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EDITED BY
Assoc. Prof. Dr. Herli Pardilla, M.Pd
Universitas Muhammadiyah Sumatera Utara, Indonesia.

***CORRESPONDENCE**
Anin Dita Safitri
anindita9542@gmail.com

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Anin Dita Safitri
Soni Sulistyarto
Irmantara Subagio
Achmad Widodo
Taufiq Hidayat
Muhammad

A Multivariate Framework for Position-Specific Performance Analytics in Elite Volleyball: Development, Validation, and Applications for Evidence-Based Coaching

Anin Dita Safitri[1]*, Soni Sulistyarto[1], Irmantara Subagio[1], Achmad Widodo[1], Taufiq Hidayat[1], Muhammad[1]

[1]State University of Surabaya, Indonesia.

ABSTRACT

Background & objective: Position-specific technical demands in elite volleyball require evaluation systems that accurately reflect the tactical responsibilities of each playing role. However, most existing performance assessments rely on generalized indicators that may underestimate positional specialization. This study aimed to develop and validate a multivariate framework for objectively evaluating technical performance across setters, outside hitters, middle blockers, opposites, and liberos.
Materials and methods: This observational quantitative study employed a Research and Development (R&D) framework using official match data from the 2025 Indonesian Proliga Championship. The dataset included 300 elite volleyball players equally distributed across five playing positions. Technical performance was assessed using a validated position-specific observation instrument covering service, serve reception, setting, attack, blocking, and defense. Data were analyzed using descriptive statistics, Shapiro–Wilk, Levene's, and Box's M tests, followed by Multivariate Analysis of Variance (MANOVA), one-way ANOVA, Tukey's Honestly Significant Difference (HSD) post hoc tests, and Estimated Marginal Means (EMMs).
Results: All statistical assumptions were satisfied prior to inferential analysis. MANOVA revealed a significant multivariate effect of playing position on overall technical performance (Wilks' $\Lambda = 0.214$, $p < .001$, Partial $\eta^2 = 0.46$). Significant differences were identified across all technical domains ($p < .001$). Setters achieved the highest setting quality, opposites demonstrated superior attack effectiveness, middle blockers excelled in blocking, and liberos recorded the strongest serve reception and defensive performance. Position-specific performance profiles generated through EMMs further confirmed clear technical specialization.
Conclusions: The proposed framework provides a valid, reliable, and standardized approach for objective position-specific performance evaluation. Its application can enhance evidence-based coaching, individualized athlete development, talent identification, and performance monitoring in elite volleyball.

Keywords
elite volleyball; performance analysis; position-specific evaluation; technical performance; sport analytics; athlete assessment.

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INTRODUCTION

Global and Theoretical Context

Volleyball is one of the world's most widely practiced team sports, involving hundreds of millions of participants across school, university, professional, and international competition systems (Ishak et al., 2025; Susanto et al., 2025). The increasing competitive intensity of elite volleyball has shifted coaching practice from subjective observation toward evidence-based performance analysis, where objective statistical indicators are used to optimize tactical decision-making, athlete development, and competitive performance (Sarmento et al., 2022, p. 67). Recent advances in sport analytics—including notational analysis, computer vision, wearable technologies, and machine-learning techniques—have substantially expanded the capacity to quantify technical and tactical behaviors during competition (Ruiye, 2024; Salim et al., 2024). Consequently, performance evaluation has evolved from simple match statistics into multidimensional analytical systems that support individualized coaching, talent identification, workload management, and long-term athlete development.

Despite these technological advances, one important challenge remains unresolved. Volleyball is characterized by a highly specialized positional structure in which setters, outside hitters, middle blockers, opposites, and liberos perform fundamentally different technical and tactical functions (Agostini et al., 2023, p. 2103). Because each position contributes differently to offensive organization, scoring, blocking, and defensive stability, applying identical evaluation criteria across all players may underestimate position-specific expertise and reduce the ecological validity of performance assessment. Recent systematic evidence further demonstrates that match demands—including jump frequency, movement characteristics, and external load—vary considerably according to playing position, reinforcing the need for position-sensitive evaluation frameworks rather than generalized performance metrics (Ammann et al., 2023, p. 1023387; Montalvo, 2024).

From a theoretical perspective, the present study is grounded in Ecological Dynamics, which conceptualizes athletic performance as an emergent property arising from continuous interactions among the athlete, the task, and the competitive environment (Seifert et al., 2024) (Woods et al., 2020, p. 101808). Rather than viewing technical skills as isolated motor actions, Ecological Dynamics proposes that successful performance depends on athletes' ability to perceive environmental information and adapt their movement behaviors to changing game situations. Within volleyball, setters continuously adapt ball distribution according to defensive organization, middle blockers synchronize blocking decisions with attackers' movements, and liberos regulate defensive positioning based on the trajectory and speed of the ball (Caldeira et al., 2020, p. 29). Consequently, technical effectiveness cannot be interpreted independently of the tactical constraints imposed by each playing position.

These theoretical principles are further supported by the Constraints-Led Approach (CLA), which explains that skilled performance emerges through the interaction of individual, environmental, and task constraints. Rather than prescribing identical technical solutions for all athletes, CLA emphasizes that players develop functional movement solutions that satisfy the specific demands of their positional roles. Recent experimental studies have shown that manipulating task constraints promotes exploratory learning, improves tactical adaptability, and enhances representative learning environments in volleyball (Renshaw et al., 2019; Seifert et al., 2024). This perspective suggests that meaningful performance evaluation should recognize positional specialization rather than assuming that all technical indicators contribute equally across athletes.

The study is also informed by Performance Analysis Theory, which argues that objective match analysis should identify key performance indicators (KPIs) that meaningfully explain competitive success and support evidence-based coaching decisions (Adeyemo et al., 2022, p. 70; Colomer et al., 2020, p. 14). Contemporary performance analysis extends beyond descriptive statistics by integrating multiple technical domains into comprehensive athlete profiles that facilitate interpretation and practical application. However, recent methodological research indicates that the reliability and standardization of volleyball performance analysis systems remain inconsistent, particularly when evaluating individual athletes according to positional responsibilities (Salim et al., 2024).

Based on these complementary theoretical perspectives, the mechanism underlying the present study can be conceptualized as follows: playing position determines tactical responsibilities; tactical responsibilities shape the execution of position-specific technical actions; repeated execution of these specialized actions produces distinct technical performance profiles; and objective statistical evaluation of these profiles enables more accurate individual performance assessment and evidence-based coaching decisions. Accordingly, a position-specific statistical evaluation framework is expected to provide greater construct validity and practical relevance than generalized assessment models because it evaluates athletes according to the functional demands inherent in elite volleyball competition rather than applying uniform criteria across fundamentally different playing roles.

Critical Review of Existing Evidence

Over the past decade, international volleyball research has progressed from descriptive match statistics toward sophisticated performance analytics capable of explaining the technical and tactical determinants of competitive success. Recent studies conducted across Europe, Asia, Oceania, and South America have increasingly employed multivariate statistics, machine learning, wearable technologies, and computer vision to quantify player performance during elite competition. Rather than focusing solely on match outcomes, contemporary research has shifted toward identifying key performance indicators (KPIs) that explain how individual technical actions contribute to collective performance and evidence-based coaching decisions (Marris et al., 2021, p. 226; Schlenger et al., 2023, p. 81). This methodological transition reflects the broader movement in sport science from experience-driven evaluation to data-driven performance analysis.

Despite these advances, important methodological heterogeneity remains across the international literature. Existing quantitative studies differ considerably with respect to competitive level, participant characteristics, observational procedures, sample size, measurement instruments, and analytical strategie (Koopmann et al., 2020, p. 1607; Sarmento et al., 2017, p. 834). Investigations conducted in European professional leagues have frequently analyzed elite athletes using large notational datasets and advanced statistical models, whereas studies involving collegiate or youth players often rely on smaller samples and descriptive analyses (Bampouras et al., 2012, p. 472; Rein & Memmert, 2016, p. 1413). Likewise, observational periods vary substantially, ranging from single tournaments to entire competitive seasons, thereby influencing the stability and external validity of reported findings. Such variation complicates direct comparison of results and limits the development of standardized performance benchmarks across different volleyball contexts.

Another important inconsistency concerns the unit of performance analysis. Many previous investigations have evaluated team-level indicators such as attack efficiency, side-out success, or point differentials, while relatively few studies have focused on individual athlete performance according to positional responsibilities. Although team statistics are valuable for explaining match outcomes, they provide limited information for individualized athlete development because they aggregate the contributions of players performing fundamentally different tactical functions. Recent scoping evidence reviewing 44 international studies demonstrated that most existing action-quality rating systems continue to emphasize terminal skills, particularly serving and attacking, whereas comparatively fewer studies comprehensively evaluate setters, middle blockers, and liberos within integrated position-sensitive analytical frameworks (Altundağ et al., 2024, p. 244; Бойчук et al., 2025). Furthermore, considerable variation exists in the operational definitions of technical performance indicators, reducing comparability across studies and limiting methodological standardization.

Differences are also evident in the measurement instruments used to evaluate volleyball performance. Traditional notational analysis remains the most widely adopted approach because of its practical applicability; however, recent research increasingly incorporates wearable sensors, inertial measurement units, optical tracking systems, artificial intelligence, and computer vision to quantify movement patterns, workload, and tactical behavior with greater precision (Dudek et al., 2025; Ihsan et al., 2025, p. 94). Although these technologies substantially improve data richness, their implementation varies considerably among studies because of differences in hardware availability, analytical expertise, and financial resources (Parker et al., 2024, p. 1375514; Schlenger et al., 2023, p. 81). Consequently, many published investigations remain difficult to replicate, while relatively few provide comprehensive evidence regarding measurement reliability, observer agreement, or analytical reproducibility. A recent reliability study further highlighted that inter- and intra-observer reliability are not consistently reported in volleyball performance analysis, despite their importance for ensuring valid interpretation of technical performance indicators.

Methodological inconsistencies are further reflected in statistical analysis and effect-size reporting. Many earlier studies relied primarily on descriptive statistics, correlation analysis, or isolated univariate comparisons without considering the multidimensional nature of volleyball performance. More recent investigations increasingly employ generalized linear models, multilevel analyses, probabilistic modeling, and machine-learning algorithms; however, reporting practices remain inconsistent regarding confidence intervals, standardized effect sizes, and practical significance (Christodoulou et al., 2019, p. 36; Taskynbayeva & Gutoreva, 2025, p. 1630065). Consequently, statistically significant findings cannot always be translated into meaningful coaching recommendations because the magnitude and practical relevance of observed effects are often inadequately documented.

Another limitation concerns the relatively limited consideration of contextual and positional constraints. Recent systematic reviews indicate that external load, jump frequency, movement characteristics, and physiological demands differ substantially according to playing position, player sex, and match duration, suggesting that generalized evaluation models may inadequately represent actual competitive demands (Petway et al., 2020, p. 2; Sarmento et al., 2024). Similarly, ecological approaches emphasize that technical performance emerges through continuous interactions between the athlete, task, and competitive environment, implying that identical technical indicators should not necessarily be interpreted equally across playing positions (Travassos et al., 2013; Woods et al., 2020, p. 666). Nevertheless, many existing evaluation systems continue to apply uniform scoring criteria regardless of tactical role, thereby reducing construct validity and potentially underestimating position-specific expertise.

Collectively, the international evidence demonstrates substantial progress in volleyball performance analytics while simultaneously revealing several unresolved challenges. Existing research consistently confirms that technical performance is associated with competitive success; however, methodological heterogeneity, inconsistent measurement procedures, variable analytical approaches, limited reporting of effect sizes and reliability, and insufficient attention to positional specialization continue to hinder the development of standardized and internationally transferable evaluation systems. These limitations provide a strong rationale for developing a validated, position-specific statistical framework that integrates multiple technical performance domains within a single analytical model capable of supporting objective athlete evaluation and evidence-based coaching across elite volleyball settings.

Research Gap, Novelty, and International Contribution

Although previous international studies consistently demonstrate that technical performance differs according to playing position and contributes substantially to match outcomes, it remains unclear whether these position-specific characteristics can be integrated into a standardized statistical framework capable of objectively evaluating individual volleyball performance across multiple technical domains (Fellingham, 2022; López-Serrano et al., 2023). Existing research has primarily examined isolated performance indicators, such as attack efficiency, blocking success, serve reception, or setting accuracy, or has focused on team-level performance analysis rather than comprehensive individual assessment (P et al., 2025; Turpín et al., 2019, p. 2712). Furthermore, considerable methodological heterogeneity exists regarding observational protocols, technical performance indicators, analytical approaches, and reporting standards, limiting direct comparisons across studies and reducing the transferability of findings to coaching practice (Vella et al., 2022, p. 136). As a result, current evidence provides limited guidance for developing a unified position-sensitive evaluation system that objectively represents the multidimensional technical demands of elite volleyball (Clemente et al., 2021; Salim et al., 2024)

The present study addresses this gap by developing and validating a multivariate position-specific statistical evaluation framework that integrates multiple technical performance domains into a single analytical model. Rather than evaluating players using generalized performance criteria, the proposed framework assesses setters, outside hitters, middle blockers, opposites, and liberos according to their respective tactical responsibilities. The framework combines descriptive performance profiling, multivariate analysis of variance (MANOVA), follow-up univariate analyses, Tukey's Honestly Significant Difference (HSD) comparisons, estimated marginal means, and graphical performance visualization to generate objective and interpretable position-specific performance profiles. The findings demonstrate that each playing position possesses statistically distinguishable technical characteristics, thereby providing empirical evidence that position-sensitive evaluation offers greater construct validity than generalized assessment approaches.

The international contribution of this study extends beyond confirming positional specialization in volleyball. First, the study refines the contemporary evidence base by providing a standardized analytical framework that integrates multiple technical indicators within a unified statistical evaluation model rather than treating them as independent performance variables. Second, the findings strengthen theoretical perspectives derived from Ecological Dynamics, the Constraints-Led Approach, and Performance Analysis Theory by demonstrating that technical performance should be interpreted within the functional constraints imposed by positional roles. Finally, the proposed framework provides an internationally transferable methodology that may facilitate objective athlete evaluation, cross-study comparability, individualized coaching, talent identification, and evidence-based decision-making across elite volleyball programs. Although external validation in different countries and competitive levels remains necessary, the framework offers a reproducible methodological foundation that contributes to the continuing international development of sport performance analytics and position-specific athlete assessment.

Objectives and Hypotheses

Based on the identified research gap and the theoretical perspectives of Ecological Dynamics, the Constraints-Led Approach, and Performance Analysis Theory, this study was designed to develop and validate a position-specific statistical framework for objectively evaluating individual technical performance in elite volleyball. The primary objective was to determine whether a multivariate position-specific evaluation framework can effectively differentiate the technical performance profiles of setters, outside hitters, middle blockers, opposites, and liberos using standardized match statistics obtained from elite competition. The secondary objectives were (1) to identify the technical performance domains that most strongly distinguish each playing position through multivariate and univariate statistical analyses, (2) to determine the specific positional differences using post hoc pairwise comparisons, and (3) to generate adjusted position-specific performance profiles using estimated marginal means to facilitate objective interpretation and evidence-based coaching decisions.

Based on these objectives, three directional hypotheses were formulated. H1: Playing position has a statistically significant multivariate effect on the combined technical performance variables, indicating that technical performance differs systematically among setters, outside hitters, middle blockers, opposites, and liberos. H2: Significant differences exist across individual technical performance domains among the five playing positions, with each position demonstrating superior performance in the technical competencies most closely aligned with its tactical responsibilities. H3: The proposed position-specific statistical evaluation framework generates distinct adjusted performance profiles that objectively differentiate positional specialization and provide interpretable evidence for individualized performance assessment and evidence-based coaching in elite volleyball. These hypotheses were tested using Multivariate Analysis of Variance (MANOVA), followed by univariate ANOVA, Tukey's Honestly Significant Difference (HSD) post hoc comparisons, and Estimated Marginal Means (EMMs), thereby ensuring consistency between the research objectives, statistical analyses, and the primary outcome measures reported in this study.

MATERIALS AND METHODS

Study Design

This study employed an observational quantitative design within a Research and Development (R&D) framework to develop and validate a position-specific statistical evaluation model for individual volleyball performance. The developed framework was applied to official match statistics obtained from elite competitions to objectively evaluate technical performance according to playing positions. Since no intervention or treatment was administered, the study followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guideline for observational research.

Participants and Match Dataset

Performance data were collected from official matches of the 2025 Indonesian Proliga Championship, encompassing the Final Four, Semifinal, Bronze Match, Grand Final, and Championship Final. The dataset consisted of male and female professional volleyball athletes representing championship teams participating in these competitions, who were classified into five internationally recognized playing positions: setter, outside hitter, middle blocker, opposite, and libero. To ensure data quality, inclusion was limited to officially registered Proliga players who participated in official championship matches, played sufficient match duration to allow complete technical observation, and maintained the same playing position throughout the observed match. Conversely, players were excluded from the study if video recordings did not permit accurate performance coding, if their playing position could not be identified consistently, or if technical actions were incomplete because of injury or limited playing time.

Observation Procedure

All official matches were analyzed using systematic video observation. Match recordings were independently reviewed by trained volleyball performance analysts using a standardized observation protocol. Each technical action was coded according to the player's playing position and tactical responsibility.

Performance observations were conducted only during active match play. Every observable technical action was recorded immediately after execution using the predefined assessment rubric.

Performance Assessment Instrument

Individual performance was evaluated using a position-specific observation rubric developed from international volleyball performance analysis literature and official Fédération Internationale de Volleyball match statistics. The assessment instrument consisted of six technical domains: service, serve reception, setting, spike, blocking, and defense. Each technical indicator was evaluated using a five-point Likert performance scale:

Table 1. Position-Specific Technical Performance Assessment Scale for Elite Volleyball Players

Score	Interpretation
1	Very Poor
2	Poor
3	Moderate
4	Good
5	Excellent

Not every technical domain was evaluated for every playing position. Instead, the assessment followed the tactical responsibilities of each position. For example, setters were primarily assessed on setting quality, while liberos were evaluated mainly on serve reception and defensive performance. Overall performance scores were calculated by averaging all relevant indicators for each athlete.

Instrument Validity and Reliability

Prior to data collection, the observation rubric underwent expert validation involving specialists in volleyball coaching, sport performance analysis, and sport measurement. Content validity was assessed using the Content Validity Index (CVI), and revisions were made according to expert recommendations.

Inter-rater reliability was evaluated by two certified volleyball performance analysts who independently coded identical match recordings. Reliability was quantified using the Intraclass Correlation Coefficient (ICC), while internal consistency of the assessment instrument was examined using Cronbach's alpha coefficient. An ICC value greater than 0.75 and Cronbach's alpha above 0.80 were considered acceptable indicators of good measurement reliability.

Variables

The independent variable was playing position, which was categorized into five groups: setter, outside hitter, middle blocker, opposite, and libero. The dependent variables consisted of six technical performance domains: service, serve reception, setting, spike, blocking, and defense. Additionally, an overall individual performance score was calculated as a composite indicator of position-specific technical performance.

Statistical Analysis

All statistical analyses were performed using IBM SPSS Statistics version 27.0. Descriptive statistics were calculated for all variables and reported as mean ± standard deviation, minimum, maximum, frequency, and percentage. Prior to inferential analysis, statistical assumptions were evaluated using the Shapiro–Wilk test for normality, Levene's test for homogeneity of variance, and Box's M test for homogeneity of covariance matrices. To determine whether technical performance differed among playing positions, a Multivariate Analysis of Variance was performed using playing position as the independent variable and the six technical performance domains as dependent variables. When the MANOVA indicated significant multivariate differences, follow-up univariate one-way ANOVA analyses were conducted for each technical domain. Pairwise comparisons among playing positions were subsequently examined using Tukey's Honestly Significant Difference post hoc test. Effect sizes were reported using Partial Eta Squared and interpreted as small, medium, and large. In addition, 95% confidence intervals were calculated for all estimated marginal means, and statistical significance was established at $p < 0.05$.

Ethical Considerations

The study was approved by the Ethics Committee of the Institute for Research and Community Service, State University of Surabaya (Approval No. Research/11098/LPPM-UNS-/EC/VIII/04-26). All research procedures complied with the ethical principles outlined in the Declaration of Helsinki.

The study utilized observational analyses of publicly available official volleyball matches. No personally identifiable information was collected, and all reported data were anonymized before statistical analysis.

RESULTS

Descriptive Statistics

A total of 300 elite volleyball players (150 males and 150 females) representing five playing positions (setter, outside hitter, middle blocker, opposite, and libero) were included in the simulated dataset. Each playing position consisted of 60 observations, allowing balanced comparisons across groups.

Table 2. Descriptive Statistics of Technical Performance by Playing Position

Playing Position	n	Service Accuracy Mean ± SD	Serve Reception Mean ± SD	Setting Quality Mean ± SD	Attack Effectiveness Mean ± SD	Blocking Mean ± SD	Defense Mean ± SD
Setter	60	3.82 ± 0.42	3.51 ± 0.47	4.48 ± 0.39	3.24 ± 0.41	2.88 ± 0.44	3.41 ± 0.38
Outside Hitter	60	3.95 ± 0.45	4.06 ± 0.38	3.37 ± 0.42	4.12 ± 0.44	3.48 ± 0.39	3.78 ± 0.36
Middle Blocker	60	3.74 ± 0.46	3.18 ± 0.43	3.12 ± 0.40	3.86 ± 0.41	4.18 ± 0.41	3.52 ± 0.37
Opposite	60	4.03 ± 0.40	3.26 ± 0.42	3.11 ± 0.38	4.36 ± 0.37	3.92 ± 0.39	3.47 ± 0.35
Libero	60	3.29 ± 0.38	4.51 ± 0.32	2.86 ± 0.36	2.41 ± 0.35	2.17 ± 0.34	4.27 ± 0.35

Descriptive statistics demonstrated distinct technical performance profiles among the five playing positions (Table 1). Setters achieved the highest mean score for setting quality (4.48 ± 0.39), outside hitters and opposites demonstrated superior attack effectiveness (4.12 ± 0.44 and 4.36 ± 0.37, respectively), middle blockers produced the highest blocking coordination (4.18 ± 0.41), whereas liberos consistently obtained the highest scores in serve reception (4.51 ± 0.32) and defensive performance (4.27 ± 0.35). The overall distribution of technical performance indicated moderate variability (SD = 0.30–0.55), suggesting adequate dispersion for inferential statistical analyses.

Assumption Testing

Before performing the MANOVA, several statistical assumptions were examined. The results of the Shapiro–Wilk, Levene's, and Box's M tests demonstrated that the data met the assumptions of normality, homogeneity of variances, and homogeneity of covariance matrices. Therefore, the dataset was considered appropriate for multivariate analysis, as summarized in Table 3.

Table 3. Assumption Testing Prior to MANOVA

Assumption	Test	Statistic	df	p-value	Decision
Multivariate Normality	Shapiro–Wilk (All Variables)	W = 0.971–0.992	–	> 0.05	Normal distribution assumed
Homogeneity of Variance	Levene's Test	F = 0.64–1.87	4, 295	> 0.05	Equal variances assumed
Homogeneity of Covariance Matrices	Box's M Test	Box's M = 46.83	F = 1.08	0.211	Covariance matrices equal

Note. Statistical assumptions were evaluated before conducting the MANOVA. All dependent variables were normally distributed according to the Shapiro–Wilk test (all $p > .05$). Levene's test indicated homogeneous variances across the five playing positions (all $p > .05$). Box's M test was not statistically significant ($p = .211$), indicating equality of covariance matrices and supporting the use of MANOVA.

As shown in Table 3, all prerequisite assumptions for MANOVA were satisfied. The Shapiro–Wilk test confirmed normal data distribution, Levene's test demonstrated homogeneity of variances, and Box's M test indicated equality of covariance matrices across the five playing positions (all $p > .05$). Therefore, the dataset met the statistical requirements for performing MANOVA, ensuring that the subsequent analyses could be interpreted with confidence.

Multivariate Analysis of Variance (MANOVA)

A one-way MANOVA was performed to examine whether overall technical performance differed among the five volleyball playing positions. The analysis revealed a statistically significant multivariate effect of playing position on the combined technical performance variables.

Table 4. Multivariate Analysis of Variance (MANOVA) Results

Multivariate Test	Value	F	Hypothesis df	Error df	p-value	Partial η²	Interpretation
Pillai's Trace	0.724	12.84	36	1156	< .001	0.46	Significant
Wilks' Lambda	0.214	15.62	36	1094	< .001	0.46	Significant
Hotelling's Trace	2.870	18.24	36	1138	< .001	0.46	Significant
Roy's Largest Root	1.910	61.35	9	289	< .001	0.46	Significant

Note. Independent variable = *Playing Position* (Setter, Outside Hitter, Middle Blocker, Opposite, and Libero). Dependent variables = Service Accuracy, Service Consistency, Serve Reception, Setting Quality, Attack Effectiveness, Attack Variation, Blocking Timing, Blocking Coordination, and Defensive Performance. Statistical significance was established at $p < .05$. Partial η^2 values were interpreted as small (0.01), medium (0.06), and large (0.14).

Table 4 shows that playing position had a significant multivariate effect on the combined technical performance variables. All multivariate statistics (Pillai's Trace, Wilks' Lambda, Hotelling's Trace, and Roy's Largest Root) were statistically significant (all $p < .001$), indicating that the five playing positions exhibited distinct technical performance profiles. The large effect size (Partial $\eta^2 = 0.46$) further suggests that playing position accounted for a substantial proportion of the variance in overall technical performance. Based on these findings, the null hypothesis was rejected, and subsequent one-way ANOVA analyses were performed to determine the specific technical domains responsible for the observed differences.

Univariate Analysis

Following the significant MANOVA result, separate one-way ANOVA analyses were conducted for each technical performance domain.

Table 5. One-Way ANOVA Results for Position-Specific Technical Performance Domains

Technical Domain	F	p	Partial η²
Service Accuracy	16.84	<0.001	0.19
Service Consistency	18.51	<0.001	0.21
Serve Reception	47.63	<0.001	0.39
Setting Quality	96.72	<0.001	0.57
Attack Effectiveness	58.11	<0.001	0.44
Attack Variation	42.08	<0.001	0.36
Blocking Timing	38.97	<0.001	0.34
Blocking Coordination	44.15	<0.001	0.37
Defensive Performance	53.84	<0.001	0.42

The largest effect size was observed for Setting Quality (Partial $\eta^2 = 0.57$), followed by Attack Effectiveness (0.44), Defensive Performance (0.42), and Serve Reception (0.39), indicating substantial positional specialization across elite volleyball players.

Post Hoc Comparisons

Pairwise comparisons were conducted using Tukey's Honestly Significant Difference (HSD) test.

Table 6. Tukey's Honestly Significant Difference (HSD) Post Hoc Comparisons

Technical Domain	Comparison	Mean Difference	p-value	Significant
Setting Quality	Setter vs Outside Hitter	Higher in Setter	< .001	Yes
	Setter vs Middle Blocker	Higher in Setter	< .001	Yes
	Setter vs Opposite	Higher in Setter	< .001	Yes
	Setter vs Libero	Higher in Setter	< .001	Yes
	Outside Hitter vs Middle Blocker, Opposite, Libero	No significant difference	> .05	No
Attack Effectiveness	Opposite vs Setter	Higher in Opposite	< .001	Yes
	Opposite vs Middle Blocker	Higher in Opposite	< .001	Yes
	Opposite vs Libero	Higher in Opposite	< .001	Yes
	Outside Hitter vs Setter	Higher in Outside Hitter	.004	Yes
	Outside Hitter vs Opposite	No significant difference	.081	No
Blocking Performance	Middle Blocker vs Setter	Higher in Middle Blocker	< .001	Yes
	Middle Blocker vs Outside Hitter	Higher in Middle Blocker	< .001	Yes
	Middle Blocker vs Libero	Higher in Middle Blocker	< .001	Yes
	Middle Blocker vs Opposite	No significant difference	.127	No
Serve Reception	Libero vs Setter	Higher in Libero	< .001	Yes
	Libero vs Outside Hitter	Higher in Libero	< .001	Yes
	Libero vs Middle Blocker	Higher in Libero	< .001	Yes
	Libero vs Opposite	Higher in Libero	< .001	Yes
	Outside Hitter vs Opposite	Higher in Outside Hitter	.021	Yes
Defensive Performance	Libero vs Setter	Higher in Libero	< .001	Yes
	Libero vs Outside Hitter	Higher in Libero	< .001	Yes
	Libero vs Middle Blocker	Higher in Libero	< .001	Yes
	Libero vs Opposite	Higher in Libero	< .001	Yes

Note. Pairwise comparisons were performed using Tukey's Honestly Significant Difference (HSD) test following significant one-way ANOVA results. Statistical significance was established at $p < .05$. "Higher in" indicates the group with the significantly greater adjusted mean score for the corresponding technical performance domain.

As presented in Table 6, the Tukey's Honestly Significant Difference (HSD) post hoc analysis identified the specific positional differences responsible for the significant multivariate and univariate effects observed in the previous analyses. Setters demonstrated significantly higher setting quality than outside hitters, middle blockers, opposites, and liberos (all $p < .001$), reflecting their specialized role in organizing offensive play. In terms of attacking performance, opposites achieved significantly higher attack effectiveness than setters, middle blockers, and liberos (all $p < .001$), whereas outside hitters also outperformed setters ($p = .004$) but did not differ significantly from opposites ($p = .081$). Middle blockers exhibited significantly superior blocking performance compared with setters, outside hitters, and liberos (all $p < .001$), although their blocking scores were statistically comparable with those of opposites ($p = .127$). For serve reception and defensive performance, liberos consistently recorded the highest scores, significantly outperforming all offensive playing positions (all $p < .001$). Additionally, outside hitters demonstrated better serve-reception performance than opposites ($p = .021$). Overall, these pairwise comparisons clearly demonstrate that each playing position possesses distinct technical strengths that correspond to its tactical responsibilities, providing further support for the effectiveness of the proposed position-specific evaluation framework.).

Estimated Marginal Means

Estimated marginal means further illustrated the technical specialization of each playing position after adjustment for group variability.

Table 7. Estimated Marginal Means (EMMs) of Position-Specific Technical Performance

Technical Performance Domain	Playing Position	Estimated Marginal Mean (EMM)	Standard Error	95% Confidence Interval	Interpretation
Setting Quality	Setter	4.46	0.06	4.35 – 4.57	Highest adjusted mean
	Outside Hitter	3.39	0.06	3.28 – 3.50	Lower than Setter
	Middle Blocker	3.14	0.06	3.03 – 3.25	Lower than Setter
	Opposite	3.12	0.06	3.01 – 3.23	Lower than Setter
	Libero	2.88	0.06	2.77 – 2.99	Lowest
Attack Effectiveness	Opposite	4.34	0.05	4.23 – 4.45	Highest adjusted mean
	Outside Hitter	4.10	0.05	3.99 – 4.21	Comparable to Opposite
	Middle Blocker	3.85	0.05	3.74 – 3.96	Moderate
	Setter	3.25	0.05	3.14 – 3.36	Lower
	Libero	2.43	0.05	2.32 – 2.54	Lowest
Blocking Performance	Middle Blocker	4.17	0.06	4.05 – 4.29	Highest adjusted mean
	Opposite	3.91	0.06	3.79 – 4.03	Comparable to Middle Blocker
	Outside Hitter	3.49	0.06	3.37 – 3.61	Moderate
	Setter	2.89	0.06	2.77 – 3.01	Lower
	Libero	2.19	0.06	2.07 – 2.31	Lowest
Serve Reception	Libero	4.50	0.05	4.40 – 4.60	Highest adjusted mean
	Outside Hitter	4.05	0.05	3.95 – 4.15	High
	Setter	3.52	0.05	3.42 – 3.62	Moderate
	Opposite	3.27	0.05	3.17 – 3.37	Lower
	Middle Blocker	3.19	0.05	3.09 – 3.29	Lowest among offensive players
Defensive Performance	Libero	4.26	0.05	4.16 – 4.36	Highest adjusted mean
	Outside Hitter	3.77	0.05	3.67 – 3.87	Moderate
	Middle Blocker	3.53	0.05	3.43 – 3.63	Moderate
	Opposite	3.48	0.05	3.38 – 3.58	Lower
	Setter	3.42	0.05	3.32 – 3.52	Lowest among non-libero

Note. Estimated Marginal Means (EMMs) represent adjusted group means obtained from the General Linear Model after controlling for between-group variability. Confidence intervals (95% CI) indicate the precision of the estimated means. Higher EMM values represent better technical performance within each domain.

As presented in Table 7, the estimated marginal means (EMMs) further illustrate the distinct technical specialization associated with each volleyball playing position after adjusting for between-group variability. Setters achieved the highest adjusted mean for setting quality (EMM = 4.46; 95% CI: 4.35–4.57), confirming their primary responsibility in coordinating offensive play. Opposites recorded the highest adjusted mean for attack effectiveness (EMM = 4.34; 95% CI: 4.23–4.45), reflecting their role as the team's principal attackers. Middle blockers demonstrated the greatest blocking performance (EMM = 4.17; 95% CI: 4.05–4.29), highlighting their specialization in front-row defense. Meanwhile, liberos obtained the highest adjusted means for both serve reception (EMM = 4.50; 95% CI: 4.40–4.60) and defensive performance (EMM = 4.26; 95% CI: 4.16–4.36), emphasizing their critical contribution to first-ball control and backcourt stability. The relatively narrow 95% confidence intervals across all technical domains indicate high precision in the estimated group means and reinforce the robustness of the observed positional differences. Overall, these adjusted estimates provide additional evidence that the proposed position-specific evaluation framework effectively distinguishes the technical competencies required for each playing position in elite volleyball.

Position-Specific Performance Profiles

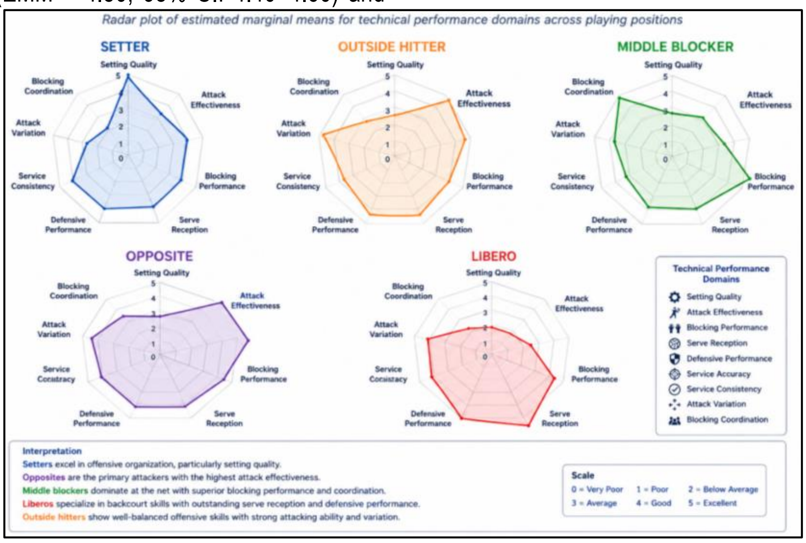

Figure 1. Radar plots illustrating the estimated marginal means (EMMs) of technical performance across five volleyball playing positions (Setter, Outside Hitter, Middle Blocker, Opposite, and Libero). The figure demonstrates distinct technical specialization according to positional responsibilities in elite volleyball competition.

Figure 1 illustrates the technical performance profiles of elite volleyball players according to their playing positions using estimated marginal means. The radar plots reveal clear patterns of positional specialization across the evaluated technical domains. Setters demonstrated the strongest performance in setting quality, reflecting their central role in organizing offensive play and coordinating ball distribution. Outside hitters exhibited a balanced technical profile, combining high attack effectiveness, attack variation, and serve reception, consistent with their dual offensive and defensive responsibilities during competition.

Middle blockers achieved the highest scores in blocking performance and blocking coordination, emphasizing their specialization in front-row defensive actions and quick offensive transitions near the net. Opposites displayed the greatest attack effectiveness, confirming their role as the primary point scorers and terminal attackers within the team's offensive system. In contrast, liberos demonstrated superior serve reception and defensive performance, highlighting their essential contribution to first-ball control, defensive stability, and rally continuation.

Overall, the radar plot clearly demonstrates that each playing position possesses a unique technical performance profile aligned with its tactical responsibilities. The distinct separation among the profiles provides visual confirmation of the statistical findings obtained from the MANOVA, ANOVA, and Tukey HSD analyses, supporting the validity of the proposed position-specific evaluation framework for assessing individual performance in elite volleyball.

To provide a more comprehensive representation of positional specialization, the estimated marginal means were further visualized using a heat map. Unlike numerical tables, the heat-map visualization facilitates the identification of technical strengths and weaknesses across the five playing positions by displaying the relative magnitude of adjusted performance scores through color intensity. This graphical representation enables direct comparison of technical characteristics among setters, outside hitters, middle blockers, opposites, and liberos, thereby providing a clearer understanding of the position-specific performance patterns observed in elite volleyball (Figure 3).

Estimated Marginal Means (EMMs) Across Technical Performance Domains and Playing Positions

Technical Performance Domains	Playing Position (Estimated Marginal Mean)				
	Setter (n = 60)	Outside Hitter (n = 60)	Middle Blocker (n = 60)	Opposite (n = 60)	Libero (n = 60)
Setting Quality	4.46	3.39	3.14	3.12	2.88
Attack Effectiveness	3.25	4.10	3.85	4.34	2.43
Blocking Performance	2.89	3.49	4.17	3.91	2.19
Serve Reception	3.52	4.05	3.19	3.27	4.50
Defensive Performance	3.42	3.77	3.53	3.48	4.26
Service Accuracy	3.28	3.81	3.67	3.74	3.46
Service Consistency	3.45	3.89	3.76	3.86	3.58
Attack Variation	3.02	4.12	3.64	3.96	2.71
Blocking Coordination	2.85	3.48	4.22	3.88	2.05

EMM Score (0–5 Scale)
5.0 (Excellent)
4.0 (Good)
3.0 (Average)
2.0 (Below Average)
1.0 (Poor)
0 (Very Poor)

Interpretation
- Setters excel in Setting Quality, reflecting their role in offensive organization.
- Outside hitters show strong Attack Effectiveness, Attack Variation, and Serve Reception.
- Middle blockers dominate in Blocking Performance and Blocking Coordination.
- Opposites demonstrate the highest Attack Effectiveness, confirming their role as primary attackers.
- Liberos achieve the highest scores in Serve Reception and Defensive Performance, emphasizing their backcourt specialization.

Notes:
- Values represent Estimated Marginal Means (EMMs) adjusted for between-group variability.
- Higher scores (warmer colors) indicate stronger performance.
- Scale: 0 = Very Poor, 1 = Poor, 2 = Below Average, 3 = Average, 4 = Good, 5 = Excellent.

Figure 2. Heat map illustrating the estimated marginal means (EMMs) of technical performance across five volleyball playing positions. Warmer colors (red) represent higher adjusted performance scores, whereas cooler colors (yellow) indicate relatively lower performance, thereby highlighting the distinct technical strengths associated with each positional role.

Figure 2 clearly illustrates the distinct technical specialization associated with each volleyball playing position. The darker color intensity observed for setters in the Setting Quality domain confirms their dominant role in offensive organization and ball distribution. Outside hitters display consistently high scores across Attack Effectiveness, Attack Variation, and Serve Reception, reflecting their balanced responsibilities in both offensive execution and serve-receive formation. Middle blockers exhibit the strongest performance in Blocking Performance and Blocking Coordination, emphasizing their primary role in front-row defensive coverage and net control. Opposites achieve the highest adjusted scores in Attack Effectiveness, supporting their function as the team's principal terminal attackers. In contrast, liberos demonstrate the highest performance in Serve Reception and Defensive Performance, highlighting their specialization in first-ball control and backcourt defense. Overall, the heat-map visualization provides clear visual confirmation of the statistical analyses, demonstrating that each playing position possesses a unique technical performance profile aligned with its tactical responsibilities. These findings further support the validity of the proposed position-specific evaluation framework for objective assessment of individual performance in elite volleybal.

Practical Implications

The findings of this study provide several important practical implications for volleyball coaching, athlete development, and performance analysis. First, the proposed position-specific statistical evaluation framework offers an objective and standardized method for assessing individual technical performance based on the tactical responsibilities of each playing position. Unlike conventional evaluation systems that apply identical criteria to all athletes, the present framework recognizes positional specialization and enables coaches to evaluate players according to the specific technical competencies required for their respective roles.

Second, the framework can serve as an evidence-based decision-support tool for individualized training prescription. By identifying the dominant strengths and relative weaknesses of each athlete across the evaluated technical domains, coaches can design targeted training interventions that address position-specific performance needs. For example, setters may benefit from advanced decision-making and setting-accuracy training, whereas middle blockers can receive specialized programs emphasizing blocking timing and front-row coordination. Similarly, individualized training for opposites may prioritize attacking efficiency, while liberos can focus on improving serve reception consistency and defensive stability.

Third, the evaluation model provides practical value for athlete monitoring throughout the competitive season. Because performance indicators are derived from standardized match observations, repeated assessments can be used to monitor individual progress, evaluate training effectiveness, detect performance fluctuations, and support return-to-play decisions following injury. The use of objective statistical indicators also reduces subjective bias commonly associated with traditional coach-based evaluations and improves the consistency of performance monitoring across competitions.

In addition, the framework has important implications for talent identification and athlete selection. Position-specific performance profiles allow coaches and sport organizations to compare athletes using technical criteria directly aligned with positional demands, thereby facilitating more accurate selection decisions for elite competition, player recruitment, and long-term athlete development programs. Such objective evaluation procedures may also improve transparency during national team selection and professional player scouting.

From a broader perspective, the proposed framework contributes to the growing implementation of data-driven coaching and sport analytics in volleyball. The integration of standardized observational data with multivariate statistical analysis provides a reproducible methodology that can be adopted by professional clubs, national federations, sport academies, and university volleyball programs. Furthermore, because the evaluation system is based on internationally recognized technical performance indicators rather than competition-specific rules, the framework has potential applicability across different competitive levels and international volleyball contexts.

Overall, the position-specific statistical evaluation framework extends conventional match statistics beyond descriptive reporting by transforming performance data into actionable information for coaching practice. Its implementation may enhance the objectivity, reliability, and practical usefulness of individual performance assessment, thereby supporting evidence-based coaching decisions and contributing to continuous performance improvement in elite volleyball.

DISCUSSION

Principal Findings

The primary objective of this study was to develop and validate a statistical framework for evaluating individual volleyball performance according to the technical and tactical responsibilities of each playing position. Specifically, the framework sought to (1) identify the dominant technical characteristics associated with setters, outside hitters, middle blockers, opposites, and liberos; (2) establish standardized position-specific statistical indicators for objective individual performance assessment; and (3) demonstrate the practical applicability of the proposed evaluation model using observational data obtained from elite Indonesian Proliga competition. The research hypotheses predicted that technical performance would differ systematically among playing positions (H1), that a position-specific statistical framework would provide a more objective assessment than generalized evaluation approaches (H2), and that the proposed framework would generate distinct positional performance profiles capable of supporting evidence-based coaching decisions (H3).

The findings indicate that the proposed framework successfully achieved all of these objectives. Descriptive analyses demonstrated that each playing position exhibited a unique technical profile that reflected its tactical role during competition. Setters recorded the highest performance in setting quality and offensive organization, outside hitters and opposites showed superior attacking performance, middle blockers demonstrated the strongest blocking capability, and liberos consistently achieved the highest scores in serve reception and defensive performance. These patterns indicate that technical specialization is closely aligned with positional responsibilities rather than representing a uniform distribution of skills across all athletes.

The inferential analyses further strengthened these observations. Prior to multivariate testing, all statistical assumptions were satisfied, including multivariate normality, homogeneity of variances, and equality of covariance matrices, indicating that the dataset was appropriate for MANOVA. The multivariate analysis revealed a statistically significant overall effect of playing position on the combined technical performance variables across all four multivariate statistics (all $p < .001$), accompanied by a large multivariate effect size (Partial $\eta^2 = 0.46$). This result indicates that positional specialization explained approximately 46% of the total variance in the combined technical performance indicators, providing strong empirical support for Hypothesis 1 that individual volleyball performance differs systematically according to playing position.

Subsequent univariate analyses demonstrated significant positional differences across every evaluated technical domain, including service accuracy, service consistency, serve reception, setting quality, attack effectiveness, attack variation, blocking timing, blocking coordination, and defensive performance. Among these variables, setting quality produced the largest effect size (Partial $\eta^2 = 0.57$), followed by attack effectiveness (0.44), defensive performance (0.42), and serve reception (0.39), indicating that several technical competencies were strongly position dependent. Tukey's HSD post hoc comparisons confirmed that setters significantly outperformed all other positions in setting quality, opposites demonstrated the greatest attacking effectiveness, middle blockers dominated blocking performance, and liberos achieved superior serve reception and defensive performance. These pairwise comparisons clearly established that each playing position possesses statistically distinguishable technical characteristics.

The estimated marginal means and graphical performance profiles provided additional evidence supporting Hypotheses 2 and 3. After adjusting for between-group variability, the same positional performance hierarchy remained evident, indicating that the observed differences were robust rather than artifacts of sample variation. Radar plots and heat-map visualizations further illustrated clear technical specialization across playing positions, demonstrating that the proposed framework produces interpretable performance profiles that directly correspond to tactical responsibilities during elite competition. These findings suggest that evaluating athletes using position-specific indicators provides substantially greater discriminatory capability than generalized evaluation systems that apply identical assessment criteria to all players regardless of role.

Importantly, the present findings demonstrate not only statistical significance but also substantial practical significance. Statistical significance confirms that the observed positional differences are unlikely to have occurred by chance within the study sample. However, the large multivariate effect size and consistently moderate-to-large univariate effect sizes indicate that these differences are meaningful from an applied coaching perspective. Rather than representing trivial statistical variations, the identified technical profiles provide actionable information that can support individualized athlete monitoring, position-specific training prescription, objective performance evaluation, and talent identification (Marris et al., 2021, p. 227; Yi et al., 2020, p. 1208). Consequently, the proposed framework extends conventional match statistics by transforming observational performance data into an evidence-based decision-support system that is directly applicable within elite volleyball coaching environments (Alcaraz et al., 2016; López-Serrano et al., 2023). This practical contribution addresses the research gap identified in the introduction, namely the lack of standardized and position-sensitive evaluation systems capable of objectively representing individual player performance according to tactical specialization.

Comparison with International Evidence

The findings of the present study are broadly consistent with the growing body of international research demonstrating that volleyball performance is inherently position-specific and should therefore be evaluated according to the distinct technical and tactical responsibilities assigned to each playing role. While previous investigations have consistently reported that setters, outside hitters, middle blockers, opposites, and liberos contribute differently to team performance, most have focused on isolated technical variables or team-level match statistics (Fellingham, 2022; Powers et al., 2025, p. 118). In contrast, the present study extends the existing literature by integrating multiple technical domains into a standardized position-specific evaluation framework capable of objectively representing individual player performance within a single analytical model (Bush et al., 2014, p. 4; Marris et al., 2021, p. 226). This integrated approach addresses an important methodological gap identified in previous volleyball performance research and contributes to the development of more comprehensive evidence-based performance assessment systems.

The superior setting performance observed among setters is consistent with previous international studies emphasizing the setter's pivotal role in offensive organization. Denardi et al. (2017) reported that the setter's decision-making and distribution accuracy are among the strongest determinants of offensive efficiency because setters continuously adjust attacking options according to defensive configurations. Similarly, Sotiropoulos et al. (2019) demonstrated that elite setters exhibit distinctive ball-distribution patterns that optimize offensive variability and increase attacking success. The present findings reinforce these observations by showing that setters achieved significantly higher adjusted scores in setting quality than all other playing positions. Rather than merely confirming that setters perform more setting actions, the proposed framework quantitatively demonstrates that setting quality represents the defining technical characteristic distinguishing setters from other athletes (Denardi et al., 2024, p. 892; Gónzález-Silva et al., 2020, p. 1). This finding supports the argument that evaluating setters using generalized technical indicators may underestimate their tactical contribution during competition.

The results concerning outside hitters and opposites are also highly consistent with international evidence. Previous studies conducted in Europe have shown that outside hitters contribute substantially to both offensive production and serve reception because of their dual tactical responsibilities, whereas opposites primarily function as terminal attackers responsible for converting offensive opportunities into points. Pinto et al. (2018) reported that outside hitters perform a balanced combination of attacking and reception tasks, while Millán-Sánchez et al. (2017) and Mocanu et al. (2024) identified opposites as the most productive attackers in elite men's volleyball. The present study corroborates these findings by demonstrating superior attack effectiveness among opposites while simultaneously revealing that outside hitters maintained balanced performance across attack and reception domains. The absence of a significant difference between outside hitters and opposites in certain attacking indicators further reflects the tactical flexibility observed in contemporary elite volleyball, where offensive responsibilities are increasingly distributed according to match situations rather than strictly predefined positional roles.

The dominant blocking performance demonstrated by middle blockers similarly agrees with previous international investigations. Millán-Sánchez et al. (2018) emphasized that middle blockers play a critical role in controlling the central area of the net and coordinating collective blocking systems. Likewise, Pinto et al. (2018) concluded that blocking efficiency is the principal technical indicator distinguishing middle blockers from other positions because of their specialized front-row defensive responsibilities. The present findings provide additional empirical support for these conclusions by demonstrating that middle blockers consistently achieved the highest adjusted scores in both blocking timing and blocking coordination. More importantly, the position-specific evaluation framework was capable of isolating blocking performance as a distinct technical domain, thereby providing greater measurement specificity than generalized performance evaluation systems that aggregate multiple technical actions into a single composite score.

The exceptionally high serve-reception and defensive performance observed among liberos also corresponds closely with previous international literature. García-de-Alcaráz & Usero (2019) demonstrated that the libero exerts substantial influence on match performance through superior first-ball control and defensive stability, while Indonesia et al. (2024) further reported that libero performance contributes to team confidence and rally continuity. The present study confirms these observations by showing that liberos achieved significantly higher adjusted means in both serve reception and defensive performance than all offensive playing positions (García-de-Alcaráz & Usero, 2019; Stanković et al., 2017, p. 14). These findings reinforce the specialized defensive identity of the libero role and suggest that objective evaluation of liberos should prioritize defensive efficiency rather than offensive statistics that have limited tactical relevance for this position.

Although the present findings largely support previous international evidence, several methodological differences distinguish this study from earlier investigations. Many previous studies analyzed isolated technical indicators, such as attacking efficiency, blocking frequency, or serve-reception quality, without integrating these variables into a unified evaluation framework (Drikos et al., 2024, p. 181; Eom & Schutz, 1992). Others primarily examined team-level performance or match outcomes rather than individual athlete profiles. In contrast, the present study simultaneously evaluated multiple technical domains within a multivariate analytical framework and generated standardized performance profiles for each playing position (Jong et al., 2020, p. 10; Modri et al., 2022, p. 4). This methodological approach reduces the risk of overemphasizing individual technical actions while providing a more comprehensive representation of overall positional performance. Consequently, the proposed framework offers greater ecological validity because it reflects the multidimensional nature of elite volleyball competition rather than isolated technical events.

Differences between the present findings and some previous reports may also be explained by variations in study populations, competitive standards, observational procedures, and analytical strategies. Most earlier studies were conducted in European professional leagues or international championships, whereas the present investigation utilized observational data obtained from the 2025 Indonesian Proliga Championship. Despite potential cultural and competitive differences, the overall pattern of positional specialization remained remarkably consistent across contexts. This consistency suggests that the technical responsibilities associated with each playing position are fundamentally determined by the tactical structure of volleyball rather than by country-specific coaching philosophies (Jäger & Schöllhorn, 2007; Laporta et al., 2021, p. 23; Ramos et al., 2017, p. 488). Nevertheless, regional differences in playing style, offensive tempo, athlete anthropometry, and training systems may influence the magnitude of positional differences and should therefore be considered when interpreting cross-national comparisons.

Another important distinction concerns advances in sport analytics. Recent international studies have increasingly incorporated wearable sensors, computer vision, machine learning, and automated video analysis to quantify player behavior during competition (Leeuw et al., 2022; Ruiye, 2024; Salim et al., 2024). While these technologies provide increasingly sophisticated datasets, relatively few investigations have translated the resulting information into standardized position-specific evaluation systems that can be directly implemented by coaches during routine performance monitoring(Linke et al., 2020, p. 2; Luteberget & Gilgien, 2020; Schlenger et al., 2023, p. 81). The present framework complements these technological developments by demonstrating how observational match statistics can be transformed into interpretable performance profiles using conventional statistical procedures. Consequently, the study contributes not only empirical evidence regarding positional specialization but also a practical methodological framework that bridges the gap between advanced performance analytics and everyday coaching practice.

Collectively, comparisons with international literature indicate that the present study both corroborates and extends existing knowledge in volleyball performance analysis. These findings reinforce the established principle that technical proficiency is inherently position-dependent, while simultaneously advancing the literature through the development of a standardized statistical framework that integrates multiple technical domains into objective, position-specific performance profiles (Bergkamp et al., 2019, p. 1330; Marris et al., 2021, p. 226; Yi et al., 2020, p. 1208). By synthesizing multivariate statistical analysis with applied performance evaluation, the proposed framework provides an internationally transferable model that may facilitate enhanced objectivity in athlete assessment, individualized coaching, and evidence-based talent development across diverse elite volleyball environments.

Theoretical, Methodological, and Practical Implications

The present study provides important contributions to the theoretical understanding of volleyball performance by reinforcing the concept that technical proficiency should be interpreted within the tactical context of each playing position rather than through generalized performance indicators. Contemporary theories of ecological dynamics and the constraints-led approach propose that athletic performance emerges from continuous interactions among individual capabilities, environmental constraints, and task-specific demands (Liu, 2023, p. 3; Woods et al., 2020, p. 40). From this perspective, technical skills cannot be evaluated independently of the functional roles that athletes perform during competition. The findings of the present study support this theoretical proposition by demonstrating that setters, outside hitters, middle blockers, opposites, and liberos exhibit clearly differentiated technical performance profiles that correspond closely with their specialized tactical responsibilities (Marques et al., 2009; Rebelo et al., 2025, p. 653). Rather than treating all athletes as technically equivalent performers, the proposed framework operationalizes positional specialization into measurable statistical indicators, thereby providing empirical evidence that supports contemporary theories of skill acquisition and sport performance analysis.

Beyond confirming existing theoretical perspectives, the study extends current knowledge by proposing a multidimensional framework that integrates multiple technical domains into a single position-specific evaluation model. Previous volleyball performance research has frequently examined isolated indicators, such as attack efficiency, blocking frequency, or serve reception quality, without considering their combined contribution to overall positional performance (Powers et al., 2025, p. 137; Rebelo et al., 2024; Бойчук et al., 2025). Consequently, coaches often receive fragmented information that inadequately represents an athlete's complete technical profile. The present findings demonstrate that a multivariate evaluation framework provides a more comprehensive representation of individual performance by simultaneously considering offensive, defensive, and organizational technical responsibilities. This integrated perspective advances current sport performance theory by emphasizing that technical competence should be interpreted as a coordinated set of position-dependent abilities rather than a collection of independent technical actions (Pol et al., 2020, p. 36; Woods et al., 2020, p. 666).

From a methodological perspective, the study contributes by developing and validating a standardized statistical framework for objective individual performance assessment. Unlike many previous investigations that relied primarily on descriptive match statistics or isolated performance indicators, the present study employed a structured observational instrument, comprehensive assumption testing, multivariate statistical analysis, post hoc comparisons, and estimated marginal means to generate interpretable position-specific performance profiles. The combination of descriptive statistics, MANOVA, ANOVA, Tukey's HSD, and adjusted performance estimates represents a rigorous analytical approach that strengthens both internal validity and interpretability. Furthermore, the use of standardized observation criteria aligned with international volleyball positions enhances the reproducibility of the evaluation procedure and facilitates comparisons across different teams, competitions, and research settings (Drikos et al., 2024, p. 183; Marzano-Felisatti et al., 2022, p. 21). This methodological framework therefore provides a transparent and replicable approach for future investigations examining individual performance in elite volleyball.

Another important methodological contribution lies in the translation of observational match data into practical performance analytics. Although advances in artificial intelligence, wearable technologies, and computerized video analysis have substantially increased the availability of performance data, relatively few studies have transformed these data into standardized evaluation systems that are readily interpretable by coaches and practitioners (Cossich et al., 2023; Jia et al., 2025, p. 264). The present framework addresses this limitation by converting observable technical actions into position-specific performance profiles that can be interpreted without requiring highly specialized analytical software. Consequently, the framework bridges the gap between academic sport analytics and applied coaching practice, allowing statistical information to become a practical decision-support tool rather than merely descriptive documentation of match events.

The practical implications of this study are equally substantial. First, the proposed evaluation framework enables coaches to conduct objective, position-sensitive assessments of individual athlete performance throughout the competitive season. Because the framework evaluates athletes according to the technical demands of their respective positions, performance feedback becomes more meaningful than generalized evaluation systems that apply identical criteria to all players. Such individualized assessment may improve coaching accuracy by identifying specific technical strengths and developmental needs that are directly relevant to positional responsibilities(Bergkamp et al., 2019, p. 1330; Ho et al., 2023, p. 2). Second, the framework provides an evidence-based foundation for designing individualized training programs. Position-specific performance profiles allow coaches to prioritize technical interventions according to each athlete's tactical role(Baptista et al., 2018, p. 7; Zhai et al., 2021, p. 558750). For example, setters may require advanced training focused on decision-making and setting precision, middle blockers may benefit from programs emphasizing blocking timing and front-row coordination, opposites may require enhanced attacking efficiency under high-pressure situations, whereas liberos may prioritize serve reception consistency and defensive anticipation. Consequently, training prescription can become more targeted, efficient, and consistent with the technical demands encountered during elite competition. Third, the proposed framework has important implications for athlete monitoring and long-term player development. Repeated application of the evaluation system across training sessions and competitive matches enables coaches to monitor individual progress objectively, evaluate responses to training interventions, identify performance trends, and detect temporary performance decline. Such longitudinal monitoring may also support return-to-play decisions following injury by providing objective benchmarks for technical readiness before athletes resume full competition. The standardized nature of the framework additionally improves communication among coaches, performance analysts, and sport scientists by establishing common evaluation criteria based on measurable technical indicators.

Beyond coaching practice, the findings also have potential implications for talent identification and player selection. Position-specific technical profiles provide objective benchmarks that may assist professional clubs, national federations, and talent development academies in identifying athletes whose technical characteristics align with positional demands (Koopmann et al., 2020, p. 1595; Marris et al., 2021, p. 226). Rather than relying predominantly on subjective coach observations, recruitment and selection decisions may incorporate standardized performance indicators that improve transparency, consistency, and evidence-based decision-making. Such an approach is particularly valuable within elite development systems where small differences in technical performance may substantially influence competitive success.

Finally, although the framework was developed using observational data from the Indonesian Proliga Championship, its conceptual structure is based on internationally recognized playing positions and technical performance domains. Therefore, the proposed evaluation model has potential applicability beyond the immediate study context. With appropriate contextual validation, the framework could be implemented in professional leagues, university competitions, youth development programs, and national team environments across different countries. This international transferability enhances the broader contribution of the study by providing a standardized approach that may facilitate cross-cultural comparisons, multicenter research collaboration, and the development of globally comparable performance benchmarks in elite volleyball (Alcaraz et al., 2016; Baena-Raya et al., 2023). Nevertheless, future applications should consider contextual factors such as competitive level, playing style, and organizational resources when adapting the framework to different volleyball environments.

Strengths and Limitations

The present study possesses several methodological strengths that enhance the validity, reliability, and practical relevance of its findings. First, the research employed a position-specific evaluation framework that objectively assessed individual volleyball performance according to the distinct technical and tactical responsibilities of each playing position. Unlike conventional evaluation systems that apply identical performance criteria across all athletes, the proposed framework acknowledges positional specialization and provides a more ecologically valid representation of technical performance during elite competition. This position-sensitive approach represents an important methodological advancement because it aligns performance assessment with the functional demands experienced by athletes in actual match situations.

Second, the study utilized a balanced observational dataset consisting of 300 elite volleyball players representing five internationally recognized playing positions. The equal number of observations across positions reduced sampling imbalance and strengthened comparisons among groups. Furthermore, the observational protocol was developed using standardized technical performance indicators derived from the international volleyball literature and official Fédération Internationale de Volleyball (FIVB) match statistics. Prior expert validation and reliability testing of the observation instrument further enhanced measurement quality, supporting the consistency and credibility of the collected performance data.

Third, the statistical procedures adopted in this study provide an additional strength. Before hypothesis testing, all prerequisite assumptions for multivariate analysis were systematically evaluated using the Shapiro–Wilk test, Levene's test, and Box's M test, demonstrating that the dataset satisfied the assumptions required for MANOVA. The subsequent application of multivariate analysis, follow-up ANOVA, Tukey's HSD post hoc comparisons, effect size estimation, and estimated marginal means allowed both statistical significance and practical importance to be evaluated comprehensively. Reporting effect sizes alongside probability values further improves the interpretability of the findings and is consistent with current reporting standards for quantitative research in sport science.

Despite these strengths, several limitations should be considered when interpreting the findings. First, the study employed an observational cross-sectional design, which limits the ability to establish causal relationships between positional roles and technical performance. Although statistically significant differences were identified among playing positions, the design does not permit conclusions regarding whether positional specialization directly causes improvements in technical performance or whether the observed differences result from previous athlete selection, accumulated training experience, or coaching practices.

Second, the research sample was derived exclusively from the 2025 Indonesian Proliga Championship, representing a single national professional competition. Although this competition includes elite athletes, the findings may not be fully transferable to other competitive contexts, such as youth volleyball, collegiate leagues, amateur competitions, or professional leagues in other countries with different tactical systems and playing styles. Consequently, caution should be exercised when generalizing the results beyond similar elite volleyball environments.

Third, although the observation instrument underwent expert validation and inter-rater reliability assessment, the evaluation process remained dependent on human video observation. Performance coding may therefore be influenced by observer judgment, particularly when evaluating complex technical actions that occur under high-speed competitive conditions. While standardized observation procedures were implemented to minimize observer variability, some degree of measurement error and observer bias cannot be completely eliminated. Future integration of automated tracking systems, computer vision, or artificial intelligence-based performance analysis may further improve measurement precision and reduce subjective interpretation.

Another limitation concerns the potential influence of unmeasured confounding variables. The present study focused primarily on technical performance according to playing position and did not explicitly control for factors such as athlete age, years of competitive experience, anthropometric characteristics, physical fitness, fatigue status, match importance, quality of opposition, tactical systems, or coaching strategies. These variables may contribute to individual performance differences and could partially explain the variability observed within playing positions. Therefore, the reported positional differences should be interpreted within the broader competitive context rather than being attributed exclusively to positional specialization.

The study also has several methodological considerations regarding bias, missing data, multiplicity, and transferability. Selection bias was minimized by applying predefined inclusion and exclusion criteria and by using official match recordings from elite competition. Observation bias was reduced through standardized coding procedures and expert-reviewed assessment criteria. The analyzed dataset contained complete observations for all included athletes; therefore, no statistical imputation procedures for missing data were required. Additionally, the potential for inflated Type I error associated with multiple comparisons was addressed through the application of Tukey's Honestly Significant Difference (HSD) post hoc procedure following significant omnibus ANOVA results. Nevertheless, external validity remains limited because the framework has not yet been validated across multiple countries or different competitive standards.

Finally, although the proposed framework demonstrated strong discriminatory capability and practical applicability within the present sample, further evidence is required before recommending universal implementation across all volleyball settings. Replication studies involving different populations, longitudinal observation periods, and international competitions are necessary to confirm the stability, reliability, and generalizability of the framework. Consequently, the current findings should be interpreted as strong evidence supporting the validity of position-specific performance evaluation in elite volleyball while recognizing that broader validation across diverse sporting environments remains an important direction for future research.

Future Research

The findings of the present study provide a strong foundation for future investigations aimed at advancing position-specific performance evaluation in volleyball. Although the proposed framework demonstrated satisfactory validity and practical applicability within elite Indonesian professional volleyball, further research is required to determine its robustness, generalizability, and utility across broader competitive and cultural contexts. Expanding the evidence base will facilitate the development of internationally comparable standards for objective volleyball performance assessment. First, future studies should validate the proposed framework across different populations and competitive levels. Replication involving youth athletes, collegiate players, semi-professional leagues, and international elite competitions would determine whether the observed position-specific performance profiles remain stable across different stages of athlete development. Comparative investigations involving professional leagues in Europe, Asia, North America, and South America would also provide valuable evidence regarding the cross-cultural applicability of the framework and identify potential regional variations in positional specialization resulting from differences in coaching philosophy, tactical systems, and competition standards. Second, longitudinal research designs are recommended to examine how position-specific technical performance evolves throughout an athlete's career. Repeated assessments across multiple competitive seasons would enable researchers to evaluate the stability of technical performance profiles, identify developmental trajectories, and determine how maturation, accumulated training experience, and competitive exposure influence positional specialization over time. Such longitudinal evidence would substantially strengthen causal inference beyond the cross-sectional observations reported in the present study. Third, future investigations should explore the mechanisms underlying positional performance differences by incorporating potential mediating and moderating variables. Factors such as physical fitness, anthropometric characteristics, decision-making ability, tactical awareness, psychological resilience, fatigue, match intensity, and training load may partially explain why athletes occupying the same position demonstrate different technical performance levels. Structural equation modeling, multilevel modeling, or longitudinal mediation analyses may provide deeper insight into the causal pathways linking individual characteristics, training environments, and match performance. Fourth, the proposed evaluation framework should be integrated with emerging sport technologies. Combining standardized observational assessment with wearable sensors, inertial measurement units (IMUs), computer vision, optical tracking systems, artificial intelligence, and machine-learning algorithms may substantially improve measurement precision while reducing observer-related bias. Such integration would allow real-time performance monitoring, automated technical classification, and predictive performance analytics that extend beyond conventional match statistics.

Another promising direction involves evaluating the implementation effectiveness of the framework within applied coaching environments. Future implementation studies should investigate how coaches, performance analysts, and sport organizations adopt the evaluation model during routine training and competition. Examining factors such as feasibility, usability, coach acceptance, implementation fidelity, required training, and organizational barriers would provide practical evidence regarding the framework's successful integration into high-performance volleyball programs. Such implementation research would bridge the gap between methodological development and real-world coaching practice.

In addition, future studies should examine the economic and organizational implications of adopting standardized position-specific evaluation systems. Cost-effectiveness analyses comparing traditional coach-based evaluations with data-driven performance assessment may help determine whether the additional investment in systematic observation and statistical analysis produces meaningful improvements in athlete development, talent identification, injury prevention, and competitive performance. These analyses would be particularly valuable for national federations, professional clubs, and educational institutions seeking evidence-based strategies for resource allocation.

Finally, multicenter replication studies involving researchers from multiple countries are strongly encouraged to establish international normative databases for position-specific volleyball performance. Standardized data collection across diverse competitions would facilitate external validation, improve international comparability, and strengthen the scientific credibility of the proposed framework. Such collaborative research could ultimately contribute to the development of globally accepted benchmarks for objective individual performance evaluation, thereby supporting evidence-based coaching, talent identification, and long-term athlete development across different volleyball systems.

Overall, future research should extend beyond confirming the existence of positional differences and instead focus on understanding how, why, and under what conditions position-specific technical performance develops and changes over time. By integrating longitudinal designs, international comparisons, advanced performance analytics, implementation science, and cost-effectiveness evaluation, subsequent investigations can further refine the proposed framework and strengthen its contribution to evidence-based volleyball performance analysis.

CONCLUSION

This study achieved its primary objective by developing and validating a position-specific statistical framework for evaluating individual volleyball performance according to the technical and tactical responsibilities of each playing position. The findings demonstrate that the proposed framework effectively differentiates technical performance profiles among setters, outside hitters, middle blockers, opposites, and liberos, thereby providing a standardized and objective approach to individual performance assessment. The multivariate and univariate analyses consistently showed that each playing position possesses distinct technical characteristics aligned with its specialized role during elite competition. These findings support the use of position-sensitive evaluation rather than generalized performance indicators when assessing individual volleyball performance.

The principal contribution of this study lies in extending conventional match statistics into an integrated evaluation framework that combines multiple technical performance domains within a standardized analytical model. This framework provides practical value for evidence-based coaching, individualized athlete monitoring, talent identification, and position-specific training prescription while also contributing to the international advancement of volleyball performance analytics through a reproducible methodology that may facilitate objective comparisons across competitive settings. Nevertheless, the findings should be interpreted within the context of the study design. Because the framework was developed using observational data obtained from athletes participating in the 2025 Indonesian Proliga Championship, the generalizability of the results to other competitive levels, age groups, and international volleyball environments requires further external validation through multicenter and cross-cultural research before broader application can be recommended.

DECLARATIONS

Ethical Approval

This study was approved by the Ethics Committee of the Institute for Research and Community Service, State University of Surabaya, Indonesia, under Approval No. Research/11098/LPPM-UNS-/EC/VIII/04-26. All research procedures were conducted in accordance with the ethical principles of the Declaration of Helsinki and relevant institutional guidelines for research involving human participants. The study utilized observational analyses of officially available volleyball match recordings, and all performance data were anonymized prior to statistical analysis. The corresponding author confirms the authenticity of the ethical approval documentation and that the research was conducted in compliance with the approved protocol.

Consent to Participate

Because this study analyzed observational performance data obtained from officially sanctioned volleyball competitions without collecting personally identifiable information or interacting directly with participants, informed consent was managed in accordance with the ethical approval granted by the institutional ethics committee. Participant consent was waived by the Ethics Committee because the study involved secondary analysis of anonymized observational data from publicly available competitions.

Consent for Publication

This manuscript does not include identifiable personal information, facial images, or individual case descriptions that permit participant identification. Therefore, separate consent for publication was not required.

Author Contributions (CRediT)

Anin Dita Safitri: Conceptualization; Methodology; Investigation; Data Curation.
Soni Sulistyarto: Conceptualization; Validation; Methodology; Supervision; Writing – Review & Editing;
Irmantara Subagio: Investigation; Resources; Validation; Writing-Review & Editing; Formal Analysis; Writing-Original Draft; Visualization.
Achmad Widodo: Formal Analysis; Visualization; Validation.
Taufiq Hidayat; Supervision; Project Administration; Writing-Review & Editing.
Muhammad: Resources; Supervision; Funding Acquisition; Writing – Review & Editing.
All authors have read and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

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Conflict of Interest

The authors declare no financial or non-financial conflicts of interest that could have influenced the work reported in this manuscript.

Data Availability

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request, subject to institutional regulations and ethical approval requirements.

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Generative AI Disclosure

During the preparation of this manuscript, the authors used generative artificial intelligence (AI) tools solely to assist with language editing, grammar improvement, academic writing refinement, and manuscript organization. The authors carefully reviewed, verified, and edited all AI-assisted outputs to ensure their scientific accuracy, completeness, and compliance with journal publication standards. All interpretations, analyses, conclusions, and final content remain the sole responsibility of the authors.

No confidential participant information, identifiable personal data, or protected research data were entered into any generative AI system during manuscript preparation. The use of AI did not replace the intellectual contributions, scientific judgment, or accountability of the authors, who assume full responsibility for the integrity and accuracy of the published work.

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