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

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A B S T R A C T

The purpose of the study. 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.

A R T I C L E I N F O

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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

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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 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%).

Research 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.

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 ($ml \cdot kg^{-1} \cdot min^{-1}$) 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 ($\bar{A}$), 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 [Institution Name], with reference number [Ethics Approval Number/Year]. 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 $ml\cdot kg^{-1}\cdot min^{-1}$) 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 $ml\cdot kg^{-1}\cdot min^{-1}$) and the Very Poor category (< 32.77 $ml\cdot kg^{-1}\cdot min^{-1}$), 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 $\alpha = .05$ 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 $ml\cdot kg^{-1}\cdot min^{-1}$), which includes outlier-level high values likely associated with athletes of exceptional aerobic capacity within the sample.

1 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 ($\rho = 0$).

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

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

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.

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.

3.3.2 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 ($ml \cdot kg^{-1} \cdot min^{-1}$)	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 $ml \cdot kg^{-1} \cdot min^{-1}$) was significantly lower than the reference value of 40.0 $ml \cdot kg^{-1} \cdot min^{-1}$ (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 (Delieoğlu et al., 2024; Wei et al., 2025).

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; α = .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 $ml \cdot kg^{-1} \cdot min^{-1}$. 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	η² (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); η² = 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, η² = .06) or VO_2max (H(4) = 2.198, p = .700, η² = .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 (η² < .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 $ml \cdot kg^{-1} \cdot min^{-1}$), compared with athletes aged 20 and 21 years (SD ≤ 0.056 m and ≤ 1.46 $ml \cdot kg^{-1} \cdot min^{-1}$). 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 (ρ = 0)	Spearman Corr.	ρ = .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 $ml \cdot kg^{-1} \cdot min^{-1}$	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 α = .05. Normality violations (Shapiro–Wilk, p < .05 for both variables) justified the application of non-parametric procedures throughout.

DISCUSSION

The present study examined lower-limb explosive power and VO_2max in male volleyball athletes aged 17–21 years using a descriptive, norm-referenced, and inferential approach. The findings demonstrated substantial inter-individual variability in both neuromuscular and aerobic capacities, underscoring the heterogeneity of physical characteristics among late-adolescent athletes within the same developmental and institutional training context. Inferential hypothesis testing further revealed a very strong bivariate association between the two performance variables, statistically significant deviations from established literature-based benchmarks, and the absence of significant age-related performance differences within this transitional cohort. These findings carry significant practical implications for athlete evaluation, selection, and training program design during the critical junior-to-senior competitive transition.

The mean lower-limb explosive power of 2.54 ± 0.13 m observed in this study is broadly consistent with reported values in the literature for developmental-level male volleyball athletes assessed using horizontal jump-based measures. Standing board jump performance has been validated as a reliable indicator of lower-limb explosive strength with demonstrated associations with vertical jump height and net-play effectiveness (Sattler et al., 2014). The minimum value of 2.19 m reflects limited neuromuscular capacity potentially associated with restricted jumping ability during spiking and blocking, while the maximum value of 2.82 m corresponds to high-performance explosive output consistent with advanced competitive readiness. Comparable performance ranges have been documented in regional and national-level volleyball athletes, supporting the ecological validity of the present findings (Erol et al., 2025; Lima et al., 2019; Sattler et al., 2014).

Lower-limb explosive power is functionally critical in volleyball given the frequency of explosive jumping actions during spiking, blocking, and jump serving, which directly influence scoring effectiveness and defensive performance (Freitas-Junior et al., 2020; Wang et al., 2025). Match-analysis investigations have demonstrated that jump-related actions contribute substantially to winning rallies, reinforcing the performance relevance of explosive strength at this competitive stage (Abdioğlu et al., 2024; Koya et al., 2022). The distribution of athletes across all five performance tiers in the present study highlights the marked inter-individual variability in neuromuscular development among athletes of comparable age and training background. This variability underscores the necessity for individualized diagnostic assessment and targeted strength and power development programming, rather than uniform training approaches applied to heterogeneous athlete groups.

In comparison with Ayed et al. (2023) , who examined explosive power using force-velocity and horizontal jump tests in North African volleyball players and confirmed correlations with sport-specific performance, the present study extends these findings by providing standardized norm-referenced thresholds applicable to Indonesian developmental-level athletes. The absence of such regional benchmarks in the prior literature represents a significant gap, as physical performance norms are known to vary by population, training methodology, and environmental context (Lolli et al., 2023; McCormack et al., 2021).

The mean VO_2max of 38.28 ± 3.67 ml·kg⁻¹·min⁻¹ reflects a moderate aerobic profile for volleyball athletes aged 17–21 years. This value aligns with previously reported VO_2max ranges of 36–42 ml·kg⁻¹·min⁻¹ for adolescent and young adult male volleyball players assessed using field-based methods, as documented by Gabbett et al. (2008) and Nikolaidis et al. (2012). Although individual volleyball actions are primarily anaerobic in nature, sustained aerobic capacity is essential for supporting repeated high-intensity efforts, facilitating inter-rally recovery, and maintaining technical execution quality across multiple sets (Delieoğlu et al., 2024; Wei et al., 2025).

The wide VO_2max range observed (29.9–53.3 ml·kg⁻¹·min⁻¹) reflects marked variability in cardiorespiratory fitness within the cohort. This inter-individual dispersion may be attributed to differences in training volume, competitive experience, positional demands, and individual physiological characteristics (Freire et al., 2023; Tao et al., 2024). Athletes in the Very Good category (> 43.80 ml·kg⁻¹·min⁻¹) likely possess greater aerobic reserves, facilitating rapid recovery between high-intensity actions and sustaining performance quality over extended match durations. Conversely, athletes in the Poor or Very Poor categories may exhibit performance decrements in later sets, a pattern consistent with prior aerobic-performance research in volleyball (Lima et al., 2021; Pawlik & Mroczek, 2022).

The application of a norm-referenced classification system based on mean ± SD intervals represents a methodologically rigorous and ecologically valid approach to standardizing physical performance data within a specific population. This framework has been previously employed in sport science for athlete profiling and selection purposes (McCormack et al., 2021) and provides a transparent, reproducible basis for performance evaluation. The five-tier structure adopted in the present study offers practitioners a granular framework for distinguishing performance levels and informing individualized training decisions(T. de P. Oliveira & Newell, 2024; T. P. Oliveira & Newell, 2023).

The designation of the Moderate category as the minimum physical readiness threshold carries practical significance for athlete development and selection in Indonesian volleyball. For lower-limb explosive power, this threshold (2.48–2.60 m) indicates sufficient neuromuscular capacity for fundamental net-play actions such as spiking and blocking. For VO_2max, the Moderate threshold (36.45–40.11 ml·kg⁻¹·min⁻¹) reflects the minimum aerobic fitness required to sustain repeated efforts across match duration. Athletes classified below these thresholds may experience limitations in physical readiness for competitive performance, warranting targeted physical conditioning interventions.

The very strong Spearman correlation between explosive power and VO_2max (ρ = .929, p < .001) observed in this study is a notable finding with implications for both theoretical understanding and practical training design. The magnitude of this association—

substantially exceeding the large-effect threshold—suggests that neuromuscular and aerobic capacities in this population are not independent attributes but share a high degree of co-variation, plausibly mediated by shared adaptations to structured volleyball training regimens (Wang et al., 2025; Wei et al., 2025). This finding supports the notion of integrated physical conditioning programs that simultaneously develop both capacities rather than isolating them within separate training blocks. However, caution is warranted in causal interpretation, as this cross-sectional correlation does not establish directional influence.

The Wilcoxon Signed-Rank test outcomes provided additional inferential context: the sample median for explosive power (2.55 m) significantly exceeded the 2.50 m reference value ($W = 307.5$, $p = .002$, $r = .43$), while the sample median for VO_2max (38.35 ml·kg⁻¹·min⁻¹) fell significantly below the 40.0 ml·kg⁻¹·min⁻¹ benchmark ($W = 230.0$, $p < .001$, $r = .56$). These contrasting patterns suggest an asymmetry in physical development within the East Java institutional context: neuromuscular conditioning appears adequate relative to published norms, while aerobic conditioning warrants targeted improvement. This imbalance may reflect a common tendency in developmental volleyball programs to prioritize technical skill and explosive power training over structured aerobic conditioning, a pattern noted in the broader sport science literature (Delieoğlu et al., 2024; Freire et al., 2023).

The absence of significant between-group differences across age subgroups (Kruskal–Wallis: $p > .69$ for both variables) indicates that chronological age within the 17–21-year window does not independently predict physical performance in this cohort. This finding challenges the assumption that older athletes within a developmental age band automatically possess superior physical capacities, and reinforces the importance of individual assessment over age-based categorization in athlete profiling (Irid et al., 2025; Sigmund & Güllich, 2021). Practitioners should therefore prioritize individual norm-referenced assessment over age-group assumptions when making selection and training decisions. The marked reduction in within-group variance across older subgroups (17–18 vs. 20–21 years) also suggests that physical development in this transitional window is characterized by progressive convergence rather than continued divergence, consistent with the plateau of morphological maturation typically observed after age 18 in male athletes.

Several limitations should be acknowledged when interpreting these findings. First, the sample was exclusively male and drawn from institutional training programs in East Java, Indonesia, which may limit generalizability to female volleyball athletes, athletes in other regions, or those competing at higher competitive levels. Second, the cross-sectional design precludes inferences about developmental trajectories or longitudinal changes in physical performance across the 17–21-year age range. Third, while the 20-m Multistage Fitness Test provides an accepted field-based estimate of VO_2max, it does not represent direct laboratory-based measurement, which may introduce estimation error (Armstrong & Welsman, 2019; Poček et al., 2020). Fourth, the norm-referenced benchmarks derived from this sample are population-specific and should be validated against larger, multi-regional cohorts before broad application in national-level selection programs. Fifth, potential confounding variables such as positional role, weekly training load, nutritional status, and sleep quality were not controlled or measured in the present study.

CONCLUSION

This study established norm-referenced standardized values for lower-limb explosive power and maximal oxygen uptake (VO_2max) in male volleyball athletes aged 17–21 years in East Java, Indonesia. The findings demonstrated substantial inter-individual variability in both neuromuscular and aerobic capacities within a relatively homogeneous developmental cohort. Lower-limb explosive power ranged from 2.19 to 2.82 m (mean ± SD: 2.54 ± 0.13 m), and VO_2max ranged from 29.9 to 53.3 ml·kg⁻¹·min⁻¹ (mean ± SD: 38.28 ± 3.67 ml·kg⁻¹·min⁻¹), generally reflecting a moderate level of physical fitness consistent with developmental-level volleyball.

The five-tier norm-referenced classification (Very Good, Good, Moderate, Poor, Very Poor), constructed using mean ± SD intervals, provided an objective and ecologically valid framework for performance categorization. The Moderate category was designated as the minimum physical readiness threshold, corresponding to lower-limb explosive power values of 2.48–2.60 m and VO_2max values of 36.45–40.11 ml·kg⁻¹·min⁻¹. Athletes whose performance falls below these thresholds may experience functional limitations in jumping ability, net-play effectiveness, and endurance during match play.

The standardized cut-off values generated by this study offer coaches, sport scientists, and national sports organizations an objective reference for athlete selection, physical readiness evaluation, and performance monitoring during the late-adolescent to early-adult competitive transition. The application of these benchmarks is expected to support evidence-based decision-making and enhance the effectiveness of volleyball athlete development programs in Indonesia. Future research should: (1) extend sample populations across multiple provinces and competitive levels to establish nationally representative norms; (2) investigate longitudinal changes in explosive power and VO_2max across the 17–21-year developmental window; (3) include female athletes to develop sex-specific normative standards; and (4) examine the associations between these physical capacities and match performance indicators using integrated performance analysis approaches.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest. All authors contributed to the study conception, data collection, analysis, interpretation, and manuscript preparation, and approved the final version for submission.

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