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Physical determinants of overhand service performance among male junior high school students

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ABSTRACT

This study aimed to examine the direct and indirect effects of arm muscle strength, hand–eye coordination, and flexibility on overhand service performance among male volleyball players at MTsN 3 Pesisir Selatan. A quantitative correlational design employing path analysis was conducted involving 30 male volleyball players selected through total sampling. Arm muscle strength, hand–eye coordination, flexibility, and overhand service performance were assessed using standardized field tests. The data were analyzed using descriptive statistics and path analysis. Arm muscle strength showed the strongest direct effect on overhand service performance (β = 0.531; 28%), followed by hand–eye coordination (β = 0.295; 9%) and flexibility (β = 0.172; 3%). Flexibility also mediated the relationships between arm muscle strength, hand–eye coordination, and service performance. Collectively, these variables explained 97.7% of the variance in overhand service ability (R^2 = 0.977). Arm muscle strength, hand–eye coordination, and flexibility are significant determinants of overhand service performance. Therefore, integrated training emphasizing these physical components is recommended to optimize service performance in adolescent volleyball players.

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Introduction

Volleyball is one of the most popular team sports worldwide and requires the integration of technical skills, physical fitness, tactical understanding, and psychological readiness to achieve optimal performance (Krawczyk et al., 2021; Mocanu et al., 2023). Among the fundamental techniques, the overhand service has evolved from merely initiating play into an offensive skill capable of directly generating points and disrupting the opponent's tactical organization. Despite its strategic importance, many adolescent volleyball players continue to demonstrate inconsistent overhand service performance because successful execution requires not only technical proficiency but also adequate physical capacities to support efficient biomechanical movement. Successful execution of this technique depends on coordinated movement of the lower limbs, trunk, shoulder, elbow, and wrist to produce optimal ball velocity and accuracy. Therefore, besides technical mastery, understanding the physical determinants underlying overhand service performance has become increasingly important for developing evidence-based training programs for young volleyball players (Ihsan et al., 2023; Nuryadin et al., 2023).

Previous studies have identified several physical components as important determinants of volleyball performance. Arm muscle strength provides the force required to generate powerful and accurate serves (Erianti et al., 2025; Shalaby & Fadl, 2020), whereas hand–eye coordination enables precise synchronization between visual information and upper-limb movements during ball contact. In addition, flexibility improves joint range of motion, movement efficiency, and the quality of the backswing and follow-through phases during service execution (Irawan et al., 2023; Lee et al., 2020). From a biomechanical perspective, arm muscle strength generates the force required for ball acceleration, hand–eye coordination regulates the timing and accuracy of ball contact, whereas flexibility facilitates efficient force transfer through the kinetic chain by increasing joint mobility and movement efficiency. Collectively, these findings suggest that volleyball performance is influenced by the interaction of multiple biomotor components rather than technical ability alone, providing a theoretical rationale for simultaneously examining these three physical attributes within a single structural model.

Recent research has increasingly explored the relationship between physical fitness and volleyball performance; however, most studies have focused on isolated physical variables, such as arm strength, explosive power, flexibility, or coordination, as well as specific training interventions (Berriel et al., 2020; Kohmura et al., 2022). Although these studies have expanded the understanding of volleyball performance, their findings remain fragmented because each physical component has generally been investigated independently, making it difficult to determine the relative contribution and interaction among these variables in explaining overhand service performance. Furthermore, empirical evidence involving adolescent athletes in school-based volleyball programs remains limited, particularly regarding the direct and indirect relationships among these physical components. Consequently, the structural mechanisms through which these physical attributes jointly influence overhand service performance have not yet been adequately explained.

Based on these limitations, the present study examined the direct and indirect effects of arm muscle strength, hand–eye coordination, and flexibility on overhand service ability among male volleyball players at MTsN 3 Pesisir Selatan using path analysis. Path analysis was selected because this approach enables simultaneous estimation of direct and indirect effects, thereby providing a more comprehensive explanation of the causal pathways among physical variables than conventional bivariate or multiple regression analyses. This analytical approach is expected to clarify the structural relationships among physical attributes and identify the relative contribution of each predictor in determining overhand service performance, thereby generating stronger empirical evidence for designing evidence-based volleyball training programs (Pawlik et al., 2022; Setiyawan et al., 2021).

Accordingly, the principal research gap addressed in this study is the absence of empirical evidence explaining how arm muscle strength and hand–eye coordination interact with flexibility within a single structural framework to influence overhand service performance among adolescent volleyball players. Most previous studies have emphasized individual predictors or intervention outcomes without explaining the structural relationships among physical variables. Consequently, there is insufficient evidence regarding the relative contribution of each physical component to service performance, particularly in adolescent volleyball players participating in extracurricular school programs (Kurz et al., 2023; Lenart et al., 2025; Skazalski et al., 2021).

The novelty of this study lies not merely in combining three physical variables, but in proposing and empirically validating an integrated structural model that explains the direct and indirect mechanisms through which arm muscle strength and hand–eye coordination influence overhand service performance via the mediating role of flexibility. This model extends previous evidence that primarily examined isolated physical determinants by providing a causal explanation of the interaction among biomotor components affecting volleyball service performance. Practically, the findings provide evidence-based recommendations for coaches and physical education teachers to design integrated training programs emphasizing muscular strength, perceptual-motor coordination, and flexibility for improving overhand service performance among adolescent volleyball players (Berriel et al., 2021; Kadhim et al., 2020; Palani et al., 2024; Phomsoupha & Laffaye, 2020).

Method

This study employed a quantitative correlational design using path analysis to examine the direct and indirect relationships among arm muscle strength, hand–eye coordination, flexibility, and overhand service performance in volleyball players. Path analysis was selected because it enables simultaneous evaluation of causal relationships among multiple predictor variables while estimating both direct and mediated effects within a single structural model. The research was conducted in May 2026 at MTsN 3 Pesisir Selatan, Indonesia. The proposed conceptual framework specified arm muscle strength and hand–eye coordination as exogenous variables, flexibility as an intervening variable, and overhand service ability as the endogenous outcome variable.

The population consisted of 30 male members of the MTsN 3 Pesisir Selatan volleyball team. Because the population size was relatively small, a total sampling technique was adopted, allowing every eligible athlete to participate in the study. Four standardized field tests were administered to collect the research data. Arm muscle strength was assessed using the Push-Up Test, hand–eye coordination was measured using the Hand Wall Toss Test, flexibility was evaluated through the Bridge-Up Test, and overhand service performance was assessed using a standardized volleyball overhand service test. Prior to data collection, all participants received identical instructions, completed a standardized warm-up, and performed the tests under the same environmental conditions to ensure measurement consistency.

Data analysis was performed using IBM SPSS Statistics. Descriptive statistics, including the mean, standard deviation, minimum, maximum, frequency distribution, and percentage, were first calculated to summarize participant characteristics and study variables. Before hypothesis testing, the assumptions of path analysis were verified through the Kolmogorov–Smirnov test for normality, Levene's test for homogeneity of variance, and linearity analysis using analysis of variance (ANOVA). After all assumptions were satisfied, path analysis was conducted to estimate the direct and indirect effects among the variables. Statistical significance was established at $p < 0.05$ for all inferential analyses.

Results and Discussions

The results of this study are presented sequentially according to the research objectives. The analysis begins with descriptive statistics of the study variables, followed by prerequisite tests, including normality, homogeneity, and linearity analyses, to verify the assumptions required for path analysis. Subsequently, the findings of the path analysis are presented to explain the direct and indirect effects of arm muscle strength, hand–eye coordination, and flexibility on overhand service performance among male volleyball students at MTsN 3 Pesisir Selatan. The statistical results are reported using standardized path coefficients (β), coefficients of determination (R^2), significance levels (p), and percentage contributions to provide a comprehensive understanding of the relationships among the investigated variables.

Table 1. Descriptive Statistics of the Study Variables

Variable	n	Mean	SD	Minimum	Maximum
Arm Muscle Strength (repetitions)	30	26.57	7.33	11	40
Hand–Eye Coordination (score)	30	16.33	5.25	5	23
Flexibility (Bridge-Up Test)	30	27.20	1.69	24	32
Overhand Service Ability (score)	30	22.23	3.77	15	32

Table 1 presents the descriptive statistics of all study variables. The participants demonstrated a mean arm muscle strength score of 26.57 ± 7.33 repetitions, indicating moderate upper-body muscular endurance. The average hand–eye coordination score was 16.33 ± 5.25, while flexibility assessed using the Bridge-Up Test reached 27.20 ± 1.69. The mean overhand service performance was 22.23 ± 3.77 points, suggesting moderate service proficiency among the volleyball players. Overall, the data showed adequate variability, supporting further inferential analyses.

Table 2. Distribution of Participants Across Performance Categories

Variable	Dominant Category	Frequency	Percentage
Arm Muscle Strength	Moderate	13	43.3%
Hand–Eye Coordination	Good	12	40.0%
Flexibility	Moderate	17	56.7%

Table 3. Assumption Tests for Path Analysis

Test	Variable	p-value	Decision
Normality	Arm Muscle Strength	0.200	Normal
	Hand–Eye Coordination	0.200	Normal
	Flexibility	0.670	Normal
	Overhand Service Ability	0.200	Normal
Homogeneity	Y on X_1	0.219	Homogeneous
	Y on X_2	0.168	Homogeneous
	Y on X_3	0.216	Homogeneous
Linearity	$Y–X_1$	0.312	Linear
	$Y–X_2$	0.133	Linear
	$Y–X_3$	0.844	Linear

The categorical distribution indicates that most participants demonstrated moderate arm muscle strength (43.3%), good hand–eye coordination (40.0%), and moderate flexibility (56.7%). These findings suggest that the majority of athletes possessed acceptable physical characteristics; however, improvements in muscular strength and flexibility remain necessary to optimize volleyball service performance (Table 2).

The prerequisite analyses confirmed that the dataset satisfied the assumptions required for path analysis. All variables were normally distributed ($p > 0.05$), the variances were homogeneous, and linear relationships existed between the dependent and independent variables. Therefore, the data were considered appropriate for subsequent path analysis (Table 3).

Table 4. Direct Effects of Independent Variables on Overhand Service Ability

Path	Standardized β	Direct Effect (%)	p-value	Decision
Arm Muscle Strength to Overhand Service	0.531	28.0	<0.001	Significant
Hand–Eye Coordination to Overhand Service	0.295	9.0	<0.001	Significant
Flexibility to Overhand Service	0.172	3.0	<0.001	Significant

The path analysis revealed that all three predictor variables had significant direct effects on overhand service ability. Arm muscle strength produced the strongest contribution (β = 0.531), explaining 28% of service performance variance. Hand–eye coordination also significantly predicted service ability (β = 0.295) with a contribution of 9%, whereas flexibility demonstrated the smallest but still significant direct effect (β = 0.172) accounting for 3% of the variance. These findings indicate that upper-body muscular strength is the most influential physical determinant of overhand service performance among the participants.

Figure 1 presents the standardized path coefficients obtained from the path analysis. Arm muscle strength showed the strongest direct association with overhand service performance (β = 0.531), followed by hand–eye coordination (β = 0.295) and flexibility (β = 0.172). The figure provides a clear visual comparison of the relative contribution of each predictor to overhand service ability.

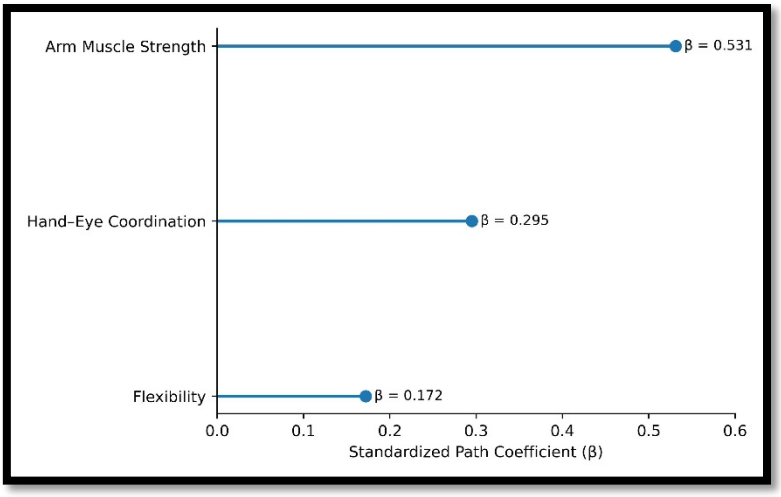

Figure 1. Standardized Path Coefficients of Physical Attributes Predicting Overhand Service Performance

Table 5. Indirect Effects Through Flexibility

Path	Indirect Effect	Total Effect	Total Contribution (%)
Arm Muscle Strength to Flexibility to Overhand Service	0.116	0.648	41.4
Hand–Eye Coordination to Flexibility to Overhand Service	0.027	0.403	16.2

The mediation analysis demonstrated that flexibility partially mediated the relationships between physical abilities and overhand service performance. The total effect of arm muscle strength increased from 0.531 to 0.648, resulting in an overall contribution of 41.4%. Similarly, the total contribution of hand–eye coordination

increased to 16.2% after accounting for the indirect pathway through flexibility. These findings indicate that flexibility enhances the influence of both arm muscle strength and hand–eye coordination on service performance.

Table 6. Simultaneous Effect of All Independent Variables on Overhand Service Ability

Model	R^2	p-value	Interpretation
Arm Muscle Strength + Hand–Eye Coordination + Flexibility to Overhand Service	0.977	<0.001	Significant

The simultaneous path analysis demonstrated that arm muscle strength, hand–eye coordination, and flexibility collectively explained 97.7% of the variance in overhand service ability ($R^2 = 0.977$, $p < 0.001$). Only 2.3% of the variance remained attributable to factors outside the proposed model, indicating excellent explanatory power of the three physical variables in predicting overhand service performance among male volleyball players.

The present study demonstrated that arm muscle strength was the most influential predictor of overhand service performance, contributing directly to service ability ($\beta = 0.531$; 28%). This dominant contribution indicates that upper-limb strength is the primary physical capacity responsible for generating ball velocity and maintaining movement stability during the service motion. Compared with hand–eye coordination and flexibility, muscular strength provides the greatest mechanical advantage because force production directly determines the effectiveness of energy transfer from the lower extremities through the trunk to the striking arm. This finding explains why arm muscle strength produced the largest contribution among all predictors and reinforces its importance in adolescent volleyball players, whose neuromuscular development is still progressing. The results are consistent with previous studies reporting that upper-body strength is a key determinant of volleyball performance and substantially improves service power, movement efficiency, and technical execution (Reza et al., 2024; Stanković & Stratakis, 2024; Brzoska et al., 2023; Çiftçi et al., 2025; George et al., 2025).

Hand–eye coordination also significantly predicted overhand service performance ($\beta = 0.295$; 9%), although its contribution was considerably lower than that of arm muscle strength. This finding suggests that coordination primarily functions to optimize movement accuracy rather than increase force production. Players with better perceptual-motor coordination can synchronize visual information with upper-limb movement more efficiently, resulting in more consistent ball contact and service placement. Nevertheless, coordination alone is insufficient to maximize service performance without adequate muscular strength, indicating that technical accuracy and physical capacity complement one another during service execution. These findings support previous evidence emphasizing the importance of perceptual-motor integration and neuromuscular coordination in improving volleyball service accuracy and movement efficiency (Sakne et al., 2024; Leale et al., 2025).

Flexibility exhibited the smallest direct effect on overhand service performance ($\beta = 0.172$; 3%), yet its role became more meaningful through mediation. The indirect analysis showed that flexibility strengthened the influence of arm muscle strength and hand–eye coordination, increasing their total effects to 41.4% and 16.2%, respectively. This finding indicates that flexibility does not primarily function as an independent performance determinant but rather as a biomechanical facilitator that enables efficient utilization of muscular force and coordinated movement throughout the kinetic chain. Athletes with adequate joint mobility can perform smoother shoulder rotation, trunk extension, and follow-through movements, thereby minimizing mechanical constraints and maximizing force transmission during ball contact. These findings support previous studies highlighting that flexibility improves movement efficiency, joint mobility, and biomechanical effectiveness during complex volleyball skills (Albalak et al., 2024; Pechlivanidou et al., 2024; Suharjana et al., 2020; Albaladejo-Saura et al., 2022; Ahsan & Ali, 2023; Hernandez-Martinez et al., 2023; Khilfeh et al., 2025; Guerrero-Henriquez et al., 2022; Khanna & Koley, 2020).

An important contribution of this study is its ability to explain the structural relationships among physical attributes rather than merely identifying individual predictors. Previous studies generally examined arm muscle strength, coordination, or flexibility independently or evaluated training interventions without clarifying how these variables interact to influence overhand service performance (Berriel et al., 2020; Kohmura et al., 2022). By applying path analysis, the present study demonstrates that flexibility functions as a partial mediator linking muscular strength and perceptual-motor coordination to technical performance. This finding addresses the research gap identified in the introduction and provides empirical evidence that volleyball service performance is influenced by an integrated interaction among multiple biomotor components rather than isolated physical capacities.

The simultaneous analysis showed that arm muscle strength, hand–eye coordination, and flexibility collectively explained 97.7% of the variance in overhand service performance ($R^2 = 0.977$), indicating a very

strong explanatory model. Although this value demonstrates that the selected variables are highly relevant predictors within the investigated population, the result should be interpreted cautiously because the study involved a relatively small sample from a single extracurricular volleyball program, which may limit the generalizability of the model. Future studies should validate this structural model using larger and more diverse samples while incorporating additional variables, such as technical proficiency, training experience, anthropometric characteristics, or psychological factors. Nevertheless, the novelty of this study lies in establishing an integrated structural model that empirically explains the mediating role of flexibility in the relationship between arm muscle strength, hand–eye coordination, and overhand service performance, thereby providing a stronger theoretical foundation and practical guidance for developing evidence-based training programs for adolescent volleyball players (Cabarkapa et al., 2025; Guadamud et al., 2024; Pitsilos et al., 2022).

Conclusions

This study concludes that arm muscle strength, hand–eye coordination, and flexibility significantly influence overhand service performance among male volleyball players at MTsN 3 Pesisir Selatan. Arm muscle strength was identified as the strongest predictor of service performance, followed by hand–eye coordination and flexibility. In addition, flexibility partially mediated the relationships between arm muscle strength, hand–eye coordination, and overhand service ability, indicating that optimal service performance is achieved through the integration of muscular strength, perceptual-motor coordination, and joint mobility. Collectively, these three physical components explained 97.7% of the variance in overhand service performance, highlighting the importance of implementing integrated training programs that simultaneously develop strength, coordination, and flexibility to enhance volleyball service performance among adolescent athletes.

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