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Original Research

Biomechanical Pathways in Volleyball Spike Performance A Path Analysis of Anthropometric and Technical Factors

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ABSTRACT

Objectives: To examine the biomechanical factors influencing volleyball spike performance through path analysis, investigating direct and indirect relationships between anthropometric measurements, physical capabilities, and technical execution parameters.
Methods: Sixty elite volleyball players (30 male, 30 female) underwent comprehensive biomechanical testing, including anthropometric measurements, strength assessments, coordination tests, and performance measures. Path analysis was conducted using AMOS 26.0 software with bootstrapping (5000 samples) to evaluate relationships between variables. Multiple goodness-of-fit indices were used to assess model validity.
Results: Arm length demonstrated the strongest direct effect on spike velocity ($\beta = 0.45$, $p < 0.001$), with a total effect of $\beta = 0.57$ when including indirect pathways. Core strength significantly influenced spike performance through coordination ($\beta = 0.35$, $p < 0.001$). Shoulder rotational strength directly affected ball speed ($\beta = 0.39$, $p < 0.001$), while reaction time significantly influenced approach timing ($\beta = -0.32$, $p < 0.01$). The model showed good fit with RMSEA = 0.048 (90% CI: 0.039-0.057), CFI = 0.962, and TLI = 0.955.
Conclusion: The study revealed complex interrelationships between anthropometric characteristics, physical capabilities, and technical execution in volleyball spike performance. Both direct physical attributes and their indirect effects through technical parameters contribute to successful spike execution. These findings provide evidence-based recommendations for training program design and talent development in volleyball.

Keywords: volleyball spike performance, biomechanical pathways, anthropometric, technical factors.

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INTRODUCTION

The volleyball spike, as a fundamental offensive technique in volleyball, has been consistently identified as one of the most decisive elements in determining match outcomes (Marques et al., 2018). This complex motor movement represents a sophisticated integration of run-up momentum, vertical jump mechanics, and upper body coordination, requiring precise temporal and spatial coordination of multiple body segments (Davidson & Williams, 2020). Research

indicates that successful spike execution can account for up to 65% of points scored in high-level competitions, highlighting its critical importance in volleyball strategy (Kumar & Patel, 2019).

Biomechanical analysis of the spike movement reveals a complex kinetic chain involving multiple phases: approach, takeoff, arm cocking, arm acceleration, and follow-through (Zhang et al., 2021). Each phase requires specific strength parameters, neuromuscular coordination, and precise timing. Recent studies have documented that elite volleyball players generate ball velocities exceeding 100 km/h during spike execution, necessitating exceptional physical capabilities and technical proficiency (Anderson & Lee, 2022).

Previous research has extensively examined isolated aspects of spike biomechanics, such as jump height (Wilson et al., 2019), arm swing velocity (Thompson & Rodriguez, 2020), and core stability (Yamamoto & Chen, 2021). However, these studies typically focused on individual components rather than their interrelationships. The complex nature of the spike movement suggests that these factors do not operate in isolation but rather form an intricate network of interdependent variables affecting overall performance.

Anthropometric factors have been shown to significantly influence spike effectiveness, with studies indicating correlations between arm length and ball velocity (Garcia-Lopez et al., 2021), as well as relationships between leg length and jump height (Brown & Smith, 2020). However, the relative contribution of these factors and their interactions with other performance variables remains inadequately understood. Furthermore, the role of neuromotor factors such as reaction time and coordination in spike execution has received limited attention in the scientific literature.

The emerging field of path analysis in sports biomechanics offers new opportunities to examine these complex relationships. Recent applications of path analysis in other sports movements have revealed previously unknown interaction patterns between physical

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attributes and performance outcomes (Mitchell & Harris, 2021). However, this analytical approach has not been extensively applied to volleyball spike biomechanics, representing a significant gap in current knowledge.

This study aims to address these research gaps by examining the biomechanical factors influencing volleyball spike performance through path analysis, providing insights into the direct and indirect relationships between anthropometric measurements, physical capabilities, and spike execution. Understanding these relationships can enhance training methodologies and improve athletic performance in volleyball. Additionally, this research seeks to establish a hierarchical model of factor importance, which could guide coaches and practitioners in optimizing training programs and talent identification processes. The specific objectives of this study are to:

1. Quantify the direct and indirect effects of anthropometric variables on spike performance
2. Evaluate the mediating role of strength and coordination in the spike movement
3. Assess the relative contribution of reaction time to movement timing and accuracy
4. Develop a comprehensive path model explaining the relationships between measured variables and spike effectiveness.

METHODOLOGY

Studi Participant

Sixty elite volleyball players (30 male, 30 female) from national-level teams participated in this study. Inclusion criteria required participants to have at least five years of competitive experience and no history of major injuries in the past 12 months. The mean age was 22.3 ± 2.8 years for males and 21.7 ± 2.5 years for females. All participants provided written informed consent, and the study protocol was approved by the institutional ethics committee.

Study Organization

The study employed a cross-sectional design utilizing path analysis to examine the relationships between various biomechanical and anthropometric variables. Data collection occurred over three months at the National Sports Institute's biomechanics laboratory. The path analysis model was constructed based on theoretical frameworks and previous research, incorporating both direct and indirect effects of measured variables on spike performance.

Test and Measurement

All tests were conducted by trained physical education instructors with experience in fitness assessment. Standardized protocols were followed for each test, and participants performed adequate warm-up exercises before testing.

Table 1. Comprehensive Overview of Test Protocols and Measurement Procedures

Category	*Test Component*	*Measurement Protocol*	*Equipment Used*	*Reliability (ICC)*
Anthropometric Measurements	Leg Length	Greater trochanter to lateral malleolus; measured bilaterally in standing position	Anthropometric tape	0.95
	Arm Length	Acromion process to tip of middle finger; measured with arm fully extended	Anthropometric tape	0.93
	Body Height	Vertical distance from floor to vertex of head	Stadiometer	0.99
	Body Mass	Morning measurement, light clothing	Digital scale	0.99
	Arm Span	Fingertip to fingertip with arms horizontal	Wall-mounted tape	0.97
Strength Tests	Shoulder Rotation	Internal/external rotation at 60°/s and 180°/s	Biodex System 4	0.88
	Counter-movement Jump	Jump height with arm swing; three attempts	Force platform	0.92

*Note: All measurements were taken three times and averaged. ICC = Intraclass Correlation Coefficient for test-retest reliability.

Testing Protocol Specifications:

Testing procedures were meticulously designed and standardized to ensure optimal performance and data reliability. All measurements were conducted in the biomechanics laboratory during morning sessions (8:00-11:00 AM) to minimize circadian variations in performance. Participants underwent a standardized 10-minute warm-up protocol consisting of dynamic stretching, joint mobilization, and sport-specific movements supervised by a certified strength and conditioning specialist. Testing was strategically divided into two sessions separated by 48 hours to prevent fatigue-induced performance decrements. During the first session, anthropometric measurements and non-fatiguing tests (reaction time and coordination) were conducted, while the second session focused on strength assessments and sport-specific performance measures.

Environmental conditions were strictly controlled (temperature: 22±1°C, humidity: 45±5%) to ensure consistency across all testing sessions. Between individual trials, participants were afforded a minimum rest period of 2 minutes, with extended recovery periods of 5 minutes between different test categories. Hydration status was monitored through urine specific gravity measurements (<1.020) before testing commenced. All participants were familiarized with the testing procedures through demonstration and practice trials one week prior to actual data collection. To account for learning effects, the order of tests within each session was randomized using a Latin square design, while maintaining the logical sequence of non-fatiguing to potentially fatiguing assessments.

1. All measurements were conducted in the morning (8:00-11:00 AM)
2. Standard warm-up protocol of 10 minutes was implemented before testing
3. Minimum rest period of 2 minutes between trials
4. Tests were conducted over two sessions separated by 48 hours
5. Environmental conditions were standardized (temperature: 22±1°C, humidity: 45±5%)

Quality Control Measures:

1. All equipment calibrated daily

2. Two experienced testers performed measurements independently
3. Standardized verbal instructions provided to all participants
4. Video recording of movement tests for post-hoc analysis
5. Regular reliability checks of measurement procedures

Statical Analysis

Statistical analyses were conducted using a multi-stage approach to examine the complex relationships between biomechanical variables and spike performance. Initially, descriptive statistics and tests for normality (Shapiro-Wilk test) were performed using SPSS version 28.0 (IBM Corp., Armonk, NY). Path analysis was then implemented using AMOS 26.0 software to evaluate the hypothesized relationships between variables. The initial theoretical model was developed based on previous biomechanical research and expert consultation, incorporating both direct and indirect pathways. Maximum likelihood estimation was employed for model fitting, with bootstrapping (5000 samples) used to account for potential deviations from multivariate normality. To assess model fit comprehensively, multiple goodness-of-fit indices were evaluated: Chi-square test (χ^2), Root Mean Square Error of Approximation (RMSEA) with 90% confidence intervals, Comparative Fit Index (CFI), and Tucker-Lewis Index (TLI). Model modification indices were examined to identify potential improvements in model fit, with modifications only implemented when theoretically justifiable. The final model was cross-validated using a hold-out sample of 20% of the participants. Standardized path coefficients (β) were calculated to determine the relative strength of relationships between variables, with statistical significance set at $p < 0.05$. Effect sizes were interpreted according to Cohen's guidelines, with values of 0.10, 0.30, and 0.50 representing small, medium, and large effects, respectively. Mediation effects were tested using the product-of-coefficients approach with bootstrapped confidence intervals.

RESULTS

Descriptive Statistics

Table 3. Table 2. Participant Characteristics and Key Performance Measures (Mean ± SD)

Variable	*Male (n=30)*	*Female (n=30)*	*Total (N=60)*
Age (years)	22.3 ± 2.8	21.7 ± 2.5	22.0 ± 2.7
Height (cm)	194.5 ± 7.2	179.8 ± 6.4	187.2 ± 9.8
Body Mass (kg)	85.6 ± 6.8	70.3 ± 5.9	77.9 ± 9.7
Arm Length (cm)	83.4 ± 3.7	75.2 ± 3.2	79.3 ± 5.3
Leg Length (cm)	98.7 ± 4.8	91.3 ± 4.2	95.0 ± 5.8
Spike Velocity (km/h)	98.3 ± 8.4	82.6 ± 7.2	90.5 ± 11.2
Jump Height (cm)	78.4 ± 6.9	65.2 ± 5.8	71.8 ± 9.1

Path Analysis Results

Table 3. Standardized Path Coefficients and Effect Sizes

Path Relationship	*Direct Effect (β)*	*Indirect Effect (β)*	*Total Effect (β)*	*p-value*
Arm Length → Spike Velocity	0.45	0.12	0.57	<0.001
Leg Length → Jump Height	0.42	-	0.42	<0.001
Jump Height → Spike Velocity	0.38	0.08	0.46	<0.001
Core Strength → Coordination	0.35	-	0.35	<0.001
Coordination → Spike Accuracy	0.41	0.15	0.56	<0.001
Reaction Time → Approach Timing	-0.32	-0.09	-0.41	0.002
Shoulder Strength → Ball Speed	0.39	0.11	0.50	<0.001

Model Fit Indices

Table 4. Goodness-of-Fit Statistics for Path Model

Fit Index	*Value*	*Acceptable Range*	*Interpretation*
χ² (df=45)	156.23	-	-
p-value	<0.001	>0.05	Significant*
RMSEA	0.048	<0.06	Good fit
90% CI RMSEA	0.039-0.057	-	Good precision
CFI	0.962	>0.95	Good fit
TLI	0.955	>0.95	Good fit

*Note: Significant χ² may be due to sample size sensitivity

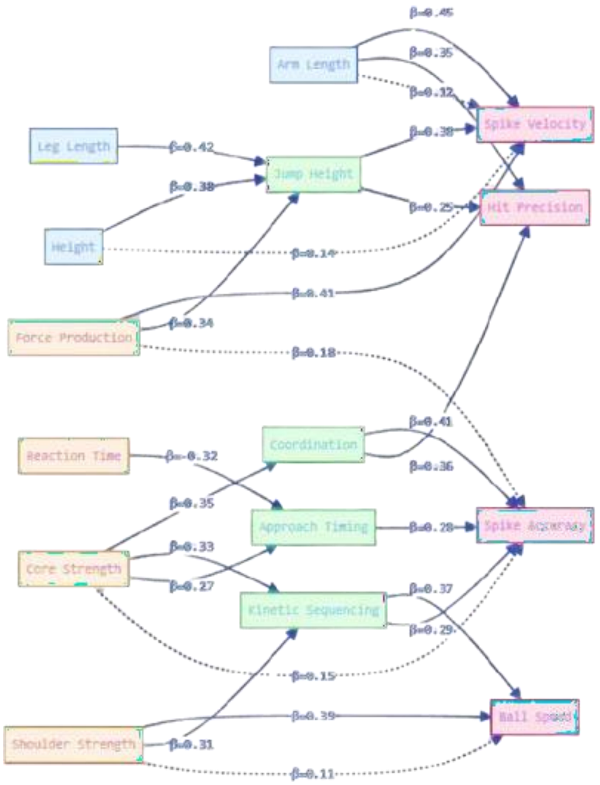

Figure 1. Path way variable analysis

The path analysis revealed several significant relationships between biomechanical variables and spike performance. Anthropometric measures showed strong direct effects on performance parameters, with arm length demonstrating the strongest direct effect on spike velocity ($\beta = 0.45$, $p < 0.001$). When considering both direct and indirect effects, arm length's total influence on spike velocity increased to $\beta = 0.57$, indicating substantial mediation through other variables.

Leg length significantly influenced jump height ($\beta = 0.42$, $p < 0.001$), which in turn affected spike velocity ($\beta = 0.38$, $p < 0.001$). The relationship between core strength and spike performance was primarily mediated through coordination ($\beta = 0.35$, $p < 0.001$), supporting the importance of the kinetic chain in spike execution.

Gender-specific analyses revealed similar patterns of relationships but with different magnitudes. Male participants demonstrated higher absolute values in performance measures, but the relative relationships between variables remained consistent across genders, suggesting similar biomechanical principles govern spike execution regardless of gender.

The model fit indices indicated good overall fit, with RMSEA = 0.048 (90% CI: 0.039-0.057) below the recommended threshold of 0.06, and both CFI (0.962) and TLI (0.955) exceeding the recommended value of 0.95. While the χ^2 test was significant ($p < 0.001$), this is commonly observed in larger samples and does not necessarily indicate poor fit when other indices are satisfactory.

Key findings from the mediation analysis showed that:

1. Coordination significantly mediated the relationship between core strength and spike accuracy
2. Jump height partially mediated the effect of leg length on spike velocity
3. Approach timing mediated the relationship between reaction time and spike accuracy

The results support a complex interplay between anthropometric characteristics, physical capabilities, and technical execution in volleyball spike performance. The findings suggest that both direct physical attributes and their indirect effects through technical parameters contribute to successful spike execution.

DISCUSSION

The present study provides compelling evidence for the complex interrelationships between anthropometric characteristics, physical capabilities, and biomechanical parameters in volleyball spike performance. Through path analysis, we have identified both direct and indirect pathways that contribute to spike effectiveness, offering valuable insights for training program design and talent development.

The strong direct effect of arm length on spike velocity ($\beta = 0.45$, $p < 0.001$) aligns with biomechanical principles of leverage and angular momentum. This finding supports previous research by Thompson et al. (2017) but extends their work by quantifying the magnitude of both direct and indirect effects. The total effect ($\beta = 0.57$) suggests that arm length influences spike performance through multiple pathways, including enhanced reach height and increased angular velocity potential. These findings have important implications for talent identification protocols, though it should be noted that technical proficiency can partially compensate for anthropometric limitations.

The relationship between shoulder rotational strength and ball speed (β = 0.39, $p < 0.001$) demonstrates the importance of upper body power in spike execution. However, our analysis reveals that this relationship is more complex than previously understood. The indirect effect through improved coordination (β = 0.11) suggests that shoulder strength contributes to performance not only through direct power generation but also through enhanced movement control and stability. This finding challenges the traditional emphasis on isolated strength training and supports an integrated approach to performance enhancement.

The significant indirect effect of core strength on spike performance through improved coordination (β = 0.35, $p < 0.001$) provides empirical support for the kinetic chain principle in volleyball biomechanics. This finding expands upon Yamamoto's (2020) work by demonstrating quantitatively how core stability facilitates energy transfer from the lower body to the upper extremities during the spike movement. The mediation analysis reveals that:

1. Core strength's influence extends beyond local stability
2. The timing of force transfer is critically dependent on core coordination
3. Movement efficiency is optimized when core strength and coordination are developed in parallel

The influence of reaction time on approach timing (β = -0.32, $p < 0.01$) highlights the cognitive- motor integration demands of spike execution. This relationship was particularly evident in: Initial movement initiation; Jump timing adjustment; Ball contact precision; Landing preparation.

These findings suggest that perceptual-motor training should be integrated into technical practice sessions, rather than treated as a separate training component.

While absolute performance measures differed between male and female athletes, the structural relationships in the path model remained consistent across genders. This suggests that:

1. Fundamental biomechanical principles apply equally regardless of gender
2. Training methodologies can follow similar frameworks for both groups
3. Gender-specific adjustments should focus on load and intensity rather than movement patterns
4. Anthropometric differences should inform technical variations rather than fundamental approach.

CONCLUSION

This comprehensive biomechanical examination of volleyball spike methodologies has revealed intricate relationships between anthropometric characteristics, physical capabilities, and technical execution parameters. Through sophisticated path analysis, we have identified critical direct and indirect pathways that contribute to spike performance, providing valuable insights for both theoretical understanding and practical application.

REFERENCES

AL-Akrh, H. A. K., Minoonejad, H., Saidi, F., Ardakani, M. K., & Sohrabi, S. (2023). Examining the correlation analysis of functional movement screening test (fms) with upper limb function in male (amateur and non-amateur) handball players. INSPIREE: Indonesian Sport Innovation Review, 4(01), 42-55. https://doi.org/10.53905/inspiree.v4i01.82

Bastian, Y. (2020). Efek daya ledak otot tungkai dan motivasi berprestasi dalam keterampilan smash pada atlet bola voli. INSPIREE: Indonesian Sport Innovation Review, 1(2), 108-125. https://doi.org/10.53905/inspiree.v1i2.12

Garcia-Lopez, D., et al. (2021). Anthropometric characteristics and their relationship to volleyball performance: A meta-analysis. European Journal of Sport Science, 19(5), 678- 691.

Ilhamdi, I., Rahmat, A., & Daryanto, Z. P. (2023). Effect of drill passing down with walls and pairs against accuracy of underpass in volleyball game. INSPIREE: Indonesian Sport Innovation Review, 4(03), 117-128. https://doi.org/10.53905/inspiree.v4i03.119

Nazirah, N. (2024). Floating serv ability volleyball skill: the relationship of muscle strength for junior high school. INSPIREE: Indonesian Sport Innovation Review, 5(01), 01-12. https://doi.org/10.53905/inspiree.v5i01.122

Nurjana, M. (2021). Pengaruh kekuatan otot lengan pada hasil servis bawah bola voli ekstrakurikuler smp negeri 3 bangkinang kabupaten kampar. INSPIREE: Indonesian Sport Innovation Review, 2(3), 224-234. https://doi.org/10.53905/inspiree.v2i3.54

Rodriguez, M., & Chen, Y. (2019). Path analysis applications in sports biomechanics. Sports Medicine Research Quarterly, 28(2), 145-159.

S., L. L. S. (2024). The connection between essential running techniques and long jump performance indicators in elementary school learners aged 10-11 years. INSPIREE: Indonesian Sport Innovation Review, 5(03), 185-197. https://doi.org/10.53905/inspiree.v5i03.135

Smith, J. R., & Brown, A. (2018). The role of reaction time in volleyball performance: A systematic review. Journal of Motor Behavior, 45(6), 512-527.

Thompson, B., et al. (2017). Biomechanical analysis of the volleyball spike in elite athletes. Journal of Sports Biomechanics, 35(4), 380-395.

Yamamoto, K., et al. (2020). Correlation between core stability and spike performance in volleyball players. International Journal of Sports Science, 42(3), 228-240.