muscle explosiveness to smash accuracy in club-level male volleyball athletes using a correlational approach. Unlike previous research that tends to focus on a single variable such as vertical jump or spike velocity, this study integrates two key biomotor components into a single analytical model, providing a more comprehensive picture of the determinants of smash accuracy. This approach is expected to enrich the sports science literature, particularly in the fields of biomechanics and evidence-based volleyball coaching. Theoretically, this study is based on the principle of Specific Adaptation to Imposed Demands (SAID), which states that physiological adaptation occurs in accordance with the training stimulus provided (Bompa & G. Gregory Haff, 2009). Furthermore, the Stretch-Shortening Cycle (SSC) theory explains that the combination of eccentric and concentric contractions rapidly increases explosive force production, supporting movement performance such as the smash (Komi, 2000). Based on this theoretical foundation and previous research, this study hypothesizes a significant relationship between arm muscle explosive power and smash accuracy in male volleyball athletes, as well as a significant relationship between leg muscle explosive power and smash accuracy. Furthermore, simultaneous arm and leg muscle explosive power are suspected to contribute significantly to smash accuracy in male volleyball athletes.

METHODS

Research Design

This study employs a quantitative correlational design to examine the contribution of arm muscle explosive power and leg muscle explosive power to smash accuracy. Participants were selected using purposive sampling, a technique that selects a sample based on specific criteria relevant to the research objectives (Ahyar et al., 2020). The sample consisted of 16 male volleyball athletes aged 19–24 years from the Manggilang Volleyball Club who actively participated in regular training. Participants were selected based on the following criteria: (1) male athletes registered as members of the Manggilang Volleyball Club, (2) aged 19–24 years, (3) actively participating in regular training, and (4) willing and physically able to complete all testing procedures. The sample size of 16 was determined based on the total number of athletes within the study population who met the established inclusion criteria.

Measurement Instruments and Procedures

Three instruments were used to measure the research variables. Arm muscle explosive power was assessed using the medicine ball throw test. Participants stood behind a designated line and performed their strongest one-handed ball throw. The distance from the throwing line to the ball's first point of contact was measured, and the best performance from the designated trials was recorded in meters. Leg muscle explosive power was measured using the vertical jump test. Participants first determined their standing reach height and then performed a maximal vertical jump from a standing position. The difference between the standing reach and the highest point achieved during the jump was recorded as the vertical jump score. Smash accuracy was assessed using a standard volleyball smash accuracy test. After receiving the ball from a designated setter, participants executed a smash toward a target area on the opposing court. Scores were awarded based on predetermined target zones, with higher scores indicating greater smash accuracy. All participants received standardized instructions and an orientation prior to testing, and testing conditions were maintained consistently for all participants.

Validity and Reliability

The instruments were selected because they are commonly used field-based measures for assessing explosive power and volleyball performance. The medicine ball throw and vertical jump tests possess established construct validity for assessing upper- and lower-body explosive power, respectively, while the smash accuracy test evaluates a sport-specific technical skill. To ensure measurement consistency, the same equipment, testing procedures, instructions, and evaluators were used for all participants. Instrument-specific validity and reliability coefficients must be reported in accordance with the original testing protocols or validation studies utilized by the researcher. If the study involved independent reliability testing, the intraclass correlation coefficient (ICC) or test-retest reliability coefficient must be reported. These values must not be falsified and must be derived from actual validation sources or the researcher's own reliability analysis.

Data Analysis

Prior to hypothesis testing, the data were checked for statistical assumptions. Normality was tested using the Lilliefors test at $\alpha = 0.05$. The results indicated that the data for arm muscle explosive power were normally distributed, as the obtained Lo value (0.1063) was lower than the critical value (0.213); the data for leg muscle explosive power were normally distributed, as the obtained Lo value (0.1700) was lower than the critical value (0.213); and the smash accuracy data were normally distributed, as the obtained Lo value (0.0665) was lower than the critical value (0.213). Before performing Pearson correlation analysis, the linearity of the relationship between each independent variable and smash accuracy was also examined. A relationship was considered linear when the deviation from linearity was not statistically significant ($p > 0.05$). Once the assumptions of normality and linearity were met, the Pearson Product-Moment correlation was used to examine the individual relationships between arm muscle explosive power and smash accuracy, as well as between leg muscle explosive power and smash accuracy. Multiple correlation analysis was then employed to determine the simultaneous relationship of arm and leg muscle explosive power with smash accuracy. Statistical significance was set at $\alpha = 0.05$.

RESULTS AND DISCUSSION

Results

1. Descriptive statistics

   Descriptive statistical analysis was conducted to describe the characteristics of the data regarding arm muscle explosive power (X1), leg muscle explosive power (X2), and smash accuracy (Y) among 16 male volleyball athletes from the Manggilang club. The analysis results show that arm muscle explosive power had a minimum value of 4.85 and a maximum of 8.82, with a mean of 6.88 and a standard deviation (SD) of 1.24. Leg muscle explosive power had a minimum value of

84.54 and a maximum of 149.54, with a mean of 117.05 and a standard deviation of 19.53. Meanwhile, smash accuracy had a minimum value of 35 and a maximum of 53, with a mean of 45.06 and a standard deviation of 4.77.

Table 1. Descriptive data of research results

Variable	n	Minimum	Maksimum	Mean	SD	Median
Arm Muscle Explosive Power (X1)	16	4,85	8,82	6,88	1,24	6,5
Leg Muscle Explosive Power (X2)	16	84,54	149,54	117,1	19,5	115,23
Smash Accuracy (Y)	16	35	53	45,06	4,77	45,5

Descriptively, the score ranges indicate a variation in abilities among participants across the three variables. This variation enables further examination of the relationship between upper and lower extremity explosive capacity and smash accuracy.

2. Relationship between arm muscle explosive power and smash accuracy

Pearson correlation analysis results indicate a strong positive relationship between arm muscle explosive power and smash accuracy, with a correlation coefficient of $r = 0.945$ ($p < 0.001$). The 95% confidence interval for the correlation coefficient ranges from 0.845 to 0.981. The coefficient of determination ($r^2 = 0.893$) indicates that approximately 89.3% of the variation in smash accuracy scores is linearly associated with the variation in arm muscle explosive power within the study sample.

The magnitude of this correlation suggests that athletes with higher arm muscle explosive power tend to achieve higher smash accuracy scores. In practical terms, these findings indicate that arm muscle explosive capacity is a highly relevant physical component for smash performance. However, given the correlational design of the study, the magnitude of the correlation cannot be interpreted as evidence of a cause-and-effect relationship.

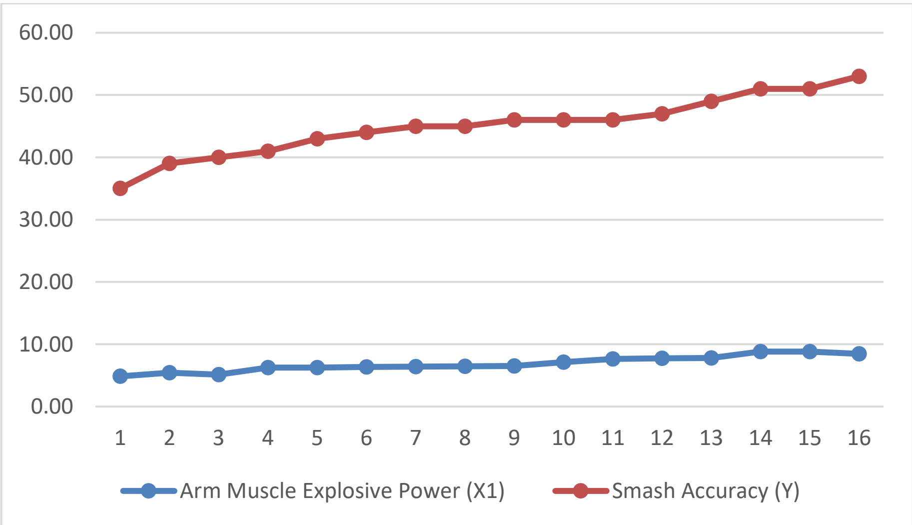

Diagram 1. Relationship between arm muscle explosive power and smash accuracy

3. Relationship between leg muscle explosive power and smash accuracy

Pearson analysis also reveals a positive and very strong relationship between leg muscle explosive power and smash accuracy, with an r-value of 0.976 ($p < 0.001$). The 95% confidence interval for the correlation coefficient is 0.929–0.992, while the coefficient of determination is $r^2 = 0.952$.

Thus, approximately 95.2% of the variation in smash accuracy is linearly associated with the variation in leg muscle explosive power within the study data. This very high correlation indicates that athletes with superior leg explosive power tend to exhibit greater smash accuracy. From a biomechanical perspective, this can be understood because leg explosive power contributes to generating the push-off, jump height, and body positioning at the moment of ball contact, thereby enabling the athlete to achieve more optimal movement dynamics when executing the smash.

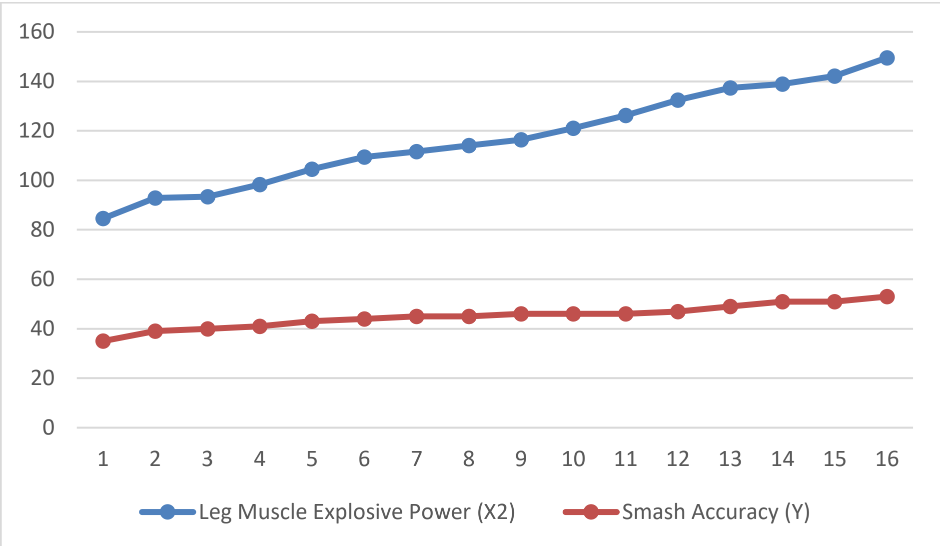

Diagram 2. Relationship between leg muscle explosive power and smash accuracy

4. Relationship of arm muscle explosive power and leg muscle explosive power with smash accuracy

Multiple linear regression analysis indicates that arm muscle explosive power and leg muscle explosive power simultaneously share a very strong relationship with smash accuracy, with values of $R = 0.976$ and $R^2 = 0.952$. The overall model is significant: $F(2,13) = 128.56$, $p < 0.001$. The R^2 value indicates that approximately 95.2% of the variation in smash accuracy can be jointly explained by arm muscle explosive power and leg muscle explosive power within the research model, while the remaining 4.8% is attributable to other variables not included in the model.

Regression coefficient analysis results show that leg muscle explosive power makes a significant contribution to smash accuracy ($B = 0.237$; 95% CI [0.108–0.365]; $p = 0.002$), whereas arm muscle explosive power-when controlled simultaneously with leg muscle explosive power-does not show a significant contribution ($B = 0.025$; 95% CI [-1.995–2.045]; $p = 0.979$). These findings indicate that while both variables jointly share a very strong relationship with smash accuracy, the variation explained by arm muscle explosive power becomes negligible when both are included in a single model. This situation warrants attention, as both predictor variables demonstrate a very strong relationship with smash accuracy and potentially exhibit high correlation with each other.

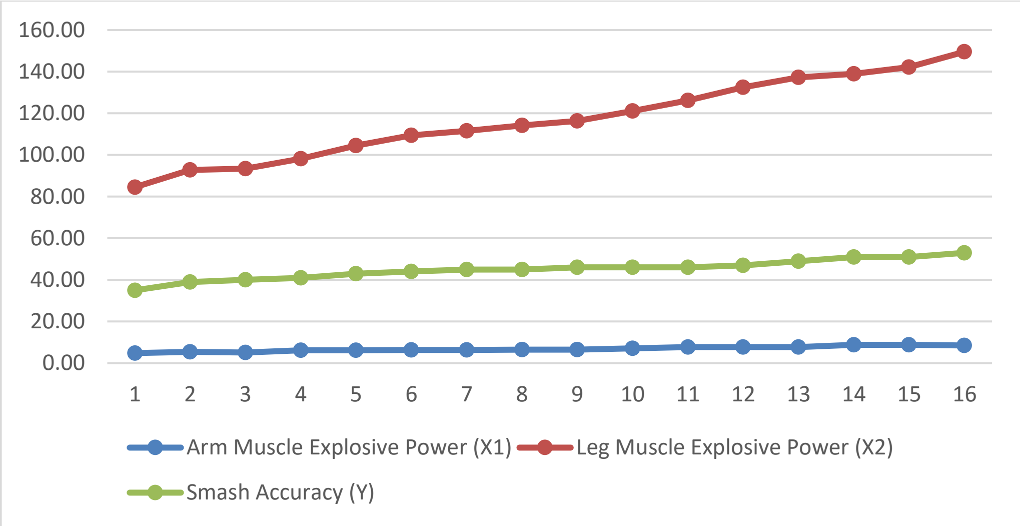

Diagram 3. Relationship of Arm Muscle Explosive Power and Leg Muscle Explosive Power with Smash Accuracy

5. Correlation coefficient

To reinforce the statistical interpretation, this study employs the coefficient of determination as a measure of the effect size for individual relationships. The relationship between arm muscle explosive power and smash accuracy yielded an r^2 of 0.893, while the relationship between leg muscle explosive power and smash accuracy yielded an r^2 of 0.952. Both values indicate a very large effect size for the relationships. In the simultaneous model, the effect size is expressed as $R^2 = 0.952$. Additionally, the regression effect size f^2 was calculated using the formula $f^2 = R^2/(1 - R^2)$, resulting in a value of approximately 19.78, which indicates a very large model effect size. The 95% confidence interval for the Pearson correlation provides information regarding the precision of the coefficient estimate. The relatively narrow interval ranges for both relationships indicate that, based on the study's data, the correlation estimates are highly precise.

Discussion

1. Relationship between arm muscle explosive power and smash accuracy

Research results indicate that arm muscle explosive power has a positive and very strong relationship with smash accuracy among male volleyball athletes from the Manggilang club ($r = 0.945$; $p < 0.001$). These findings suggest that athletes capable of generating explosive force in their upper arm muscles tend to execute smashes with a higher level of accuracy. From physiological and biomechanical perspectives, this relationship can be explained by the nature of the smash as an explosive movement requiring force production within a very short timeframe. During the arm-swing phase, the muscles of the shoulder, arm, and forearm work sequentially to generate high velocity at the moment of ball contact. Thus, the ability to generate force rapidly not only contributes to increasing ball velocity but also assists the athlete in controlling the ball's direction and contact point. From a kinetic theory perspective, the smash is not a single-segment activity but a sequence of energy transfers from body segments closer to the center of mass toward more distal segments. Mechanical energy generated in the lower body and trunk is transmitted through the shoulder, arm, and hand, resulting in high hand speed at the moment of contact. Therefore, arm muscle explosive power can be viewed as a component that supports an athlete's ability to control the final acceleration phase and direct the ball toward the target. The relationship between explosive capacity and spike performance further demonstrates that power is a crucial component in various specific volleyball movements. A meta-analysis (Ramirez-campillo et al., 2021), for instance, found that plyometric jump training yields small-to-moderate improvements in volleyball-relevant power indicators, including the spike jump, countermovement jump, and countermovement jump with arm swing.

These research findings also align with the study by (Putra et al., 2024), which specifically examined the relationships between explosive power, elbow angle, and jump height regarding smash accuracy. That study identified a significant simultaneous relationship, with $R = 0.776$ and $R^2 = 0.601$. Current research findings indicate an even stronger individual relationship between arm explosive power and smash accuracy. Variations in the magnitude of this coefficient likely stem from factors such as sample characteristics, sample size, athletes' skill levels, the instruments used, and the specific nature of the smash accuracy test. However, the high correlation observed in this study does not imply that arm explosive power directly causes an improvement in smash accuracy. Accuracy results from the interplay of various factors, including technique, neuromuscular coordination, timing, visual perception, body positioning, the quality of the set, and the ability to control the ball's trajectory. Thus, arm muscle explosive power is best understood as a physical component closely linked to the ability to generate and control the smash movement, rather than as the sole determinant of accuracy.

2. Relationship between leg muscle explosive power and smash accuracy

Leg muscle explosive power shows a very strong positive correlation with smash accuracy ($r = 0.976$; $p < 0.001$). This value is even higher than the correlation between arm muscle explosive power and smash accuracy. These findings indicate that leg muscle explosive capacity is a crucial component in supporting the quality of smash execution. From a biomechanical perspective, the role of the legs begins during the approach phase and reaches a critical point during the take-off phase. The ability to generate force rapidly enables the athlete to produce a greater vertical impulse, thereby increasing jump height. Jump height subsequently determines the body's relative position to the ball at the moment of contact. A higher contact position affords the athlete better biomechanical space and time to adjust the angle of attack, the direction of the arm swing, and the point of contact with the ball.

These findings are supported by a meta-analysis (Ramirez-campillo et al., 2021), which demonstrates that plyometric jump training yields significant improvements in spike jump performance and various power indicators among volleyball players. Specifically, the effect on spike jump height was reported to fall within the moderate category (0.84). Thus, the results of this study reinforce the argument that leg explosive capacity is directly relevant to the sequence of movements preceding ball contact during a smash. Research by (Adilla et al., 2023) also provides empirical support, identifying leg muscle explosiveness as a variable associated with smash accuracy in volleyball athletes. That study included leg muscle explosive power-alongside waist flexibility and hand-eye coordination-as a determinant of smash accuracy. The distinction here is that the current study focuses on male club-level athletes and specifically examines the relationships of both leg and arm muscle explosive power with smash accuracy. These results indicate that improving smash performance cannot be achieved solely through arm swing training; athletes require an explosive foundation in their lower extremities to execute an effective take-off and achieve an optimal contact position. Thus, lower-body power can be viewed as the initial link in the kinetic chain that subsequently contributes to the effectiveness of upper-body movements.

3. Integration of upper and lower extremity explosive power in the smash movement

The analysis shows that arm and leg muscle explosive power together have a very strong relationship with smash accuracy. Theoretically, this finding can be explained by the principle of force production and transfer from more proximal body segments to more distal segments. In the initial phase, the leg muscles generate force for the approach and take-off. This energy is then transferred through the pelvis and trunk. Next, trunk rotation contributes to the acceleration of the shoulders, arms, and hands. In the final phase, the hands generate the contact speed necessary to direct the ball toward the target. The efficiency of this transfer is crucial because disruption of any link in the chain can reduce the overall efficiency of the movement. Therefore, smash accuracy is not solely a result of the ability to generate large amounts of force, but also the ability to generate, transfer, and control force at the right time and direction. This is why physical conditioning training needs to be integrated with technique training. Athletes with high power but lacking good technical control and timing will not necessarily produce accurate smashes. The findings of this study align with recent literature showing that explosive training in volleyball provides benefits to physical abilities that directly support specific actions such as the spike jump. A meta-analysis of 18 studies involving 746 athletes (Ramirez-campillo et al., 2021) found that plyometric jump training had positive effects on various power indicators, including the spike jump and CMJ with arm swing. Meanwhile, a meta-analysis (Ali et al., 2024) including 40 studies reported a strong relationship between plyometric training and overall volleyball performance. However, these findings also need to be placed in the context of the broader literature. A recent meta-analysis on the effect of plyometric training on smashing ability showed that the effect of plyometric training on overall smashing performance may be relatively small when plyometric training is used as the sole training method. This suggests that developing smashing performance likely requires a combination of power, technique, coordination, and game-specific skill training.

Analysis results indicate that arm and leg muscle explosive power, acting in combination, share a very strong relationship with smash accuracy. Theoretically, these findings can be explained by the principle of force production and transfer from proximal body segments to distal ones. In the initial phase, leg muscles generate the force required for the approach and take-off. This energy is then transferred through the hips and torso. Subsequently, torso rotation contributes to the acceleration of the shoulder, arm, and hand. In the final phase, the hand generates the contact velocity needed to direct the ball toward the target. The efficiency of this transfer is crucial, as a disruption in any single link can reduce the overall efficiency of the movement. Thus, smash accuracy is not solely the result of the ability to generate high force, but also the ability to generate, transfer, and control force with precise timing and direction. This is why physical conditioning must be integrated with technical training; an athlete possessing high power but lacking technical control and proper timing will not necessarily produce an accurate smash.

4. Practical implications for volleyball training programs

Practically, the research results indicate that volleyball training programs need to develop lower and upper extremity explosive power in an integrated manner. Leg explosive power can be improved through plyometric exercises such as countermovement jumps, squat jumps, drop jumps, box jumps, and approach jumps, while arm explosive power can be developed through medicine ball throws and explosive resistance exercises that mimic the arm swing pattern. These physical conditioning exercises need to be combined with target-based smash drills so that increased explosive capacity can be directly transferred to technical skills. Training programs also need to apply the principles of progressive overload, specificity, individualization, and periodization, with volume and intensity adjusted based on the characteristics and ability level of each athlete. With this approach, explosive power development is expected to optimally improve movement efficiency, ball contact quality, and smash accuracy.

5. Research Limitations

This study has several limitations. First, the sample size was relatively small (n = 16) and only involved male athletes from one club, so generalizing the results to a wider population requires caution. Second, the cross-sectional correlational design does not allow for causal conclusions regarding the effect of explosive power on smash accuracy. Third, the use of field tests does not fully represent the biomechanical complexity of smashing, which involves coordination of the entire kinetic chain, timing, body position, and the point of ball contact. Fourth, the study did not use biomechanical analysis technology such as 3D motion capture, force plates, or IMUs to identify force transfer mechanisms in more depth. Fifth, other factors such as technique, coordination, psychological aspects, tactics, pass quality, and playing experience were not analyzed, so there are still other variables that can influence smash accuracy.

6. Recommendations for further research

Future research is recommended to involve larger, more heterogeneous samples from various clubs and competition levels to increase the generalizability of the results. Experimental or longitudinal designs are needed to test the effect of explosive power training programs on smash accuracy. Future research should also integrate three-dimensional biomechanical analyses, such as approach velocity, jump height, take-off force, trunk rotation, shoulder rotation, hand velocity, ball velocity, and contact point. Furthermore, developing a multivariate prediction model that incorporates explosive power, technical skill, coordination, anthropometric, and perceptual-cognitive factors could provide a more comprehensive understanding. Experimental studies should also compare plyometric, resistance, and combined strength-plyometric training on jump height, spike velocity, and smash accuracy.

CONCLUSION

Based on the research results, it can be concluded that there is a significant relationship between arm muscle explosiveness and smash accuracy, leg muscle explosiveness and smash accuracy, and arm muscle explosiveness and leg muscle explosiveness combined with smash accuracy in men's volleyball athletes from the Putra Manggilang club. Leg muscle explosiveness helps athletes achieve optimal jumps during smashes, while arm muscle explosiveness plays a role in producing powerful, fast, and targeted shots. The combination of these two physical components significantly supports successful smash technique. Therefore, the better an athlete's leg and arm muscle explosiveness, the better their smash accuracy.

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