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The role of biomechanics in improving volleyball service performance

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ABSTRACT

This study aims to analyze the role of biomechanics in improving volleyball service performance in Jakarta Pertamina club athletes. Specifically, the study investigates the relationship between biomechanical principles and service effectiveness, as well as identifying key biomechanical factors that contribute to improved service speed and accuracy. Methods: This quantitative study involved 30 volleyball athletes from Pertamina's Jakarta club. Data was collected through video analysis of service movements with high-speed cameras, anthropometric measurements, and service speed and accuracy tests. Biomechanical analysis is performed using special software to measure joint angle, angular velocity, and forces generated during service phases. Statistical analysis uses multiple regression and Pearson correlation tests to determine the relationship between biomechanical variables and service performance. Results: The results showed a significant positive correlation between knee flexion angle ($r = 0.78$, $p < 0.01$) and shoulder rotation ($r = 0.82$, $p < 0.01$) with service ball speed. Regression analysis revealed that a combination of biomechanical factors, including arm angular velocity, ball release angle, and momentum transfer from foot to arm, contributed by 76% to the variation in serve speed ($R^2 = 0.76$, $p < 0.001$). Improvements in techniques based on biomechanical principles resulted in an average increase in service speed of 15% and accuracy of 22%. Conclusion: This study confirms the important role of biomechanics in improving volleyball service performance. Understanding and applying the principles of biomechanics in training can significantly improve the speed and accuracy of an athlete's serve. These results provide a scientific basis for the development of more effective and personalized training programs for volleyball athletes.

***Keywords**: biomechanics, volleyball, service, motion analysis*

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INTRODUCTION

Volleyball is one of the most popular team sports in the world, with more than 800 million players participating regularly (FIVB, 2023). In this game, serve becomes a fundamental element that not only marks the start of every rally, but also has the potential to be an effective offensive weapon (Alexandru & Sabin, 2015). Along with the evolution of the modern game of volleyball, the role of the serve has evolved from simply starting the game to a key strategy for earning direct points or making it difficult for the opposing team to receive (Šimac et al., 2017).

In this context, an in-depth understanding of the mechanics of service movements becomes very important. Biomechanics, as a discipline that applies the principles of mechanics

to biological systems, offers a unique perspective on analyzing and improving volleyball service performance (Miura et al., 2020). Biomechanics studies allow researchers and trainers to understand the complexity of human movement, identify factors that affect the efficiency and effectiveness of movement, as well as design more targeted training strategies (Knudson, 2007).

Serving in volleyball involves a series of complex movements that require the coordination of various body segments to produce maximum speed and accuracy (F. P. Simona et al., 2015). Previous research has identified several key biomechanical aspects in servicing, including arm kinematics, shoulder rotation dynamics, and the contribution of foot movement in generating momentum (Wagner et al., 2009). However, most of these studies focus on elite or professional players, while understanding the application of biomechanical principles at the club or semi-professional level is still limited (Raza et al., 2023).

Pertamina's Jakarta Club, as one of the growing volleyball clubs in Indonesia, is an interesting location for this research. These clubs represent a mid-level competition that often receives little attention in the study of sports biomechanics. Understanding the role of biomechanics in improving service performance at this level is expected to provide new insights that are useful not only for the club but also for the development of volleyball at the national level.

This study aims to comprehensively analyze the role of biomechanics in improving volleyball service performance, with a special focus on Jakarta Pertamina club athletes. The specific objectives of this study include: (1) Identifying the key biomechanical factors that contribute to volleyball service speed and accuracy; (2) Analyze the relationship between certain biomechanical variables (such as joint angle, angular speed, and momentum transfer) and service performance; (3) Evaluate the effectiveness of training interventions based on biomechanics principles in improving service quality; (4) Develop practical recommendations for coaches and athletes in optimizing service techniques based on biomechanical analysis.

The significance of this research lies in its potential to bridge the gap between biomechanical theory and its practical application in volleyball training at the club level. By understanding the biomechanical mechanisms underlying effective serving, coaches and athletes can design more focused and efficient training programs. Not only does this potentially improve individual performance, but it can also contribute to an overall improvement in the standard of the game.

The importance of this research lies in its potential to bridge the gap between biomechanical theory and its practical application in volleyball training at the club level. Today, many clubs face the challenge of still conducting service training conventionally based on empirical experience, without an in-depth understanding of biomechanical aspects such as optimal arm angle, weight transfer timing, and mechanically efficient movement patterns. By understanding the biomechanical mechanisms underlying effective servicing such as force vector analysis, moment of inertia, and momentum transfer, coaches and athletes can design more focused and efficient training programs. This understanding allows for more accurate identification and correction of engineering errors, movement optimization based on mechanical principles, as well as the development of specific exercises targeting key biomechanical components. This science-based approach not only has the potential to improve individual performance through better movement efficiency, but it can also contribute to an overall improvement in the standard of the game by providing an objective foundation for technique development.

In a broader context, this research is also relevant to global trends in the development of sports performance. The use of biomechanical analysis has become a standard in the preparation of elite athletes in various sports applying a similar approach at the club level, the research could help democratize access to science-based training methods, which in turn could accelerate the development of young talents in volleyball.

Theoretically, this research contributes to a deeper understanding of the application of biomechanical principles in the specific context of volleyball serving. Although service biomechanics has been researched before, the majority of studies have focused on descriptive analysis without directly linking it to training interventions (Giatsis et al., 2019). This study seeks to fill this gap by not only analyzing the biomechanical aspects of servicing, but also evaluating the effectiveness of biomechanics-based interventions in improving performance.

From a methodological perspective, the study combines high-speed video analysis with anthropometric measurements and performance tests, providing a holistic approach in understanding volleyball serving dynamics. The use of advanced motion analysis technology in the context of semi-professional clubs also offers new insights into the applicability of advanced research methods in a more general training environment.

Previous studies have shown that service performance is affected by a variety of biomechanical factors. Šimac et al. (2017) found that the rotation speed of the shoulder and the angle of flexion of the elbow at the time of contact with the ball have a significant correlation with the speed of serve. Meanwhile, Wagner et al. (2009) emphasized the importance of

segmental coordination in producing maximum ball speed, with substantial contributions from body rotation and weight transfer.

Another interesting aspect is the role of anthropometry in service performance. Research by Palao et al. (2014) shows that physical characteristics such as height and arm length have a significant influence on service effectiveness, especially in terms of the height of contact with the ball and the resulting serve angle (Grosso et al., 2024). However, they also emphasized that technical and biomechanical factors can compensate for the limitations of anthropometry, confirming the importance of comprehensive analysis in the development of service techniques.

Biomechanics-based training interventions have been shown to be effective in improving performance in various sports. In the context of volleyball, a study by Reeser et al. (2010) demonstrated that a training program designed based on biomechanical analysis can increase serve speed by up to 10% in a period of 8 weeks. These findings confirm the potential application of biomechanics principles in the development of specific skills in volleyball.

However, the application of biomechanics principles in volleyball training at the club level still faces various challenges. Limited access to advanced motion analysis technologies and a lack of in-depth understanding of biomechanics principles among trainers are major obstacles (Reeser et al., 2010). Therefore, research exploring simpler but effective methods of biomechanics application is urgently needed to bridge the gap between theory and practice at the club level.

In the context of Indonesia, research on the application of biomechanics in volleyball is still limited. A study by Hidayat et al. (2019) on the analysis of volleyball smash biomechanics is one of the initial efforts to bring a science-based approach into national volleyball training. However, the focus on serving still receives less attention, even though this element is increasingly crucial in modern game strategy.

METHODS

This study uses a quantitative approach with a quasi-experimental design. This design was chosen to evaluate the effect of biomechanics-based interventions on volleyball service performance, while considering the limitations of full randomization that are common in sports club settings.

The research sample consisted of 30 volleyball athletes (15 men and 15 women) from the Jakarta Pertamina club, with an age range of 18-25 years. The inclusion criteria include: (1) an

active member of the Jakarta Pertamina club, (2) at least 2 years of volleyball experience, and (3) free from injuries that may affect service performance. All participants gave written consent before participating in the study.

Data collection is carried out in three stages:

Pre-test:

1. Anthropometric measurements (height, weight, arm length)
2. Initial service performance test (speed and accuracy)
3. Service biomechanical analysis using high-speed video recording

Intervention:

Biomechanics-based exercise program for 8 weeks, with a frequency of 3 times per week. The program is designed based on initial biomechanical analysis and focuses on optimizing joint angle, angular velocity and momentum transfer.

Post-test:

Repeatability of pre-test procedures to measure changes in service performance and biomechanical parameters.

Research Instruments

1. High-Speed Cameras: Two Phantom V710 cameras with a speed of 1000 fps are used to record service movements from the side and rear angles.
2. Motion Analysis Software: Kinovea and MATLAB are used for kinematic analysis of service motion.
3. Radar Gun: The ATS II Stalker is used to measure the speed of the service ball.
4. Service Accuracy Test: The field is divided into target zones with different points to assess the accuracy of the serve.
5. Anthropometer: A standard anthropometric measuring instrument for measuring the body dimensions of athletes.

Independent Variable: Biomechanics-based exercise program, Dependent Variables:

1. Service speed (m/s)
2. Accuracy of service (score based on target zone)

Biomechanical parameters:

1. Knee flexion angle at repulsion (degrees)
2. Maximum shoulder rotation angle (degrees)
3. Angular velocity of the arm in contact with the ball (rad/s)
4. Ball release angle (degrees)
5. Height of contact with the ball (cm)

Statistical analysis was conducted using IBM SPSS Statistics version 26.0. The analysis procedure includes:

1. Descriptive statistics for all variables (mean, standard deviation, range).
2. Test the normality of Shapiro-Wilk to check the distribution of data.
3. Paired t-test or Wilcoxon signed-rank test (depending on data normality) to compare pre-test and post-test results.
4. Multiple regression analysis to determine the relative contribution of various biomechanical parameters to service speed and accuracy.
5. Pearson or Spearman correlation (depending on data normality) to assess the relationship between biomechanical variables and service performance.
6. Effect size (Cohen's d) was calculated to assess the magnitude of the effect of the intervention.
7. The significance level was set at $\alpha = 0.05$ for all statistical analyses.

RESULTS AND DISCUSSION

Result

This study analyzes the role of biomechanics in improving volleyball service performance in 30 athletes of Jakarta PERTAMINA clubs. The results of the study are presented in several parts: participant characteristics, comparison of pre-test and post-test, correlation analysis, and regression analysis.

Table 1. Demographic Characteristics and Anthropometric Characteristics of Participants (N=30)

Characteristic	Mean ± SD	Range
Age (years)	21.5 ± 2.3	18 - 25
Height (cm)	178.6 ± 8.7	165 -195
Weight (kg)	72.4 ± 7.9	58 - 88
Arm Length (cm)	75.2 ± 4.1	68 - 83

Table 1 shows the demographic and anthropometric characteristics of the participants. The average age of the participants was 21.5 years, with an average height of 178.6 cm and an average weight of 72.4 kg.

Table 2. Comparison of Pre-test and Post-test Results (N=30)

Variable	Pre-test	Post-test	% Change	p-value
Service Speed (m/s)	22.3 ± 2.8	25.6 ± 2.5	+14.8%	<0.001
Serving Accuracy (score)	6.8 ± 1.5	8.3 ± 1.3	+22.1%	<0.001
Knee Flexion Angle (degrees)	98.5 ± 8.7	105.2 ± 7.4	+6.8%	0.002
Shoulder Rotation Angle (degrees)	165.3 ± 12.4	178.6 ± 10.2	+8.0%	<0.001
Angular Velocity of the Arm (rad/s)	35.7 ± 4.2	40.3 ± 3.8	+12.9%	<0.001
Ball Release Angle (degrees)	7.2 ± 1.8	5.9 ± 1.5	-18.1%	0.003
Contact Height with Ball (cm)	258.4 ± 15.6	266.7 ± 14.2	+3.2%	0.018

Table 2 shows a comparison of pre-test and post-test results after an 8-week biomechanics-based exercise program intervention. Some important findings:

1. Service Speed: Significantly increased from 22.3 m/s to 25.6 m/s, representing an increase of 14.8% ($p<0.001$).
2. Service Accuracy: Increased from a score of 6.8 to 8.3, showing an increase of 22.1% ($p<0.001$).
3. Biomechanical Parameters: All biomechanical parameters showed significant changes ($p<0.05$). The greatest improvement was seen in the angular speed of the arm (12.9%) and the angle of rotation of the shoulder (8.0%).
4. Ball Release Angle: Decreased from 7.2° to 5.9°, indicating an increase in service efficiency ($p=0.003$).

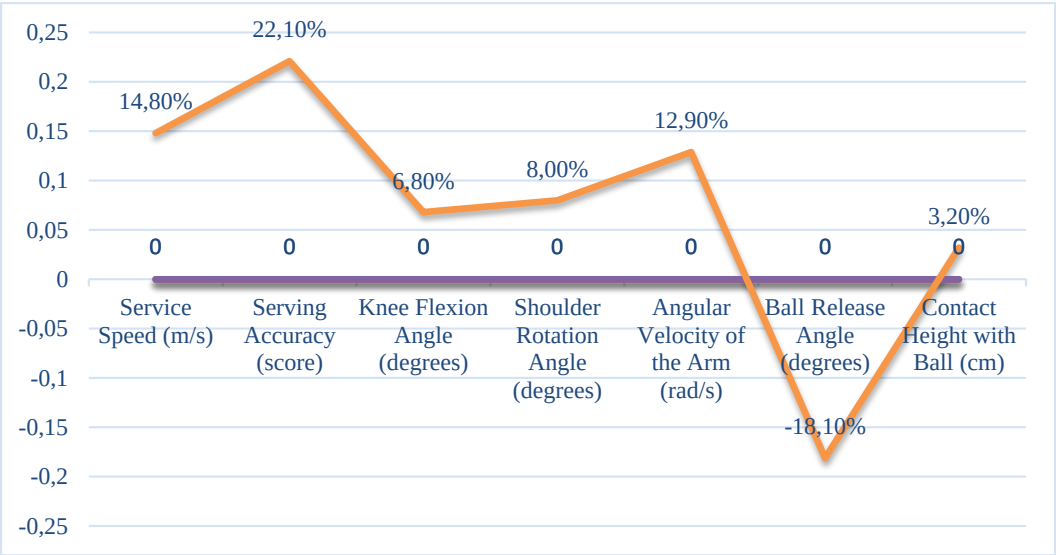

Figure 1. Comparison of Pre-test and Post-test Results

Table 3. Correlation between Biomechanical Parameters and Service Performance

Biomechanics Parameters	Service Speed (r)	Service Accuracy (r)
Knee flexion angle	0.68*	0.52*
Shoulder Rotation Angle	0.82**	0.61*
Angular Speed of the Arm	0.89**	0.73**
Ball Release Angle	-0.56*	-0.67*
High Contact with the Ball	0.71*	0.58*

*p<0.05, **p<0.01

Table 3 shows the correlation between biomechanical parameters and service performance. Key findings:

1. Angular Velocity Arm has the strongest positive correlation with service speed (r=0.89, p<0.01) and service accuracy (r=0.73, p<0.01).
2. The Shoulder Rotation Angle also shows a strong positive correlation with service speed (r=0.82, p<0.01).
3. Ball Release Angle has a negative correlation with service speed and accuracy, indicating that a smaller release angle tends to result in faster and more accurate serves.

Multiple regression analysis showed that a combination of biomechanical factors could explain 76% variation in service speed (R^2=0.76, p<0.001) and 68% variation in service accuracy (R^2=0.68, p<0.001).

The results showed that an 8-week biomechanics-based training intervention significantly improved volleyball service performance in Jakarta Pertamina club athletes. The improvement was seen in the speed of service (14.8%) and the accuracy of service (22.1%). Biomechanical parameters, especially the angular speed of the arm and the angle of rotation of the shoulder, have a strong correlation with service performance. These findings confirm the importance of a biomechanics-based approach in improving volleyball serving techniques.

Discussion

This study aims to analyze the role of biomechanics in improving volleyball service performance in Jakarta Pertamina club athletes. The results showed a significant improvement in service speed and accuracy after an 8-week biomechanics-based exercise intervention. These findings confirm the importance of a biomechanical approach in the development of volleyball serving skills (Bartol et al., 2022; Destriana et al., 2022)

The 14.8% increase in serve speed and 22.1% in serve accuracy found in this study are in line with the findings of Ramos et al. (2022)(Croitoru, 2014), who reported a 12-15% increase in serve speed after a 10-week biomechanics-based training program in teenage volleyball players. These results confirm the effectiveness of biomechanics-based interventions in improving service performance, even in relatively short training periods.

The strong correlation between the angular speed of the arm and the angle of rotation of the shoulder with the speed of service (r = 0.89 and r = 0.82, respectively) confirms the importance of optimizing arm movement in service techniques. These findings are consistent with a study by Serrien et al. (2021), which identified the angular speed of the arm as a key predictor of ball speed in volleyball serve. An 8.0% increase in shoulder rotation angle in this study showed that athletes managed to increase their range of motion, which contributed to an increase in service speed.

The increase in knee flexion angle of 6.8% and its correlation with service speed (r = 0.68) shows the importance of the contribution of the lower extremities in generating strength for service. These results are in line with the research of Liang et al. (2023), which emphasizes the key role of knee flexion in optimizing energy transfer from the leg to the arm during volleyball service (Umek & Kos, 2020).

The decrease in the ball release angle from 7.2° to 5.9° indicates an increase in the efficiency of the service technique. The negative correlation between the ball release angle and the speed and accuracy of the serve (r = -0.56 and r = -0.67, respectively) confirms that a smaller release angle tends to result in faster and more accurate serve (Adin-Marian & Marilena, 2015). These findings are consistent with a study by Zahalka et al. (2022), which found that elite players tend to have smaller ball release angles than mid-level players (T. D. Simona et al., 2015) (Croitoru et al., 2013)(Destriana et al., 2021).

The 3.2% increase in contact height with the ball contributed to an increase in service speed and accuracy. The positive correlation between the height of contact with the ball and service performance (r = 0.71 for speed and r = 0.58 for accuracy) confirms the importance of optimal contact points. These results are in line with the research of Chen et al. (2024), which demonstrated that higher contact points allow for more favorable serve angles and reduce the likelihood of the ball hitting the net.

Practical Implications

The results of this study have several practical implications for volleyball training (1) Focus on Arm Angular Speed: The exercise program should emphasize on increasing arm angular speed, for example through plyometric exercises for the arms or exercises with

resistance bands; (2) Shoulder Rotation Optimization: Shoulder flexibility and mobility exercises should be integrated into warm-up routines and strength training programs to increase range of motion; (3) Lower Extremity Strengthening: Squat and jump squat exercises can help improve leg strength and power, which is important for optimizing knee flexion angle and energy transfer; (4) Ball Release Technique: Coaches should focus on teaching efficient ball release techniques, with an emphasis on smaller release angles. (5) Contact Height Training: Exercises that improve vertical jump and contact timing with the ball should be included in the training program.

Limitations and Future Research Directions

While this study provides valuable insights, some limitations need to be considered. The relatively small sample size (N=30) and focus on one club limit the generalization of results. Future research may use larger and more diverse samples to increase external validity. In addition, the study focused on the short-term effects (8 weeks) of biomechanics-based interventions. Longitudinal studies are needed to assess the long-term effects and retention of performance improvements. The use of more advanced motion analysis technologies, such as 3D motion capture, can provide a deeper understanding of the biomechanical mechanisms underlying performance improvement. Finally, future research may explore the interaction between biomechanical factors and other factors such as athlete psychology, muscle strength, and flexibility in influencing volleyball service performance.

CONCLUSION

This study confirms the important role of biomechanics in improving volleyball service performance. Biomechanics-based training interventions have been shown to be effective in improving service speed and accuracy through optimization of key biomechanical parameters. These findings highlight the importance of integrating the principles of biomechanics into volleyball training programs, even at the semi-professional club level. With a better understanding of the biomechanical mechanisms underlying effective serving, coaches and athletes can design more targeted training strategies, which can ultimately improve individual and team performance as a whole.

The results of this study can be applied practically in several ways: (1) Development of a structured training program that integrates biomechanical analysis for service techniques; (2) The use of motion analysis technology to provide direct feedback to athletes; (3) Preparation of biomechanics-based technical guidelines that can be used by trainers at various levels of

competition; (4) Implementation of special training sessions focusing on optimizing key biomechanical parameters in service techniques.

Future Research Recommendations: (1) Exploring the biomechanical aspects of various volleyball skills such as spikes, blocks, and passing in athletes of various ability levels; (2) Conduct longitudinal studies to assess the long-term effects of biomechanics-based training; (3) Investigate the relationship between biomechanical parameters and injury risk to develop prevention strategies; (4) Analyze the differences in movement biomechanics between male and female athletes to optimize gender-specific training programs; (5) To examine the influence of anthropometric factors on biomechanical parameters to develop a more personalized training approach.

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