

Original Research

Profile of Brazilian Under-19 Volleyball Team Athletes: Anthropometry, Jump Performance, Stiffness and Pre-Stretch Augmentation Percentage

Guilherme Berriel, PhD¹, Ananda Silveira Cardoso, PhD^{1a}, Maria Eduarda Cavagni, Student¹, Luiz Fernando Krue L, PhD¹, Leonardo Alexandre Peyré-Tartaruga, PhD¹

¹ School of Physical Education, Physiotherapy and Dance, Universidade Federal do Rio Grande do Sul

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Introduction

Although the stretch-shortening cycle (SSC) influence is well determined on jump performance in adult professional volleyball, the influence of this mechanism on jump in volleyball players in the development phase is unknown. The aim of this study was to evaluate anthropometric profile, jump performance, stiffness and pre-stretch augmentation percentage (PSAP) in Brazilian under-19 volleyball team athletes.

Methods

Twenty-nine male volleyball athletes who were members of the Brazilian under-19 volleyball team were recruited. Squat jump (SJ) and countermovement jump (CMJ) were assessed followed the protocol suggested by Bosco et al. on a contact mat, along with the determination of lower limb stiffness and PSAP. The data were evaluated using descriptive statistics.

Results

The subjects were 18.2±0.5 years (Body mass: 87.59±10.93 kg, height: 195.75±9.21 cm.) The mean results included stiffness 0.43±0.15 N.m-1.kg-1, CMJ height 39.9±5.21 cm, SJ height 41.99±5.7 cm, and PSAP 5.22±3.18 %.

Discussion

The anthropometric profile results highlight the inclusion of athletes of large stature for volleyball, and that SJ and CMJ values are still below those found in adult athletes.

Conclusion

Brazilian athletes from the under-19 national team show potential for improvement in the efficiency of the stretch-shortening cycle (SSC), as indicated by the PSAP values.

Level of Evidence

3b

a Corresponding Author

Ananda Silveira Cardoso

PhD of Human Movement Science (UFRGS)

Address: Federal University of Rio Grande do Sul - 750 Felizardo Street, Porto Alegre (City), Rio Grande do Sul (State), Brazil. Postal Code 90690-200 - Telephone 55 51 33085820.

Phone: 55 51 991946906 or 55 51 33085820

FAX: 55 51 33085817

Email: anandascf@gmail.com

INTRODUCTION

Brazil stands out in the top positions of the International Volleyball Federation (FIVB) ranking, due to the results achieved by the adult national team in international competitions including world championships and the Olympics, as well as by the under-19 and under-21 youth categories in world championships. Some of the key factors contributing to success in volleyball relate to the ability to jump vertically, given that volleyball dynamics involve repeated maximal effort jumps for serving, attacking or blocking, and quick responses to external stimuli.¹ Therefore, the height of vertical jumps associated with the anthropometric profile of athletes, especially stature, is crucial, as greater stature (height) seems to indicate players with better performance in jumping actions,^{2,3} making jumping variables pivotal in both the talent identification process and ultimately the composition of youth category teams. Greater stature also enables athletes to be part of adult national teams in the future.⁴

Along with body composition assessments such as height and body mass, the importance of vertical jump performance is highlighted as a criterion for athletes to join national teams. This underscores the importance of an objective method to evaluate maximum vertical jump performance, using jumps such as the countermovement jump (CMJ) and the squat jump (SJ). These tests enable analysis aligned with specific volleyball movement patterns and serve as performance indicators.^{5,6} Given the importance of vertical jump actions in gameplay, which reflect the explosive strength of the lower limbs^{7,8} using the stretch-shortening cycle (SSC), the squat jump (SJ) is associated with block jump performance, while the countermovement jump (CMJ) is related to attack jumps.⁹ Berriel evaluated the correlations between height and reach of block and attack jumps and the effectiveness of such actions in official games and the relationship between height and reach of attack and block jumps and the height achieved in squat jump (SJ), countermovement jump (CMJ), and CMJ with an arms swing (CMJA). They showed that block jump height was strongly correlated with SJ height ($r = 0.82$; $p < 0.01$), and attack jump height was strongly correlated with CMJ height ($r = 0.86$; $p < 0.01$), and attack jump height was moderately correlated with attack effectiveness ($r = 0.57$; $p = 0.05$).¹⁰

The SSC involves two muscle actions occurring in rapid succession, so that during the eccentric phase of movement, elastic energy is stored in elastic structures and subsequently, this stored energy is used during the concentric phase of movement, which occurs immediately after the end of the eccentric action.¹¹⁻¹³ This mechanism is crucial for the phenomenon of muscle power amplification.¹⁴ The current literature on the SSC in young athletes has significant gaps, especially in understanding the mechanisms that influence the efficiency of the SSC at different stages of maturation.¹⁵ SSC performance improves with age, however, the neuromuscular and biomechanical processes underlying these improvements are not fully understood. In addition, the effectiveness of different training protocols, such as plyometric training for optimizing SSC in young

athletes is inconclusive, mainly due to the lack of adequate control groups in many studies. Future research should clearly focus on delineating specific neuromuscular adaptations that occur during development and how they affect SSC efficiency, as well as establishing clear guidelines for prescribing exercises that consider the maturation stage and individual athletes' abilities.¹⁶

Elastic energy is predominantly stored in tendon structures. Thus, an increased rate of stretching has the potential to enhance both the storage and utilization of elastic energy during SSC movements. Energy accumulation is directly related to stiffness (rigidity) of the muscle-tendon structure, so that higher stiffness indicates greater rigidity, resulting in more energy accumulation and consequently greater power production compared to the same movement performed without using the SSC.¹⁷ Stiffness is commonly defined as the ability of an object to deform in response to an external force or the resistance of an object or body to a change in length.¹⁸⁻²⁰ Mechanical stiffness in the lower limbs appears to significantly influence various athletic variables, including rate of force development, contact and flight times in vertical jumps, and stride length and frequency in sprints.

However, the ideal mechanical stiffness required for movements such as running and jumping remains a topic of debate within the scientific and sports communities. Research on this subject has shown varied results. For example, some authors argue that greater mechanical stiffness seems beneficial for movements like running and jumping.^{21,22} Evaluating male high school volleyball players, Mroczek et al.²³ found an increased stiffness in anterior tibial and quadriceps muscles after six weeks of plyometric training, measured by MyotonPRO Digital Palpation Device, along with a significant improvement in SJ and CMJ performance. However, little has been addressed in the literature regarding stiffness behavior in high-performance athletes.

Seeking information regarding the SSC involvement in muscular actions of jumps, the elastic coefficient uses the difference between the heights achieved in CMJ and SJ, as there is a recognized difference reported in the literature. CMJ's typically presents higher jump heights compared to SJ's, and this difference suggests a better capacity for elastic energy utilization and storage in the CMJ.^{24,25}

Since, anthropometric profile, jump performance, stiffness and elastic coefficient are crucial for performance in this sport, it is necessary to verify the anthropometric profile, jump performance, stiffness and elastic coefficient in volleyball athletes. Therefore, the aim of the current study was to assess the anthropometric profile, jump performance, stiffness, and pre-stretch augmentation percentage (PSAP) in Brazilian under-19 volleyball team players.

MATERIALS AND METHODS

EXPERIMENTAL APPROACH TO THE PROBLEM

This study is an observational cohort design. The subjects first underwent assessments to measure their height and

body mass. After these evaluations, tests were carried out to evaluate lower limbs stiffness and vertical jump performance. Before starting the tests, a standard warm-up of five minutes of running at 8.5 km.h⁻¹ on a treadmill was performed, followed by 15 seconds of passive stretching for each muscle group of the lower limbs. The interval time between CMJ and SJ test was 15 minutes. The elastic coefficient calculation was subsequently carried out based on CMJ and SJ results.

SUBJECTS

All athletes on the team were recruited to participate in the study. The athletes belonged to the Brazilian youth volleyball team, with two years of experience in national competitions and a minimum training volume of four hours per day. The athletes read and signed the free and informed consent form, which contained all the information pertinent to the study. The study was approved by a Research Ethics Committee.

PROCEDURES

Body mass and height. To determine body mass, a Filizola scale (São Bernardo do Campo, BRAZIL) with a resolution of 100 g was used, and to determine height, a Sanny® stadiometer (São Paulo, BRAZIL) was used, which consists of a metric scale with a resolution of 1 mm.

Previous literature has shown the intraclass correlation coefficient (ICC) for test–retest reliability, typical error of measurement (TEM), and coefficient of variation (CV) for height (ICC) of 0.99 range (95% interval, 0.9947–0.9994), TEM (0.28%), and CV (2.78%); and for body mass (ICC) of 0.99 range (95% interval, 0.97–0.99), TEM (2.32%), and CV (6.9%).

Jump performance. SJ and CMJ assessments followed the protocol suggested by Bosco et al.²⁶ on a contact mat (Jump Test – Hidrofit, Belo Horizonte, Brazil), which estimates the vertical jump height according to the flight time, using a specific software, with the following equation where h is the height, g is the value of the acceleration due to gravity, and t is the flight time:

$$h = g \cdot t^2 \cdot 0.5$$

For the SJ test, the individual started from a standing position with the hips and knees flexed to approximately 90 degrees, and the hands were fixed on the hips. After the buzzer sound command, the individual quickly extended the hips and knees to perform the jump without the use of countermovement. For the CMJ test, the individual started from a standing position with their hands on the hips. After the buzzer sound command, the individual quickly flexed the hips and knees (to approximately 90 degrees), followed by extension of these joints to perform the jump.⁵ The test consisted of performing three SJ and three CMJs attempts, and the highest value obtained for each type of jump was recorded.

Stiffness. To measure lower limbs stiffness, the protocol proposed Dalleau et al.²⁷ was used. Stiffness was measured while the subject was jumping with both legs at a frequency

of 2.5 Hz. An electronic metronome was used for the subject to maintain the required frequency through an auditory signal. The subjects jumped in place for 10 seconds, with their hands on the hips, on a contact mat (Jump Test – Hidrofit, Belo Horizonte, Brazil) that estimates flight time and contact time, through a specific program. Stiffness was calculated for each jump and the mean value over the jumps during the 10 seconds was calculated using the following formula:

$$K_N = \frac{M \times \pi (T_f + T_c)}{T_c 2 \left(\frac{T_f + T_c}{\pi} - \frac{T_c}{4} \right)}$$

K_N = Stiffness, M = body mass, T_f = flight time, T_c = ground contact time.²⁷

After data collection, the results were normalized by body mass and expressed in N.m⁻¹.kg⁻¹.

Pre-stretch augmentation percentage (PSAP). This index represents the difference between SJ and CMJ and enables the indirect evaluation of the ability to use the SSC in jump performance. From the values found in the CMJ and SJ tests, PSAP is calculated using the formula:

$$PSAP = 100 \times (CMJ - SJ) / SJ$$

PSAP represents the SSC efficiency as it indirectly assesses how much the musculoskeletal system can produce mechanical power via the elastic mechanism, thereby reducing the need for metabolic energy production during jumping actions.²⁹

STATISTICS

The data were evaluated using descriptive statistics, and the results are described using mean, standard deviation and confidence interval. Statistics were performed using SPSS software version 22.0 (IBM, Chicago, USA).

RESULTS

Twenty-nine male volleyball athletes who were members of the Brazilian under-19 volleyball team, with a mean age of 18.2 ± 0.5 years participated in the study.

[Table 1](#) presents body mass and height data for all athletes participating in the study.

[Table 2](#) presents data regarding the mean values for lower limb stiffness, jump performance (SJ, CMJ) and pre-stretch augmentation percentage (PSAP).

DISCUSSION

The aim of the present study was to evaluate the anthropometric profile, jump performance, stiffness, and PSAP in Brazilian under-19 volleyball team athletes. The mean height of athletes selected for the Brazilian under-19 national team in 2021 was $195.75 \text{ cm} \pm 9.21 \text{ cm}$, and their body mass was $87.59 \text{ kg} \pm 10.93 \text{ kg}$. These findings align with previous studies, such as Stanganelli,³⁰ which reported similar values (198.7 cm and 85.80 kg) for Brazilian U-19 athletes, and Ciccarone,³¹ who observed comparable measurements (195.4 cm and 83 kg) in Italian U-19 players.

Table 1. Mean values, standard deviations (SD) and 95% confidence intervals (95% CI) of body mass in kilograms (Kg) and height in centimeters (cm).

	Mean (n= 29)	± SD	95% CI	
			Lower	Upper
Body mass (Kg)	87.59	10.93	83.43	91.75
Height (cm)	195.75	9.21	192.25	199.26

Table 2. Mean values, standard deviations (SD) and 95% confidence intervals (95% CI) of lower limbs stiffness, jump performance (SJ, CMJ) and pre-stretch augmentation percentage (PSAP).

	Mean (n= 29)	± SD	95% CI	
			Lower	Upper
Stiffness (N/m/kg)	0.43	0.015	0.37	0.49
CMJ height (cm)	39.9	5.21	37.91	41.88
SJ height(cm)	41.99	5.7	39.82	44.16
PSAP (%)	5.22	3.18	4.01	6.43

Counter movement jump (CMJ), squat jump (SJ), relationship between the unit of force (Newton), distance (meter) and mass (kilogram) (N/m/Kg), centimeter (cm)

This consistency suggests that the anthropometric profile for elite male volleyball players under 19 has remained stable over time, likely due to the sport's inherent demands. Given the importance of height and vertical jump in high-performance volleyball—as well as in sports like basketball—coaches prioritize recruiting tall athletes with optimal physical traits. Moreover, the rigorous selection process for national teams, as highlighted by Teixeira et al.,⁴ reinforces the link between greater stature and superior performance, further explaining the persistence of these anthropometric characteristics in elite U-19 players.^{2,3} The values obtained for SJ and CMJ were 39.9 cm and 41.98 cm, respectively, slightly lower than those found in the study of de Stanganelli et al.³⁰ who found SJ and CMJ heights of 40.5 cm and 42.8 cm, respectively, in Brazilian under-19 team athletes. Ciccaronne et al.³¹ found values for Italian athletes quite similar to those in the current study with a SJ height of 37.8 cm (slightly lower) and a CMJ height of 42.84 cm (slightly higher than in the present study). The little variation found between the results of the studies mentioned above and the current study suggests that the athletes, though not yet professionals but part of the youth categories of the main national teams worldwide show only minor performance variation due to their conditioning level.

However, when comparing the current results with those of adult athletes from Brazilian teams participating in the main national and international competitions, differences emerge. Dal Pupo et al.³² observed a CMJ height of 48.38 cm in athletes with a mean age of 23.6 years old, while Horta et al.³³ found a comparable CMJ height (46.94 ± 5.92 cm) in slightly older athletes (26.9 years old). Berriel et al.⁵ examined younger players (23.8 years old), demonstrating performance differences between squat jumps (SJ: 42.90 cm) and countermovement jumps (CMJ: 51.60 cm), reinforcing the expected range of lower-body power in high-level volleyball athletes. These comparisons may indicate

that athletes from the under-19 team show potential for performance growth as they mature into adulthood, which may be related to factors such as maturation, experience, and training time. Longitudinal evidence demonstrates distinct gender-specific patterns in vertical jump development during maturation. Male athletes exhibit significant progressive improvements in jump height throughout adolescence, while female athletes typically reach a performance plateau after puberty.³⁴ This divergence likely stems from fundamental differences in neuromuscular adaptation and hormonal influences between genders, particularly the greater androgen-mediated muscle hypertrophy observed in males. Furthermore, muscle mass emerges as a critical determinant of vertical jump performance across all maturation stages, with greater lean mass consistently correlating with higher jump heights regardless of age or sex.³⁵ This relationship underscores the importance of strength-to-mass ratio in explosive lower-body performance, suggesting that training protocols should prioritize muscular development alongside jump technique for optimal results.

Stiffness is known to influence the mechanics of body-ground interaction during vertical jump, during which higher stiffness in lower limbs results in shorter ground contact times. Farley et al.³⁶ and Granata et al.³⁷ reported that stiffness increased with jumping frequency during drop jumps, while Arampatzis et al.³⁸ reported that as running speed increased, an associated increase in lower extremity stiffness was observed. Ramírez-dela Cruz et al.³⁹ show in a systematic review that plyometric training is capable of improving stiffness values, as well as vertical jump performance.

Musculotendinous stiffness appears crucial for jump performance in volleyball athletes, as it significantly influences the efficiency of the stretch-shortening cycle (SSC) mechanism. Research demonstrates that optimal stiffness enhances the SSC's effectiveness by improving energy stor-

age and release in the tendon structures, thereby increasing the rate of force development.⁴⁰ A well-developed SSC enhances both neural activation patterns and musculotendinous performance, resulting in greater maximal force production within shorter ground contact times and with lower metabolic cost.³⁹ These physiological adaptations are particularly beneficial for volleyball-specific movements requiring explosive jumps and rapid direction changes.

Stiffness of the included athletes was $0.43 \text{ (N}\cdot\text{m}\cdot\text{kg}^{-1})$. Hughes and Watkins⁴¹ studied university volleyball athletes, and found that when normalized by body mass, the stiffness values were $0.21 \text{ (kN}\cdot\text{m}\cdot\text{kg}^{-1})$ for men (21 years old) and $0.17 \text{ (kN}\cdot\text{m}\cdot\text{kg}^{-1})$ for women. Other studies evaluating different populations, such as healthy individuals,^{27, 38,39} runners,³⁸ and young adults⁴⁰ present different values from those found in the present study. This disparity may be attributed to various stiffness assessment models and the units of measurement adopted to quantify stiffness levels.

The PSAP represents the difference between SJ and CMJ and indirectly assesses the ability to use the SSC by athletes for improving jump height.^{25,42} In the present study, a mean PSAP of 5.22% was determined. Suchomel et al.²⁵ conducted a comprehensive analysis of 183 elite athletes (age 21.3 ± 2.1 years) across multiple sports (volleyball, basketball, track and field, and softball), comparing body composition characteristics. Their findings revealed that high-performance female volleyball athletes exhibited a mean body fat percentage of 17%, which was significantly lower than athletes in other team sports evaluated. This study specifically analyzed NCAA Division I collegiate athletes during their competitive season, providing relevant benchmarks for elite female volleyball players in peak competition conditions. Another study reporting this variable in ski racing athletes SUB 19 and SUB 21 categories, showed that high-level athletes presented a mean PSAP of $9.2 \pm 13.3\%$, while amateurs presented $-0.3 \pm 9.0\%$. Thus, there seems to be a difference in PSAP between elite and amateur athletes, and the sample of the present study consists of elite athletes under 19 years old who may have not yet reached peak physical and technical development, potentially explaining the lower values compared to Suchomel et al.²⁵ and Hébert-Losier et al.⁴³ findings for professional athletes.

Previous studies on runners have demonstrated that adolescents exhibit higher musculotendinous elasticity compared to adult athletes.⁴⁴ This phenomenon may be attributed to biological factors such as lower collagen cross-linking in developing tendons or reduced neuromuscular stiffness. In contrast, the lower elasticity values observed in this study among young volleyball athletes could reflect: Training adaptations: Chronic plyometric loading during professional training may increase tendon stiffness over time; Developmental factors: Incomplete maturation of coordinative strategies (e.g., intermuscular coordination) during jumping tasks.

Results of the current study should be considered in light of several limitations: Cross-sectional design prevents causal inferences about training effects; Lack of biomechanical data on landing techniques may influence tendon loading and other results. Potential confounding by maturational status (e.g., biological age vs. chronological age) exists. To address these gaps, the authors propose that future studies investigate intersegmental coordination, Phase angle analysis of hip-knee-ankle coupling during CMJ to identify age-related kinematic differences, longitudinal monitoring to track lasticity changes throughout adolescence in sport-specific contexts to disentangle training effects from biological development

CONCLUSION

This study evaluated the anthropometric profile, vertical jump performance, musculotendinous stiffness, and Pre-Stretch Augmentation Percentage (PSAP) in athletes from the Brazilian under-19 volleyball team. The results highlight that these young athletes exhibit are tall (height: $195.75 \pm 9.21 \text{ cm}$; body mass: $87.59 \pm 10.93 \text{ kg}$) consistent with international standards for the sport reinforcing the fact that recruitment of tall athletes for high-performance sports occurs.

Jump performance in the SJ ($39.9 \pm 5.21 \text{ cm}$) and CMJ ($41.99 \pm 5.7 \text{ cm}$) was slightly lower than that observed in elite adult athletes, indicating room for improvement of these parameters as the athletes mature biologically and accumulate training experience. Musculotendinous stiffness ($0.43 \pm 0.15 \text{ N}\cdot\text{m}^{-1}\cdot\text{kg}^{-1}$) and PSAP ($5.22 \pm 3.18\%$) measures also suggest that while the athletes already efficiently utilize the stretch-shortening cycle (SSC), there is potential for optimization, particularly compared to professional athletes.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest relevant to the content of this article.

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