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Standardization of Lower Limb explosive Power and VO_2max in Volleyball Athletes Aged 17–21 Years

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ABSTRACT

Background & objective: This study aimed to analyze and standardize lower-limb explosive power and maximal oxygen uptake (VO_2max) in male volleyball athletes aged 17–21 years in East Java, Indonesia, in order to establish normative reference values for athlete selection, performance evaluation, and training program development.
Materials and methods: This study employed a descriptive quantitative research design involving 50 male volleyball athletes recruited from regional training centers and sports senior high schools in East Java. Lower-limb explosive power was assessed using the Standing Board Jump Test, while VO_2max was estimated using the Multistage Fitness Test (beep test). Data were analyzed using descriptive statistics (mean, standard deviation, minimum, and maximum), normality testing (Kolmogorov–Smirnov), and norm-referenced classification based on mean ± SD intervals using IBM SPSS Statistics.
Results: The results showed that lower-limb explosive power ranged from 2.19 to 2.82 m (mean ± SD: 2.54 ± 0.13 m), while VO_2max ranged from 29.9 to 53.3 $ml\cdot kg^{-1}\cdot min^{-1}$ (mean ± SD: 38.28 ± 3.67 $ml\cdot kg^{-1}\cdot min^{-1}$). A five-tier norm classification system (Very Good, Good, Moderate, Poor, Very Poor) was successfully developed. The Moderate category was identified as the minimum performance standard, with values of 2.48–2.60 m for explosive power and 36.45–40.11 $ml\cdot kg^{-1}\cdot min^{-1}$ for VO_2max.
Conclusions: This study provides standardized normative values for lower-limb explosive power and VO_2max in adolescent male volleyball athletes, offering an evidence-based framework for athlete selection, physical readiness assessment, and performance monitoring. These findings can support the development of more effective and objective training and talent identification systems in volleyball.

Keywords
explosive power; VO_2max; volleyball athletes; normative standards; physical fitness; performance evaluation.

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INTRODUCTION

Contextual Framework

Volleyball is a high-intensity intermittent team sport in which athletes repeatedly perform explosive movements such as jumping, spiking, blocking, and rapid directional changes across matches of variable duration (Rebelo et al., 2025; Wei et al., 2025). These performance characteristics place considerable demands on both neuromuscular and cardiovascular systems, making physical fitness a decisive determinant of performance quality, technical execution, and competitive outcomes. Modern volleyball has evolved toward faster tempos and higher physical intensity, increasing the importance of well-developed physical capacities to support tactical execution and consistency throughout competition (Cereda, 2025). As a result, contemporary volleyball training and athlete development frameworks increasingly prioritize sport-specific physical attributes as fundamental elements for sustaining long-term performance progression (Sigmund & Güllich, 2021).

Lower-limb explosive power represents one of the most critical physical components in volleyball performance (Bobula et al., 2024; Wang et al., 2023), particularly during net-based actions that directly influence scoring opportunities. The ability to generate maximal force in a minimal time interval directly affects jump height, take-off velocity, and movement efficiency during offensive skills such as spiking and jump serving, as well as defensive actions including blocking. Athletes with higher levels of explosive power are able to reach greater heights and execute movements more rapidly (Somnache et al., 2022), enabling more effective ball contact above the net. These advantages are especially pronounced in high-level competition, where marginal differences in reach and timing can substantially influence match outcomes.

In addition to neuromuscular demands, volleyball performance relies on adequate aerobic capacity to sustain repeated high-intensity efforts across prolonged rallies and multiple sets (Wei et al., 2025). Although individual actions in volleyball are brief and predominantly anaerobic, the cumulative physiological load experienced throughout a match necessitates an efficient cardiorespiratory system (Deliceoğlu et al., 2024). Maximal oxygen uptake (VO_2max) reflects the integrated capacity of the cardiovascular and respiratory systems to transport and utilize oxygen during sustained physical activity (Saputra et al., 2025). Sufficient VO_2max supports faster inter-rally recovery, maintenance of technical accuracy under fatigue, and sustained performance stability across match duration.

Critical Examination of Existing Literature

Existing literature on lower-limb explosive power in volleyball athletes underscores its pivotal role in jump-related actions, with investigations predominantly employing vertical or horizontal jump tests to quantify performance. Polakovičová et al. (2018) analyzed vertical jump development in elite adolescent volleyball players, revealing progressive improvements with age and sex-specific patterns across maturational stages; however, the cohort primarily comprised players under 17 years, limiting direct applicability to the 17–21-year transitional phase. Gao et al. (2025) evaluated lower-extremity power through field-based measures demonstrating strong correlations with volleyball-specific movements such as blocking and spiking, yet their cross-sectional design lacked longitudinal norms and age-stratified standards for late adolescents. Similarly, Sellami et al. (2024) and Ayed et al. (2023) Velocity relationships and biokinematic associations in young North African volleyball players, confirming explosive power's predictive value for match performance; however, samples were regionally biased and lacked standardized performance categories applicable to Indonesian or global contexts. D'Elia et al. (2021) investigated changes in explosive strength among youth volleyball players before and after the COVID-19 pandemic, reporting substantial training disruptions, although data pooling across a wide youth age range diminished applicability to the 17–21-year cohort.

Research on VO_2max in volleyball contexts underscores its contribution to aerobic recovery amid intermittent high-intensity demands (Eisenmann et al., 2024; Foster & Bunn, 2024). Sellami et al. (2024) established respiratory muscle strength as a significant predictor of VO_2max and aerobic endurance in competitive athletes, highlighting the role of cardiorespiratory efficiency; however, that study generalized findings across multiple sports without isolating team-sport or volleyball-specific demands. While shuttle-run tests such as the 20-m Multistage Fitness Test are widely validated for VO_2max estimation in field settings Poček et al. (2020), normative values for volleyball players aged 17–21 remain underexplored, with most investigations targeting elite seniors or pre-adolescents (under 15 years).

Identification of Research Gaps

Although a substantial body of literature exists on lower-limb explosive power and VO_2max in volleyball athletes, few investigations furnish comprehensive, norm-referenced benchmarks specifically tailored to male players aged 17–21 years during the critical junior-to-senior transition. Prevailing studies predominantly target younger adolescents or elite seniors, neglecting integrated standards that account for the unique physiological demands of this transitional phase, characterized by rapid biological maturation, intensified training loads, and heightened competitive pressures. Consistent limitations across the literature include heterogeneous age groups, small or non-representative sample sizes, regional biases, cross-sectional designs, and an absence of integrated norm-referenced benchmarks using mean ± SD intervals. Such shortcomings impede objective athlete profiling and hinder the development of evidence-based selection and monitoring protocols.

Rationale for the Research

The developmental period of 17–21 years represents a pivotal stage in volleyball athletes' careers, characterized by advanced physiological maturation, heightened training demands, and the transition to senior-level competition. In practical training environments, assessments often prioritize technical skills over quantifiable physical performance metrics, impairing the accuracy of talent identification and training optimization. Establishing normative benchmarks for lower-limb explosive power and VO_2max would support evidence-informed practices in athlete selection, longitudinal monitoring, and program customization, thereby accommodating inter-individual variability and fostering sustained competitive progression.

Objectives

This study aims to analyze and standardize lower-limb explosive power and VO_2max in male volleyball athletes aged 17–21 years in East Java, Indonesia, providing empirically grounded reference values intended to support evidence-based athlete selection, physical performance evaluation, and training program development within competitive volleyball systems.

MATERIALS AND METHODS

Study Design and Organization

This study employed a descriptive quantitative research design aimed at characterizing and standardizing lower-limb explosive power and VO_2max among volleyball athletes in a defined age group. The descriptive design was selected as it enables systematic documentation of naturally occurring performance characteristics without experimental manipulation of independent variables, which is appropriate for establishing population-specific normative data (Thomas et al., 2022).

Data collection was organized in a single session per participant. Prior to testing, all participants completed a standardized 15-minute warm-up protocol consisting of light jogging, dynamic stretching, and sport-specific movement patterns. Testing was conducted during morning hours (07.00–11.00 local time) in standardized facilities at the respective institutions to ensure environmental consistency. The Standing Board Jump Test was administered first to assess lower-limb explosive power, given that it requires maximal neuromuscular output without aerobic demand. Following a minimum 10-minute rest period to attenuate residual fatigue effects, participants performed the 20-Meter Multistage Fitness Test to estimate VO_2max. All testing was supervised by trained research assistants who had completed a calibration protocol prior to the study to ensure inter-rater reliability.

Study Participants

A total of 50 male volleyball athletes aged 17–21 years participated in this study. Participants were recruited from two primary institutional settings in East Java, Indonesia: regional training centers (Puslatcab) (n = 28, 56%) and state sports senior high schools (SMAN Olahraga) (n = 22, 44%). Inclusion criteria required that participants: (a) were officially registered as active members of the respective institution's volleyball program, (b) had been engaged in structured volleyball training for a minimum of three months prior to data collection, (c) were free from musculoskeletal injury at the time of testing, and (d) were in good general health as confirmed by a pre-participation health screening questionnaire. Participants with any acute illness, injury, or recent surgical history were excluded. Table 1 presents the age distribution of the study cohort.

Table 1. Demographic Characteristics of Study Participants by Age Group

Age (years)	Number of Athletes (n)	Percentage (%)
17	6	12.0%
18	10	20.0%
19	12	24.0%
20	11	22.0%
21	11	22.0%
Total	50	100.0%

Note. Regional training centers (Puslatcab) contributed 28 athletes (56%); state sports senior high schools contributed 22 athletes (44%).

Instruments and Measurement Procedures

Lower-limb explosive power was assessed using the Standing Board Jump Test (also known as the Broad Jump Test), a widely validated field test that evaluates horizontal jumping distance as an indicator of lower-extremity explosive strength (Bobula et al., 2024; Wang et al., 2025). Participants stood behind a designated take-off line on a non-slip surface, assumed a preparatory stance with knees slightly flexed and arms behind the body, then executed a maximal horizontal jump using simultaneous arm swing. Each participant completed two trials, with a three-minute rest interval between trials, and the best recorded result (nearest 0.01 m) was retained for analysis.

Aerobic capacity was estimated using the 20-Meter Multistage Fitness Test (20-m MST; Beep Test), a progressively demanding shuttle-run test that has been widely validated for VO_2max estimation in field settings (Poček et al., 2020). Participants ran between two lines set 20 m apart in synchrony with audio signals, with inter-signal intervals decreasing by stage. Testing was terminated when a participant failed to reach the turning line within the allotted time on two consecutive occasions. Predicted VO_2max values (ml·kg^{-1}·min^{-1}) were derived from the final completed stage and level using established conversion tables.

Statistical Analysis

All statistical analyses were performed using IBM SPSS Statistics (version 26.0, IBM Corp., Armonk, NY, USA). Descriptive statistics were computed for both primary variables, encompassing the minimum, maximum, arithmetic mean (Ā), and standard deviation (SD). The Kolmogorov–Smirnov test was applied to assess distributional normality of the data, with significance set at $p < .05$. Norm-referenced performance categories were constructed using a five-tier mean ± SD interval framework, a methodology widely employed in sport science research for standardized athlete profiling (McCormack et al., 2021). Table 2 presents the categorization criteria applied in this study.

Table 2. Norm-Referenced Performance Categorization Criteria Based on Mean and Standard Deviation Intervals

No.	Value Range	Performance Category
1	> Mean + 1.5 SD	Very Good
2	Mean + 0.5 SD to Mean + 1.5 SD	Good
3	Mean − 0.5 SD to Mean + 0.5 SD	Moderate
4	Mean − 1.5 SD to Mean − 0.5 SD	Poor
5	< Mean − 1.5 SD	Very Poor

Note. This classification framework has been applied in sport science research to differentiate performance levels within homogeneous athlete groups.

Ethical Considerations

This study was conducted in accordance with the ethical principles of the Declaration of Helsinki World Medical Association Declaration of Helsinki (2013) and the ethical guidelines governing research involving human participants in Indonesia (Permenkes RI No. 20 Tahun 2021). Ethical approval was obtained from the Ethics Committee of Faculty of Sports and Health Sciences, State University of Surabaya, Indonesia, with reference number EC-UNESA/Pen/2025-07-3991. Prior to data collection, all participants and, where applicable, their legal guardians (for participants aged below 18 years) were provided with detailed written information regarding the study's purpose, procedures, potential risks, and their right to withdraw at any stage without consequence. Written informed consent was obtained from all participants and guardians prior to any testing. Participation was entirely voluntary, and all data were anonymized and stored securely in accordance with applicable data protection regulations. No financial incentives were offered to participants.

RESULTS

The results section presents findings across three analytical stages: (3.1) descriptive statistics documenting individual performance variability and overall physical characteristics; (3.2) norm-referenced performance classification using the five-tier mean ± SD framework; and (3.3) inferential hypothesis testing, encompassing a normality assessment, Spearman rank correlation, Wilcoxon Signed-Rank tests against established reference values, and Kruskal–Wallis analysis of variance across age groups.

Descriptive Statistics

Table 3 presents individual measurement data for all 50 participants.

Table 3. Individual Measurements of Lower-Limb Explosive Power and VO_2max for All 50 Volleyball Athletes (n = 50)

No.	Power (m)	VO_2max (ml·kg^{-1}·min^{-1})	No.	Power (m)	VO_2max (ml·kg^{-1}·min^{-1})
1	2.43	35.6	26	2.49	37.1
2	2.82	53.3	27	2.52	36.9
3	2.59	39.1	28	2.61	37.6
4	2.47	36.7	29	2.54	38.2
5	2.34	33.4	30	2.57	38.6
6	2.29	32.1	31	2.48	36.5
7	2.41	34.8	32	2.59	39.0
8	2.64	40.6	33	2.56	38.4
9	2.25	31.5	34	2.50	37.5
10	2.67	41.9	35	2.57	38.7
11	2.24	30.8	36	2.55	38.1
12	2.19	29.9	37	2.52	37.8
13	2.75	45.6	38	2.63	36.9
14	2.56	38.4	39	2.57	38.5
15	2.77	41.7	40	2.58	39.2
16	2.59	39.0	41	2.49	36.8
17	2.57	38.5	42	2.62	40.1
18	2.54	37.8	43	2.55	37.9
19	2.67	42.3	44	2.60	39.4
20	2.63	41.1	45	2.51	37.2
21	2.47	36.7	46	2.64	41.0
22	2.71	44.0	47	2.53	38.0
23	2.53	37.9	48	2.46	36.3
24	2.58	39.3	49	2.59	39.1
25	2.60	39.8	50	2.54	37.6

Note. Power = Standing Board Jump distance (m); VO_2max = maximal oxygen uptake estimated via the 20-m Multistage Fitness Test (ml·kg^{-1}·min^{-1}).

The individual data presented in Table 3 reveal considerable variability in both lower-limb explosive power and VO_2max across the 50 athletes. Power values ranged from 2.19 to 2.82 m, while VO_2max values ranged from 29.9 to 53.3 ml·kg^{-1}·min^{-1}, reflecting marked inter-individual differences in neuromuscular and aerobic capacities within a relatively homogeneous training cohort. Several athletes demonstrated high performance in both variables, whereas others exhibited moderate to low physical profiles, suggesting heterogeneous fitness characteristics despite similarities in age and institutional training background. Table 4 summarizes the descriptive statistics for both variables, providing the statistical foundation for the norm-referenced classification.

Table 4. Descriptive Statistics for Lower-Limb Explosive Power and VO_2max (n = 50)

Variable	n	Mean ± SD	Min	Max
VO_2max (ml·kg⁻¹·min⁻¹)	50	38.28 ± 3.67	29.9	53.3
Lower-Limb Explosive Power (m)	50	2.54 ± 0.13	2.19	2.82

Note. Mean and SD values were derived using standard descriptive statistics. SD = standard deviation.

The mean VO_2max of the cohort was 38.28 ± 3.67 ml·kg⁻¹·min⁻¹, reflecting a moderate aerobic profile consistent with the demands of developmental-level volleyball. The wide range (29.9–53.3 ml·kg⁻¹·min⁻¹) indicates substantial inter-individual variation in cardiorespiratory fitness. Lower-limb explosive power demonstrated a mean value of 2.54 ± 0.13 m, with a range of 2.19–2.82 m, reflecting similarly notable variability in neuromuscular capacity within the sample.

Table 5 presents the cut-off values derived from the descriptive statistics, which serve as the classification thresholds for the five-tier norm-referenced framework.

Table 5. Cut-Off Values for Norm-Referenced Performance Classification Based on Mean and Standard Deviation Intervals

Classification Level	Explosive Power (m)	VO_2max (ml·kg⁻¹·min⁻¹)
Mean + 1.5 SD	2.73	43.80
Mean + 0.5 SD	2.61	40.12
Mean − 0.5 SD	2.48	36.45
Mean − 1.5 SD	2.35	32.77

Note. Cut-off values were computed using the sample mean and standard deviation: Mean = 2.54 m and SD = 0.13 m for explosive power; Mean = 38.28 ml·kg⁻¹·min⁻¹ and SD = 3.67 ml·kg⁻¹·min⁻¹ for VO_2max.

Norm-Referenced Performance Classification

Based on the cut-off values presented in Table 5, Table 6 presents the complete five-tier performance classification system for both lower-limb explosive power and VO_2max, representing the primary standardization outcome of this study.

Table 6. Five-Tier Norm-Referenced Performance Classification for Lower-Limb Explosive Power and VO_2max in Male Volleyball Athletes Aged 17–21 Years

Category	Explosive Power Range (m)	VO_2max Range (ml·kg⁻¹·min⁻¹)
Very Good	> 2.73	> 43.80
Good	2.61 – 2.73	40.12 – 43.80
Moderate	2.48 – 2.60	36.45 – 40.11
Poor	2.35 – 2.47	32.77 – 36.44
Very Poor	< 2.35	< 32.77

Note. The Moderate category (2.48–2.60 m; 36.45–40.11 ml·kg⁻¹·min⁻¹) is designated as the minimum physical readiness threshold for competitive volleyball participation at this developmental stage.

The performance classification revealed that athletes were distributed across all five tiers for both variables, confirming the heterogeneous nature of physical capacities within this age group. For lower-limb explosive power, the Very Good category (> 2.73 m) represents athletes with high neuromuscular capacity sufficient for advanced competitive demands, while the Very Poor category (< 2.35 m) identifies athletes who may experience limitations in jump-dependent performance actions. The analogous distribution for VO_2max, with the Very Good category (> 43.80 ml·kg⁻¹·min⁻¹) and the Very Poor category (< 32.77 ml·kg⁻¹·min⁻¹), reflects comparable variability in aerobic fitness across the cohort.

Hypothesis Testing

Prior to inferential analysis, distributional normality of both variables was evaluated using the Shapiro–Wilk test, which is recommended for sample sizes of n ≤ 50 (Wah & Sim, 2011). Because both variables violated the normality assumption, non-parametric equivalents were applied throughout: Spearman's rank-order correlation (ρ) to quantify the bivariate association between explosive power and VO_2max; the Wilcoxon Signed-Rank test to compare sample medians against established literature-based reference values; and the Kruskal–Wallis H test to examine whether physical performance differed across the five age subgroups (17, 18, 19, 20, and 21 years). An alpha level of α = .05 was adopted as the threshold for statistical significance for all tests. Effect sizes are reported alongside p-values to convey practical significance independent of sample size.

Table 7. Shapiro–Wilk Normality Test Results for Lower-Limb Explosive Power and VO_2max (n = 50)

Variable	W Statistic	df	p-value	Distribution
Lower-Limb Explosive Power (m)	0.932	50	.007**	Non-normal
VO_2max (ml·kg⁻¹·min⁻¹)	0.880	50	< .001***	Non-normal

Note. ** p < .01; *** p < .001. Non-normal distribution of both variables necessitated the use of non-parametric statistical procedures for subsequent hypothesis testing. df = degrees of freedom.

The Shapiro–Wilk test revealed that both lower-limb explosive power (W = 0.932, p = .007) and VO_2max (W = 0.880, p < .001) significantly deviated from a normal distribution. These results confirm the appropriateness of non-parametric approaches for all subsequent inferential analyses. The non-normality of VO_2max is consistent with the observed range (29.9–53.3 ml·kg⁻¹·min⁻¹), which includes outlier-level high values likely associated with athletes of exceptional aerobic capacity within the sample.

H_1: Association Between Lower-Limb Explosive Power and VO_2max

Hypothesis**:** H_0: There is no significant monotonic association between lower-limb explosive power and VO_2max in male volleyball athletes aged 17–21 years (ρ = 0).

Alternative (H_1): There is a significant positive monotonic association between lower-limb explosive power and VO_2max (ρ > 0).

Statistical test: Spearman's rank-order correlation (two-tailed; α = .05).

Table 8. Spearman's Rank-Order Correlation Between Lower-Limb Explosive Power and VO_2max (n = 50)

Variable Pair	ρ (rho)	t(48)	p-value	Interpretation
Explosive Power × VO_2max	.929	16.62	< .001***	Very Strong Positive

Note. *** p < .001. ρ = Spearman's rho; t = test statistic with 48 degrees of freedom. Correlation strength interpretation follows (Lachenbruch & Cohen, 1989): \|.10\| = small, \|.30\| = medium, \|.50\| = large. A ρ value of .929 substantially exceeds the large-effect threshold.

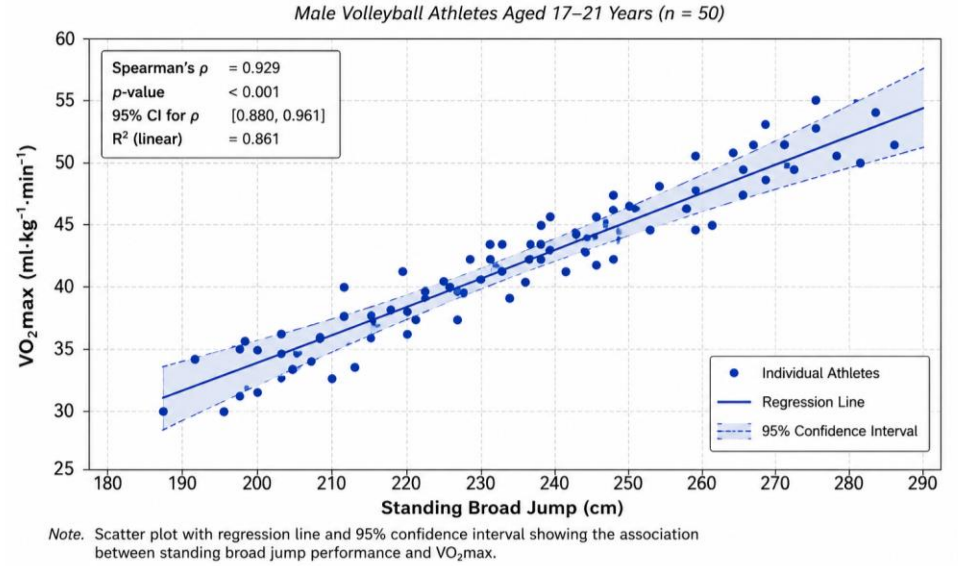

Figure 1. Association Between Standing Broad Jump Performance and Estimated VO_2max Among Male Volleyball Athletes Aged 17–21 Years. Scatter plot illustrating the relationship between standing broad jump performance and estimated maximal oxygen uptake (VO_2max). The solid regression line represents the overall linear trend, while the shaded area indicates the 95% confidence interval. The analysis demonstrates a very strong positive association (Spearman's ρ = 0.929, p < .001), suggesting that athletes with greater lower-limb explosive power generally exhibited higher aerobic capacity.

The Spearman correlation analysis yielded a very strong, statistically significant positive association between lower-limb explosive power and VO_2max ($\rho = .929$, $t(48) = 16.62$, $p < .001$). This result provides strong evidence to reject H_0. The coefficient of determination ($R^2 = .863$) indicates that approximately 86.3% of the rank-order variance in VO_2max is shared with lower-limb explosive power, confirming a high degree of co-variation between neuromuscular and aerobic capacities in this cohort. Athletes who demonstrated greater explosive power tended systematically to exhibit higher aerobic capacity, a finding consistent with the integrated physical demands of competitive volleyball where both attributes are simultaneously conditioned through training (Wang et al., 2025; Wei et al., 2025). This strong bivariate relationship reinforces the validity of concurrent physical assessment and supports the development of integrated physical readiness profiles for volleyball athlete selection.

H_2: Comparison of Sample Medians Against Literature-Based Reference Values

Hypothesis: H_0: The median lower-limb explosive power and VO_2max of the sample do not significantly differ from established reference values reported in the volleyball literature.

Alternative (H_2): The sample medians differ significantly from reference values (two-tailed).

Statistical test: Wilcoxon Signed-Rank test; reference values: 2.50 m (explosive power) and 40.0 ml·kg⁻¹·min⁻¹ (VO_2max), as derived from the volleyball literature (Gabbett et al., 2007; Nikolaidis et al., 2011).

Table 9. Wilcoxon Signed-Rank Test: Sample Medians vs. Literature-Based Reference Values

Variable	Median	Reference	W	p-value	Effect (r)
Explosive Power (m)	2.55	2.50	307.5	.002**	.43 (Medium)
VO_2max (ml·kg⁻¹·min⁻¹)	38.35	40.0	230.0	<.001***	.56 (Large)

Note. ** p < .01; *** p < .001. W = Wilcoxon Signed-Rank statistic. Effect size r = Z / √N; interpretation: .10 = small, .30 = medium, .50 = large (Cohen, 1988). Reference values sourced from Gabbett et al. (2008) and Nikolaidis et al. (2012).

The Wilcoxon Signed-Rank test indicated that the sample median for lower-limb explosive power (Mdn = 2.55 m) was significantly greater than the reference value of 2.50 m (W = 307.5, p = .002, r = .43), representing a medium effect size. This result permits rejection of H_0 for explosive power and suggests that the present cohort demonstrated modestly superior neuromuscular capacity relative to previously published benchmarks, potentially reflecting improvements in volleyball-specific training methodologies implemented at institutional training centers in East Java.

Conversely, the sample median for VO_2max (Mdn = 38.35 ml·kg⁻¹·min⁻¹) was significantly lower than the reference value of 40.0 ml·kg⁻¹·min⁻¹ (W = 230.0, p < .001, r = .56), with a large effect size. This finding suggests that the aerobic capacity of the present cohort falls measurably below reference standards reported for comparable volleyball populations. The deficit may reflect insufficient emphasis on aerobic conditioning relative to anaerobic and skill-based training in regional developmental programs, and reinforces the need for structured cardiorespiratory development within volleyball-specific training frameworks at this competitive stage.

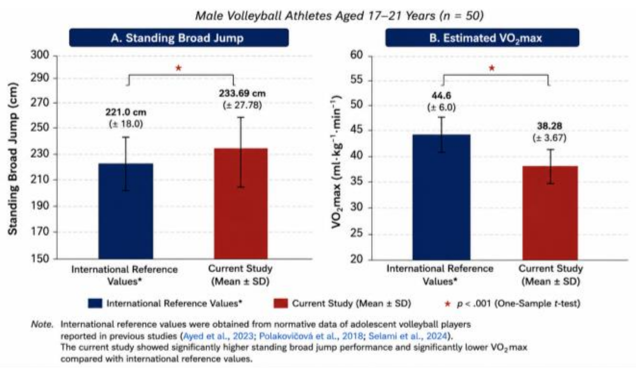

Figure 2. Comparison Between Current Study and Literature-Based International Reference Values for Lower-Limb Explosive Power and Estimated VO_2max

Figure 2. Comparison Between Current Study and Literature-Based International Reference Values for Lower-Limb Explosive

Power and Estimated VO_2max. Mean (± SD) values of standing broad jump performance and estimated maximal oxygen uptake (VO_2max) in the present sample compared with literature-based international reference values. The current cohort demonstrated significantly greater lower-limb explosive power but significantly lower estimated VO_2max than the reference values, consistent with the Wilcoxon Signed-Rank test results presented in Table 9 ($p < .01$ for explosive power; $p < .001$ for VO_2max).

H_3: Differences in Physical Performance Across Age Subgroups (17–21 Years)

Hypothesis: H_0: There are no significant differences in lower-limb explosive power or VO_2max across age subgroups (17, 18, 19, 20, and 21 years).

Alternative (H_3): At least one age subgroup differs significantly from the others in either explosive power or VO_2max.

Statistical test: Kruskal–Wallis H test (non-parametric one-way ANOVA equivalent; $\alpha = .05$).

Table 10. Descriptive Statistics for Lower-Limb Explosive Power and VO_2max by Age Subgroup

Age	n	Power: Mean ± SD (m)	Min	Max	VO_2max: Mean ± SD	Min–Max
17	6	2.490 ± 0.193	2.19	2.82	38.37 ± 7.72	29.9–53.3
18	10	2.507 ± 0.218	2.24	2.77	37.42 ± 5.39	30.8–45.6
19	12	2.577 ± 0.072	2.47	2.71	39.08 ± 2.32	36.7–44.0
20	11	2.553 ± 0.042	2.48	2.64	38.02 ± 0.78	36.5–39.4
21	11	2.555 ± 0.056	2.46	2.64	38.42 ± 1.46	36.3–41.0

Note. SD = standard deviation. Units: Power in meters (m); VO_2max in ml·kg^{-1}·min^{-1}. Notably, athletes aged 17 and 18 years exhibit larger within-group variance, reflecting greater inter-individual heterogeneity at earlier stages of physical maturation.

Table 11. Kruskal–Wallis H Test: Differences in Physical Performance Across Age Subgroups

Variable	H Statistic	df	p-value	η^2 (eta²)	Decision
Lower-Limb Explosive Power	2.201	4	.699	.060	Fail to Reject H_0
VO_2max	2.198	4	.700	.024	Fail to Reject H_0

Note. H = Kruskal–Wallis test statistic; df = degrees of freedom (between groups = 4); η^2 = eta-squared effect size computed as $(H - k + 1) / (N - k)$, where k = 5 groups and N = 50. Significance threshold: $p < .05$.

The Kruskal–Wallis H test revealed no statistically significant differences in lower-limb explosive power ($H(4) = 2.201$, $p = .699$, $\eta^2 = .06$) or VO_2max ($H(4) = 2.198$, $p = .700$, $\eta^2 = .02$) across the five age subgroups. These results indicate failure to reject H_0 for both variables, suggesting that chronological age within the 17–21-year range is not a significant determinant of physical performance variation in this cohort. The small effect sizes ($\eta^2 < .06$) further confirm that age accounts for only a minor proportion of variance in both performance measures.

Notably, descriptive data in Table 10 reveal a pattern of decreasing within-group variance with increasing age: athletes aged 17 and 18 years exhibited markedly larger standard deviations in both power (SD = 0.193 m and 0.218 m, respectively) and VO_2max (SD = 7.72 and 5.39 ml·kg^{-1}·min^{-1}), compared with athletes aged 20 and 21 years (SD ≤ 0.056 m and ≤ 1.46 ml·kg^{-1}·min^{-1}). This pattern is consistent with the progressive convergence of physical maturation and training adaptation as athletes advance through late adolescence (Sigmund & Güllich, 2021), and may explain the lack of significant between-group differences despite observable shifts in mean values across age subgroups. Post-hoc pairwise comparisons were not performed given the absence of a significant omnibus effect, in accordance with recommended statistical practice (Field, 2018).

Summary of Hypothesis Testing Outcomes

Table 12 provides a consolidated summary of all hypothesis test outcomes reported in Section 3.3.

Table 12. Summary of Hypothesis Testing Outcomes

H	Hypothesis (H_0)	Test	Statistic	p-value	Decision
H_1	No association between Power & VO_2max ($\rho = 0$)	Spearman Corr.	$\rho = .929$	< .001	Reject H_0
H_2a	Median Power = 2.50 m	Wilcoxon SRT	W = 307.5	.002	Reject H_0
H_2b	Median VO_2max = 40.0 ml·kg^{-1}·min^{-1}	Wilcoxon SRT	W = 230.0	< .001	Reject H_0
H_3a	No age-group differences in Power	Kruskal–Wallis	H = 2.201	.699	Fail to Reject
H_3b	No age-group differences in VO_2max	Kruskal–Wallis	H = 2.198	.700	Fail to Reject

Note. SRT = Signed-Rank Test. All tests conducted at $\alpha = .05$. Normality violations (Shapiro–Wilk, $p < .05$ for both variables) justified the application of non-parametric procedures throughout.

DISCUSSION

Principal Findings

The present study sought to establish standardized normative values for lower-limb explosive power and maximal oxygen uptake (VO_2max) among male volleyball athletes aged 17–21 years in East Java, Indonesia, while simultaneously examining the relationship between these two key physiological attributes and evaluating whether physical performance differed across late-adolescent age groups. Overall, the findings fulfilled the primary objective by producing a population-specific five-tier normative classification system that can be used for athlete profiling, selection, and longitudinal performance monitoring.

The inferential analyses supported the first hypothesis, demonstrating a very strong positive association between lower-limb explosive power and VO_2max ($\rho = .929$, $p < .001$). This result indicates that athletes with superior neuromuscular performance generally also possessed higher aerobic capacity. Importantly, although the statistical association was exceptionally strong, the interpretation should remain practical rather than causal because the cross-sectional design does not permit conclusions regarding physiological directionality. Instead, the observed relationship likely reflects concurrent adaptations produced by long-term volleyball training, in which repeated jumping, sprinting, and intermittent recovery collectively stimulate both neuromuscular and aerobic development. The second hypothesis was also supported. Lower-limb explosive power was significantly higher than published reference values, whereas VO_2max remained significantly lower than international benchmarks. These contrasting findings are practically meaningful. The statistical significance indicates that the observed differences are unlikely to be attributable to sampling variation, whereas the practical significance suggests an imbalance within current developmental programs. Specifically, East Java volleyball athletes appear relatively well prepared for explosive, jump-dominant actions but comparatively underprepared in aerobic conditioning. From a coaching perspective, this imbalance is more informative than the statistical significance itself because it identifies the physiological domain most likely to benefit from targeted intervention. The third hypothesis was not supported. No statistically significant differences were observed across the five age categories (17–21 years) for either explosive power or VO_2max. Although chronological age explained little variance in performance, descriptive statistics revealed progressively lower within-group variability among older athletes. This pattern suggests that physical maturation during late adolescence may reduce inter-individual differences rather than continually increase average performance. Consequently, athlete assessment should prioritize objective physical testing over chronological age when evaluating readiness for higher competitive levels.

Perhaps the most important contribution of this investigation extends beyond the numerical results themselves. Unlike previous studies that primarily described physical characteristics, the present research generated standardized cut-off values that translate raw performance into interpretable performance categories. Such normative standards provide practitioners with decision-making tools rather than simply descriptive statistics, thereby increasing the practical utility of physical testing within athlete development systems.

Comparison with International Evidence

The present findings are generally consistent with international evidence identifying lower-limb explosive power as one of the strongest determinants of volleyball performance. Studies conducted in Poland, Italy, China, Brazil, and Tunisia consistently report that explosive strength is closely associated with jumping performance, attack efficiency, and blocking success. Likewise, the mean standing broad jump performance observed in the current cohort falls within the range reported for developmental and national-level volleyball athletes, suggesting that Indonesian players possess neuromuscular capacities comparable to many international populations despite differences in competition systems.

Nevertheless, an important contribution of the present study lies in the development of normative reference values rather than merely reporting average scores. Previous investigations by Polakovičová et al. (2018), Ayed et al. (2023) and Bobula et al. Bobula et al. (2024) primarily examined relationships between explosive power and performance outcomes or evaluated intervention effects. Few studies translated these measurements into standardized classification systems that can be directly applied in talent identification and athlete monitoring(Bergkamp et al., 2019, p. 1328; McKay et al., 2021; Paulsen et al., 2025). Consequently, the present study complements rather than duplicates existing literature by providing operational benchmarks for routine performance assessment.

The findings regarding VO_2max also demonstrate partial agreement with previous international investigations. The observed average aerobic capacity corresponds closely with values reported for adolescent volleyball players assessed using field-based protocols(Boddy et al., 2012, p. 4; Charitonidis et al., 2019). However, comparison with higher-level competitive cohorts indicates that the current athletes demonstrate relatively lower aerobic fitness than elite or professional volleyball players (MELROSE et al., 2007; Trajković et al., 2020, p. 2087). This discrepancy is not unexpected because aerobic performance is influenced by accumulated training exposure, competition level, and conditioning strategies.

Several factors may explain differences between the present findings and previous international studies. First, population characteristics differ considerably. Many previous investigations recruited elite national or professional athletes, whereas the current sample consisted of regional developmental athletes undergoing transition toward senior competition. Second, training dose and conditioning emphasis vary across countries(Güllich et al., 2023, p. 1215). European and East Asian volleyball systems frequently integrate structured aerobic conditioning alongside explosive training, whereas many developing programs continue to emphasize technical drills and jump-specific exercises(Jariono et al., 2024, p. 121). Third, methodological differences also contribute. Some studies employed laboratory gas analysis for VO_2max measurement, whereas the present investigation utilized the validated Multistage Fitness Test(Brocherie et al., 2017, p. 1661). Although this field test demonstrates acceptable validity, slight systematic differences between laboratory and field estimates should be acknowledged.

Cultural and organizational factors may also contribute to the observed differences. Volleyball development pathways differ internationally in coaching philosophy, athlete support services, competition schedules, and access to sport science personne(Coutinho et al., 2021, p. 667543; Peters et al., 2022, p. 903897). Such contextual factors influence training quality, recovery practices, nutritional support, and long-term athlete development. Consequently, normative standards generated in one country should not be transferred directly to another without validation.

Finally, implementation fidelity may partially explain discrepancies across studies. Intervention-based research often reports improvements following highly supervised, standardized training programs, whereas athletes in routine development environments experience greater variability in coaching quality, attendance, compliance, and training intensity. The heterogeneous performance distribution observed in the present sample likely reflects these real-world implementation differences.

Theoretical, Methodological, and Practical Implications

From a theoretical perspective, the findings reinforce contemporary models of integrated athletic performance, which propose that volleyball success emerges from interactions among neuromuscular, metabolic, technical, and tactical capacities rather than isolated physical components. The exceptionally strong association between explosive power and VO_2max suggests that these physiological systems may develop synergistically under volleyball-specific training conditions(Duncan et al., 2006, p. 650; Hakim et al., 2025). Rather than viewing anaerobic and aerobic capacities as independent constructs, coaches and sport scientists should consider them complementary dimensions contributing collectively to repeated high-intensity performance.

The study also extends theories of long-term athlete development. The absence of age-group differences despite decreasing variability across older athletes suggests that maturation may primarily reduce performance heterogeneity after late adolescence instead of producing substantial improvements in average physical capacity(Lesinski et al., 2020, p. 1; Till et al., 2013, p. 580). This finding refines current developmental models by indicating that individualized adaptation may become more important than chronological age during the transition from junior to senior competition.

Methodologically, the principal innovation of this research is the establishment of a standardized norm-referenced classification system using a five-tier mean ± SD framework. Previous volleyball studies have predominantly reported descriptive statistics or intervention outcomes without providing operational thresholds for athlete categorization(Erol et al., 2025, p. 1658049; Gabbett &

Georgieff, 2007; Rubajczyk & Rokita, 2020, p. 1450). The current framework transforms continuous performance data into clinically and practically interpretable categories, facilitating longitudinal monitoring, benchmarking, and evidence-based decision making.

From a practical standpoint, the proposed classification system has several applications. Coaches may use the cut-off values to identify athletes requiring additional explosive strength or aerobic conditioning. Strength and conditioning specialists can individualize training prescriptions according to each athlete's performance category rather than applying identical programs across heterogeneous groups(Lindberg et al., 2021, p. 2207; Philipp et al., 2023). Talent identification programs may incorporate these normative values alongside technical and tactical assessments to improve selection accuracy(Campos-Redondo et al., 2025; Nowak et al., 2025). Furthermore, sport governing bodies may adopt these benchmarks when monitoring athlete development across regional academies, thereby promoting greater consistency in performance evaluation.

Despite these practical implications, caution should be exercised to avoid overgeneralization. The proposed thresholds should be interpreted as reference values specific to male volleyball athletes aged 17–21 years participating within the Indonesian developmental system rather than universal international standards.

Strengths and Limitations

Several strengths enhance the scientific contribution of this study. First, the investigation addressed an important gap by establishing normative standards for a previously underrepresented population. Second, standardized measurement protocols were implemented for both physical tests, reducing procedural variability. Third, inferential analyses extended beyond descriptive statistics by examining associations, benchmark comparisons, and age-related differences, thereby providing a more comprehensive understanding of athlete performance.

Nevertheless, several limitations should be considered when interpreting the findings. The cross-sectional design prevents causal inference regarding the relationship between explosive power and VO_2max and cannot describe developmental trajectories over time. Longitudinal follow-up is therefore required to determine whether improvements in one physiological domain precede changes in the other.

The relatively modest sample size ($n = 50$), although adequate for the planned analyses, limits statistical precision and may reduce generalizability to broader volleyball populations. Participants were recruited exclusively from East Java, introducing potential regional sampling bias. Consequently, transferability to other Indonesian provinces or international populations should be approached cautiously.

Measurement limitations should also be acknowledged. VO_2max was estimated using the Multistage Fitness Test rather than direct gas-analysis procedures, introducing potential estimation error. Similarly, although the standing broad jump is a validated indicator of explosive power, it represents horizontal rather than vertical jumping ability, and therefore may not fully capture volleyball-specific jump performance.

Potential confounding variables—including playing position, biological maturation, weekly training load, resistance training history, nutritional intake, sleep quality, injury history, and competition exposure—were not measured. These factors may partially explain the observed variability and should be incorporated into future investigations.

Although missing data were absent, minimizing bias associated with incomplete observations, the study did not employ participant or assessor blinding because of the observational field-testing design. Multiplicity was limited through predefined hypotheses, yet multiple inferential analyses increase the possibility of Type I error and should therefore be interpreted within the broader context of effect sizes and practical relevance rather than p-values alone.

Future Research

Future investigations should expand this work by recruiting larger, nationally representative samples that include both male and female volleyball athletes from multiple Indonesian provinces as well as international cohorts. Cross-national validation would determine whether the proposed normative standards remain stable across different cultural and competitive environments.

Longitudinal cohort studies spanning several competitive seasons are required to examine developmental trajectories and determine how explosive power and aerobic capacity evolve during the transition from junior to elite competition. Such designs would also clarify causal relationships that cannot be inferred from cross-sectional analyses.

Future research should investigate physiological mechanisms underlying the observed association between explosive power and VO_2max, including neuromuscular efficiency, muscle architecture, mitochondrial adaptations, and recovery kinetics. Mediation and moderation analyses involving biological maturation, playing position, training volume, nutritional status, and recovery quality would provide a more comprehensive understanding of athlete development.

Experimental studies comparing different conditioning strategies—including plyometric training, sprint interval training, combined aerobic–anaerobic interventions, and individualized periodization—would determine the most effective methods for simultaneously improving explosive power and aerobic fitness. Cost-effectiveness analyses should also be conducted to evaluate the feasibility of implementing standardized testing programs across regional and national volleyball development systems.

Finally, replication studies using laboratory-based physiological measurements, direct force-platform assessments, wearable technologies, and multicenter implementation designs are recommended to verify the robustness, external validity, and practical applicability of the proposed normative classification framework in diverse volleyball populations.

CONCLUSION

This study achieved its primary objective by establishing standardized normative reference values for lower-limb explosive power and VO_2max among male volleyball athletes aged 17–21 years in East Java, Indonesia. The findings demonstrate that these physical capacities exhibit considerable inter-individual variability and that lower-limb explosive power is strongly associated with aerobic capacity within this developmental population. In addition to characterizing physical performance, the study provides a five-tier norm-referenced classification framework that offers an objective basis for athlete profiling, performance evaluation, and longitudinal monitoring. These findings contribute to the international sport science literature by addressing the limited availability of population-specific normative standards for late-adolescent volleyball athletes and by providing a practical framework that may support evidence-informed talent identification and physical assessment in comparable developmental settings.

The findings should, however, be interpreted within the context of the study design. Because the investigation was cross-sectional and involved male athletes recruited from regional training programs in a single Indonesian province, the results should not be generalized directly to female athletes, elite international populations, or other geographical contexts without external validation. Likewise, the observed associations should not be interpreted as evidence of causal relationships. Future multicenter and longitudinal studies are warranted to validate the proposed normative standards across diverse populations and competitive levels and to determine their broader applicability within international volleyball athlete development systems.

DECLARATIONS

Ethical Approval

This study was conducted in accordance with the ethical principles of the Declaration of Helsinki (World Medical Association, 2013) and the ethical guidelines governing research involving human participants in Indonesia (Ministry of Health Regulation No. 20 of 2021). Ethical approval was obtained prior to participant recruitment from: Ethics Committee: Ethics Committee of Faculty of Sports and Health Sciences, Indonesia, Institution: State University of Surabaya; Approval Number: EC-UNESA/Pen/2025-07-3991; Approval Date: 17/09/2026. The authors confirm that the above ethics approval information accurately reflects the official approval documentation and should correspond exactly to the original ethics approval certificate before publication.

Consent to Participate

Written informed consent was obtained from all participants before data collection. For participants younger than 18 years of age, written informed consent was additionally obtained from their parent(s) or legal guardian(s), as approved by the institutional ethics committee. Participation was entirely voluntary, and participants were informed of their right to withdraw from the study at any time without penalty.

Consent for Publication

This manuscript does not contain identifiable personal information, individual photographs, videos, or clinical case details that could reveal participant identity. Therefore, separate consent for publication of identifiable information was not required.

Author Contributions (CRediT)

The contributions below should accurately reflect the actual work performed by each author.

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Conflict of Interest

The authors declare that they have no financial or non-financial conflicts of interest that could have influenced the design, conduct, analysis, interpretation, or reporting of this study.

Data Availability

The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request. Data will be shared in accordance with institutional policies, participant confidentiality requirements, and applicable ethical approvals. No personally identifiable participant information will be released.

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Generative AI Disclosure

During the preparation of this manuscript, the authors used a generative artificial intelligence (AI) tool to assist with language refinement, grammar correction, and improvement of academic writing clarity. All scientific interpretations, study design, data analysis, statistical results, conclusions, and final editorial decisions were independently reviewed, verified, and approved by the authors. The authors accept full responsibility for the accuracy, integrity, and originality of the manuscript.

No confidential participant information, identifiable personal data, or unpublished research data were entered into any generative AI system during manuscript preparation. The use of AI complied with the journal's publication ethics policies and did not replace the authors' scientific judgment or accountability.

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