



Explosive Arm Power, Hand Eye Coordination, and Volleyball Service Accuracy: Path Analysis

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Abstract

Background: Arm explosive power, hand eye coordination, and overhead-serve performance are related components of youth volleyball, but their cross-sectional associations require cautious interpretation. **Objective:** This study examined a prespecified pathway model linking arm explosive power and hand-eye coordination with two serve-test scores among junior high school extracurricular athletes. **Method:** Twenty students aged 13–15 years (9 boys and 11 girls) were purposively selected from 40 program members. Two regression submodels were estimated. Because all measures were collected in one fixed-order session and the two serve tests both used landing-zone scores, the analysis is descriptive and does not establish temporal or causal mediation. **Results:** Arm explosive power ($\beta = .542$, $p = .004$) and hand-eye coordination ($\beta = .417$, $p = .019$) were associated with the overhead-serve score. In the accuracy submodel, arm explosive power ($\beta = .310$, $p = .019$), hand-eye coordination ($\beta = .334$, $p = .007$), and the overhead-serve score ($\beta = .476$, $p = .003$) were associated with accuracy. Adjusted R^2 values were .557 and .856. Standardized indirect associations were .258 and .198. Sobel results were $p = .016$ and $p = .038$, respectively, but no bootstrap confidence intervals were available. **Conclusion:** The observed coefficients are consistent with the hypothesized pathway model in this selected sample, but small-sample instability, selection bias, unmeasured confounding, and operational overlap between the two serve tests limit inference and generalizability.

Keywords: arm explosive power; hand-eye coordination; overhead serve; serve accuracy; mediation analysis

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A. Introduction

Volleyball is classified as a net/wall game and requires coordinated physical, technical, and tactical performance. In school extracurricular programs, the overhead serve is a relevant learning outcome because successful execution requires force production, visual tracking, timing, and controlled hand–ball contact. Development varies within the same chronological age; therefore, this study does not assume a universal sensitive period or equivalent biological maturity among students aged 13–15 years (Valladares et al., 2020).

The overhead serve initiates the rally and requires the player to project the ball over a regulation-height net while controlling its landing location. The archived manuscript referred to preliminary percentages of successful and accurate serves, but it did not retain the number observed, observation date, trial count, or operational cut-offs. Those unverifiable percentages were removed. The height of the net used in the main test and whether it was adjusted for age or sex were also not documented and should be reported from the original testing record.

Arm explosive power describes the capacity to produce force rapidly. Volleyball biomechanics research provides a plausible rationale for

examining upper-extremity power in relation to an overhead serve, but the present study did not measure joint kinetics, segment sequencing, ball velocity, or a minimum power threshold. Accordingly, the medicine-ball score is treated as a general field indicator associated with serve-test performance, not as proof of a biomechanical mechanism or necessary threshold (Bompa & Buzzichelli, 2019; Liu et al., 2025).

Hand–eye coordination supports visual tracking, toss control, swing timing, and hand–ball contact. The wall-toss test used here is a general visuomotor proxy rather than a volleyball-specific coordination measure. Its relationship with an overhead serve is theoretically plausible, but convergent validity against sport-specific kinematic or ball-contact measures was not evaluated in this sample (Li et al., 2024).

Previous volleyball studies have reported associations between physical or coordinative measures and technical performance, but the reviewed literature was not a systematic search and cannot support claims that a pathway analysis has never or rarely been conducted. The contribution of the present study is therefore contextual: it applies a prespecified two-submodel regression decomposition to one junior high school extracurricular group. A major

measurement concern is that both the proposed mediator and outcome were scored from serves directed toward court zones. Unless the overhead-serve score includes independently rated technique indicators, the constructs may be operationally overlapping and the indirect pathway may partly reflect criterion contamination.

The hypothesized ordering was arm explosive power and hand-eye coordination $\rightarrow$ overhead-serve score $\rightarrow$ serve-accuracy score. This order was motivated by a conceptual distinction between general physical or visuomotor capacity, task execution, and spatial outcome. Empirically, however, all tests were collected in one session and temporal precedence was not established. Path analysis decomposes covariance conditional on the specified model; it does not identify causality, exclude reverse ordering, or control unmeasured factors such as sex, maturation, anthropometry, training experience, and playing position (Kline, 2023).

The study examined five direct associations: $X_1 \rightarrow Y_1$, $X_2 \rightarrow Y_1$, $X_1 \rightarrow Y_2$, $X_2 \rightarrow Y_2$, and $Y_1 \rightarrow Y_2$; and two model-based indirect associations: $X_1 \rightarrow Y_1 \rightarrow Y_2$ and $X_2 \rightarrow Y_1 \rightarrow Y_2$. The objective was to estimate these sample coefficients and their uncertainty, not to demonstrate causal effects.

B. Methods

Research Design. This was a single-site, cross-sectional quantitative correlational study using two ordinary least-squares regression submodels. The pathway specification was theory-informed, but the observational design cannot establish temporal order or causal mediation. Alternative models, including reversed ordering of the serve measures or a common underlying serve-performance construct, may fit the same covariance pattern.

Population and Sample. The population comprised 40 students enrolled in the volleyball extracurricular program at SMP Negeri 1 Majalengka. Twenty students (9 boys and 11 girls), aged 13–15 years, were purposively selected. Eligibility required at least three months of active participation, no acute injury, availability for all tests, and a non-libero position. The archived record did not show how many of the other 20 students failed each criterion, whether eligibility was assessed independently of serve proficiency, or the distribution of age, grade, height, mass, training exposure, playing position, and competition level. Excluding liberos may reflect their different competition serving role, but it may also introduce selection bias. No a priori power analysis was retained; with $n = 20$ and three predictors in the second submodel, estimates are

vulnerable to overfitting and should be regarded as exploratory.

Research Variables. The exogenous variables were arm explosive power (X_1) and hand–eye coordination (X_2). The model treated the overhead-serve score (Y_1) as an intermediate variable and the serve-accuracy score (Y_2) as the final outcome. This statistical role does not resolve the empirical overlap between Y_1 and Y_2 .

Research Instruments. Arm explosive power was assessed with a two-hand medicine-ball put using a 3-kg ball; the best of three distances was retained and later expressed as a T-score. Hand–eye coordination was assessed with a 60-second wall-toss task; the best of two trials was retained. The overhead-serve test comprised six attempts scored 0–4 by landing zone (maximum 24), and the accuracy test comprised ten attempts scored 0–3 by landing zone (maximum 30). The source file did not retain the medicine-ball starting posture, measuring device, foul rule, recovery interval, age-specific justification for 3 kg, wall distance, target dimensions, ball type, throwing hand or pattern, court-zone dimensions, service distance, net height, target sequence, net/out rules, or diagrams. These protocol details must be recovered from the testing manual or field record before replication. Selecting the best trial can yield optimistic

scores; the rationale and trial-level reliability were not available.

Measurement Quality. Three experts—a sport-measurement specialist, a volleyball specialist, and a language specialist—reviewed the instruments. The archived manuscript did not provide item blueprints, individual ratings, Aiken’s V or content-validity-index values, decision thresholds, or revisions. It also stated that test–retest reliability was high but did not report the pilot-sample size and characteristics, retest interval, coefficient type and value for each measure, confidence intervals, or standard error of measurement. Because service scoring may involve judgment, assessor blinding, inter-rater reliability, and the specific technical indicators separating Y_1 from Y_2 are also required. Thus, measurement validity and reliability cannot be independently verified from the manuscript.

Data Collection and Ethics. Testing occurred in May 2026 on the school volleyball court after a standardized warm-up. The fixed order was anthropometry, medicine-ball put, wall toss, overhead-serve test, and accuracy test. The archived record did not specify rest intervals, assessor number and qualifications, assessor training or blinding, environmental conditions, counterbalancing, safety screening,

adverse-event procedures, or whether fatigue influenced the final tests. School permission was acknowledged, but the ethics-review authority and approval number, written parental or guardian consent, student assent, confidentiality procedure, right to withdraw, and injury-management protocol were not documented in the manuscript. These items must be verified from original records before publication and must not be inferred retrospectively.

Data Analysis. IBM SPSS Statistics 26 was used. Descriptive statistics were reported for the four observed scores. Shapiro–Wilk and Kolmogorov–Smirnov tests described marginal distributions but do not establish normal regression residuals. Archived outputs did not include residual Q–Q plots, partial-residual plots, leverage, Cook’s distance, Mahalanobis distance, or multivariate-outlier diagnostics; therefore, regression assumptions and influential cases could not be fully reassessed. Linearity and Glejser tests were retained as limited screening evidence and interpreted cautiously. Durbin–Watson and runs-test conclusions were removed because case ordering in this cross-sectional sample was not meaningful. Two regressions were estimated: Y_1 on X_1 and X_2 , and Y_2 on X_1 , X_2 , and Y_1 . Standardized coefficients are denoted β . Unstandardized 95% confidence intervals

were calculated as $B \pm t_{critical} \times SE$ using $df = 17$ and $df = 16$, respectively. Indirect associations were reported both as standardized products and as unstandardized $a \times b$ products. The Sobel test was retained as the analysis originally conducted, but its normal-product approximation is unreliable in a sample this small; participant-level data were unavailable for bootstrap confidence intervals, cross-validation, or optimism correction (Fritz & MacKinnon, 2007; MacKinnon et al., 2004; Preacher & Hayes, 2004).

Path Model. The prespecified model allowed X_1 and X_2 to covary and included residual terms for Y_1 and Y_2 . Residual path coefficients derived from the reported R^2 values were $\sqrt{(1-.604)} = .629$ and $\sqrt{(1-.879)} = .348$. The archived output did not report the X_1 – X_2 correlation. The diagram is therefore a descriptive representation of the fitted sample model, not a causal graph.

C. Result and Discussion

Descriptive Statistics. Table 1 summarizes the four measures. X_1 is reported as a T-score, although the method recorded medicine-ball distance in meters; the transformation formula, reference norm, and raw-distance summary were not retained. Standardizing only X_1 reduces substantive interpretability and should be

corrected from the original dataset. Score ranges show observed dispersion but do

not, by themselves, establish model adequacy.

Table 1. Descriptive Statistics of Research Variables

Variable	N	Minimum	Maximum	Mean	SD
Arm explosive power (X_1)	20	41.00	61.00	51.35	6.41
Hand-eye coordination (X_2)	20	23.00	37.00	27.90	3.78
Overhead service ability (Y_1)	20	10.00	23.00	15.85	3.90
Service accuracy (Y_2)	20	12.00	28.00	18.65	4.80

Assumption Screening. Table 2 reports marginal normality tests. None was statistically significant at $\alpha = .05$, but failure to reject normality with $n = 20$ is not confirmation of normality and does not

substitute for residual diagnostics. The required graphical and influence diagnostics were not available in the manuscript.

Tabel 2. Normality Test

Variable	Shapiro-Wilk	df	Sig.	K-S	Sig.	Skewness/SE	Kurtosis/SE	Decision
X_1	0.940	20	0.242	0.128	0.200	-0.280	-1.236	Normal
X_2	0.930	20	0.156	0.192	0.058	1.548	0.087	Normal
Y_1	0.957	20	0.495	0.136	0.200	0.627	-0.623	Normal
Y_2	0.937	20	0.209	0.154	0.120	1.006	-0.819	Normal

Table 3 reports the available linearity screening. The linear components were significant and deviation-from-linearity tests were not significant. Because these tests have limited power in

a sample of 20, the results are compatible with, but do not prove, linearity; scatterplots and partial-residual plots are needed for a defensible assessment.

Table 3. Linearity Test Results

Relationship	F Linearity	Sig.	F Deviation	Sig.
$X_1 \rightarrow Y_1$	10.999	0.011	0.565	0.804
$X_2 \rightarrow Y_1$	9.540	0.015	1.073	0.470
$X_1 \rightarrow Y_2$	20.749	0.002	1.031	0.493
$X_2 \rightarrow Y_2$	23.387	0.001	1.571	0.267
$Y_1 \rightarrow Y_2$	57.711	0.000	0.934	0.550

Table 4 shows VIF values from 1.101 to 2.525 and tolerance values from .396 to .908. No severe coefficient inflation was indicated by a conservative VIF threshold of 5. Nevertheless, these

diagnostics do not address criterion contamination between Y_1 and Y_2 , and the predictor correlation matrix was not retained.

Table 4. Multicollinearity Diagnostics

Model	Predictor	Tolerance	VIF	Decision
Substructure 1	X ₁	0.908	1.101	No multicollinearity
	X ₂	0.908	1.101	No multicollinearity
Substructure 2	X ₁	0.543	1.842	No multicollinearity
	X ₂	0.649	1.540	No multicollinearity
	Y ₁	0.396	2.525	No multicollinearity

Table 5 presents the available Glejser screening. Predictor associations with absolute residuals were not statistically significant; accordingly, no evidence of heteroscedasticity was detected by this test. This wording does not

confirm homoscedasticity, particularly without residual-versus-fitted plots. Autocorrelation statistics were removed because the cross-sectional case order had no documented temporal meaning.

Table 5. Heteroscedasticity and Autocorrelation Test Results

Model	Test	Statistic	Sig.	Decision
Substructure 1	Glejser (X ₁)	r = 0.282	0.229	Homoscedastic
	Glejser (X ₂)	r = -0.222	0.347	Homoscedastic
	Durbin-Watson	1.627	—	No autocorrelation
Substructure 2	Glejser (X ₁)	r = 0.159	0.504	Homoscedastic
	Glejser (X ₂)	r = 0.113	0.635	Homoscedastic
	Glejser (Y ₁)	r = 0.354	0.126	Homoscedastic
	Durbin-Watson	2.359	—	Inconclusive
	Runs test	—	0.443	No autocorrelation

Path Model Estimates. Submodel 1 yielded $R^2 = .604$ and adjusted $R^2 = .557$, $F(2, 17) = 12.962$, $p < .001$. Submodel 2 yielded $R^2 = .879$ and adjusted $R^2 = .856$, $F(3, 16) = 38.585$, $p < .001$. The high in-sample R^2 for Submodel 2 may reflect real

covariance, overfitting, sample homogeneity, and overlap between the two serve measures. Without bootstrap validation, cross-validation, or an external sample, it should not be interpreted as validated predictive performance.

Table 6. Path Analysis Model Summary

Model	R	R ²	Adjusted R ²	SE	F	Sig.
Substructure 1: X ₁ , X ₂ → Y ₁	0.777	0.604	0.557	2.593	12.962	0.000
Substructure 2: X ₁ , X ₂ , Y ₁ → Y ₂	0.937	0.879	0.856	1.824	38.585	0.000

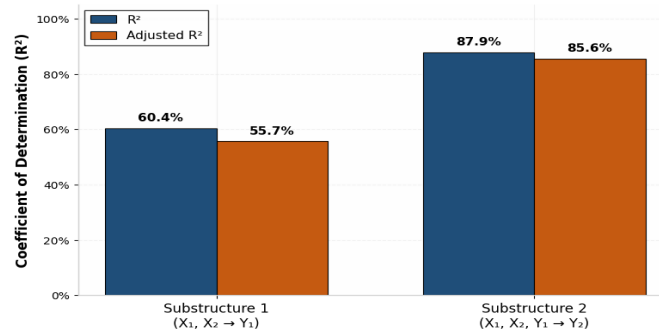


Figure 1. Path Analysis Model Summary

Table 7 presents Submodel 1. Arm explosive power was positively associated with Y₁ ($B = .329$, 95% CI [.124, .534], $\beta = .542$, $p = .004$), as was hand-eye coordination ($B = .429$, 95% CI [.081,

.777], $\beta = .417$, $p = .019$). Confidence intervals were calculated from the reported B and SE ; standardized-coefficient confidence intervals were not recoverable.

Table 7. Path Coefficients for Substructure 1 (X₁, X₂ → Y₁)

Predictor	B	SE	ρ	t	Sig.
Constant	-13.040	5.708	—	-2.285	0.036
X ₁ (Arm explosive power)	0.329	0.097	0.542	3.382	0.004
X ₂ (Hand-eye coordination)	0.429	0.165	0.417	2.601	0.019

Table 8 presents Submodel 2. X₁ ($B = .232$, 95% CI [.043, .421], $\beta = .310$, $p = .019$), X₂ ($B = .425$, 95% CI [.135, .715], $\beta = .334$, $p = .007$), and Y₁ ($B = .587$, 95% CI [.224, .950], $\beta = .476$, $p = .003$) were

positively associated with Y₂. Although β for Y₁ was numerically largest, differences among standardized coefficients were not tested and should not be interpreted as statistically meaningful rankings.

Table 8. Path Coefficients for Substructure 2 (X₁, X₂, Y₁ → Y₂)

Predictor	B	SE	ρ	t	Sig.
Constant	-14.413	4.592	—	-3.139	0.006
X ₁ (Arm explosive power)	0.232	0.089	0.310	2.618	0.019
X ₂ (Hand-eye coordination)	0.425	0.137	0.334	3.093	0.007
Y ₁ (Overhead service ability)	0.587	0.171	0.476	3.438	0.003

Table 9 reports standardized coefficient products. The model-based indirect association was $.542 \times .476 = .258$ for X₁ and $.417 \times .476 = .198$ for X₂. Corresponding total standardized

associations were .568 and .533. These are descriptive decompositions under the specified model, not causal effects; bootstrap confidence intervals were unavailable.

Table 9. Decomposition of Standardized Direct, Indirect, and Total Effects

Path	Direct Effect	Indirect Effect (via Y ₁)	Total Effect
X ₁ → Y ₁	0.542	—	0.542
X ₂ → Y ₁	0.417	—	0.417
X ₁ → Y ₂	0.310	0.258	0.568
X ₂ → Y ₂	0.334	0.198	0.533
Y ₁ → Y ₂	0.476	—	0.476

Table 10 reports the original Sobel calculations based on unstandardized products: $.329 \times .587 = .193$ and $.429 \times .587 = .252$. The asymptotic tests yielded $z = 2.411$, $p = .016$ and $z = 2.074$, $p = .038$. These results differ in scale from Table 9

and should be treated as provisional because the normal approximation to the product is unstable at $n = 20$ and no bootstrap confidence intervals were available.

Table 10. Sobel Test for Indirect Effects

Indirect Path	Indirect Effect (B)	SE	z	Sig.
X ₁ → Y ₁ → Y ₂	0.193	0.080	2.411	0.016
X ₂ → Y ₁ → Y ₂	0.252	0.121	2.074	0.038

Discussion

Arm Explosive Power and the Overhead-Serve Score. The positive X₁–Y₁ coefficient is consistent with a plausible relationship between rapid upper-extremity force production and serve performance. However, the study did not measure kinematics, ball velocity, contact force, or compensatory movement patterns. Biomechanical explanations drawn from external literature should therefore be understood as hypotheses rather than mechanisms demonstrated in these students (Liu et al., 2025). The coefficient may also reflect body size, sex, maturation, or training experience, none of which was controlled.

Hand–Eye Coordination and the Overhead-Serve Score. The positive X₂–Y₁

coefficient is compatible with the role of visual tracking and timing in ball contact. It does not establish that the wall-toss score captures volleyball-specific coordination, nor is $\beta = .417$ a population effect-size estimate with demonstrated stability. Sport-specific validity and confidence intervals should be assessed in a larger sample before instructional thresholds are proposed (Li et al., 2024).

Arm Explosive Power and Serve Accuracy. X₁ remained positively associated with the accuracy score after Y₁ and X₂ were included. The data do not reveal why. Ball speed, force consistency, tactical value, and proximal stability were not measured, so they cannot be presented as observed explanations. The finding is limited to the target-zone accuracy test used

in this session.

Hand–Eye Coordination and Serve Accuracy. X_2 was also positively associated with Y_2 . Visual tracking, toss control, and timing offer plausible interpretations, but online correction and hand-orientation kinematics were not observed. The association supports further sport-specific validation; it does not demonstrate that coordination drills will improve accuracy.

Relationship Between the Two Serve Scores. Y_1 had the numerically largest standardized coefficient in Submodel 2, but coefficient differences were not tested. Both measures used serves to landing zones, so their association may reflect shared task content or scoring rather than a distinct sequence from technical mastery to accuracy. The study did not assess motor-learning stage, automaticity, or attentional allocation.

Indirect Associations. The Sobel calculations were consistent with the hypothesized statistical pathway, but the cross-sectional design does not validate a mechanism. The standardized indirect-to-total ratios were approximately 45% for X_1 and 37% for X_2 ; these are unstable descriptive proportions under the fitted model, not percentages of causal influence. Reverse ordering, a latent common serve-performance factor, and confounding could generate similar associations. Modern

mediation guidance favors bootstrap or product-distribution confidence intervals and adequate sample-size planning (Fritz & MacKinnon, 2007; MacKinnon et al., 2004; Preacher & Hayes, 2004).

Practical Implications and Limitations. The results identify candidate components for future training research, not demonstrated intervention effects. A subsequent experiment could test whether medicine-ball or coordination exercises combined with standardized serve instruction improve independently measured technique and accuracy. The present evidence is limited by $n = 20$; purposive selection of half the program; no a priori power analysis; single-site recruitment; unreported age, maturation, anthropometry, position, and training distributions; fixed test order and possible fatigue; incomplete instrument and assessor reliability; possible Y_1 – Y_2 contamination; unavailable residual and influence plots; no bootstrap inference or external validation; and the use of all measures in one session. These constraints also limit the interpretation of the high R^2 .

D. Conclusion

In this selected sample of 20 junior high school volleyball participants, arm explosive power and hand–eye coordination were positively associated with the overhead-serve and serve-

accuracy scores in the prespecified regression pathway model. Five direct paths and two model-based indirect associations met the original $p < .05$ criterion. These results are consistent with, but do not prove, the proposed ordering. The study cannot establish causal direction, clinical or instructional thresholds, or training effectiveness. Larger prospectively planned studies should use transparent recruitment, distinct and validated technique and accuracy measures, participant-level covariates, randomized or counterbalanced testing, bootstrap confidence intervals, and external validation.

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F. Conflict of Interest

The authors declare no conflict of interest.

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