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Morpho-Functional Characteristics Related to Lower limb Stiffness, Explosive Power, and Reactive Strength Index (RSI) in Female Volleyball Players: Individual Variability and Performance Implications

Características Morfofuncionales Relacionadas con la Rigidez de los Miembros Inferiores, la Potencia Explosiva y el Índice de Fuerza Reactiva (RSI) en Jugadoras de Voleibol: Variabilidad Individual e Implicaciones en el Rendimiento

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SUMMARY: In volleyball, the ability to perform explosive vertical jumps is crucial for success in both offense and defense. The main factors determining jump height are lower limb stiffness, explosive power, and the Reactive Strength Index (RSI), which reflect neuromuscular efficiency, tendon elasticity, and the ability to generate force quickly. The aim of this study was to analyze lower limb stiffness, explosive power, and RSI in female volleyball players, as well as to assess individual differences and their implications for performance. The study included 18 elite female volleyball players. Anthropometric parameters recorded were height, body mass, and Body mass index (BMI). Lower limb stiffness and explosive power were measured using the Multiple Repeated Stiffness Jump Test (MRSJT) with the Globus Ergo Tester Jump System, through six consecutive maximal vertical jumps. Mean values, ranges, and coefficients of variation were analyzed, and Pearson correlations were used to examine relationships between anthropometric parameters and jump performance. The mean lower limb stiffness was 24.93 N/m, mean jump height was 31.37 cm, explosive power was 46.34 W/kg, and mean RSI was 2.66. Individual values showed considerable variation (stiffness 13.37–43.02 N/m, jump height 26.63–36.48 cm, explosive power 31.65–56.10 W/kg, RSI 1.77–3.44. Players with higher RSI demonstrated an optimal synergy of stiffness, jump height, and explosive power. No statistically significant correlations were observed between jump performance and anthropometric parameters, suggesting that neuromuscular and technical factors have a greater influence. The study highlights the presence of individual differences in lower limb stiffness, explosive power, and RSI among elite female volleyball players. An individualized training approach focusing on explosive power the lower limbs and enhancing reactive strength is recommended.

KEY WORDS: Volleyball players; Stiffness test; RSI; Explosive power; Jump performance.

INTRODUCTION

Volleyball is a demanding and dynamic high-intensity team sport that requires a combination of technical, tactical, and physiological abilities. Within the game, explosive actions such as vertical jumps, rapid changes of direction, and powerful take-offs form the basis for successfully executing offensive and defensive tasks (Bahr & Bahr, 2014; Tramel *et al*., 2019). These actions require a high level of neuromuscular coordination, rapid motor unit recruitment, and the ability of the lower limbs to generate force within a very short time interval. Therefore, the vertical jump, as the most frequently repeated explosive action in volleyball, is considered one of the key indicators of physical preparedness and an important measure of overall performance in female volleyball players (Ziv & Lidor, 2010; Čabarkapa *et al*., 2024).

Within a biomechanical framework, three parameters stand out as primary determinants of jump height and quality: lower limb stiffness, explosive power, and the RSI. The stiffness of the muscle–tendon system enables more efficient force transmission, faster energy transition, and joint stability

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during dynamic movements. However, while optimal stiffness contributes to enhanced performance, excessive stiffness can have a negative effect by increasing the mechanical load on muscles and tendons, thereby raising the risk of injury (Granata *et al*., 2002; Hughes & Watkins, 2006). Explosive power, often expressed relative to body mass (W/kg), represents the athlete's ability to generate maximal force in minimal time, which is crucial for the efficiency of jumps and take-offs under real game conditions. At the same time, RSI is used as a reliable measure of the efficiency of the stretch–shortening cycle (SSC), that is, the ability to quickly transition from eccentric to concentric contraction, which forms the basis of biomechanical movement economy in sports that demand repetitive jumping (Flanagan & Comyns, 2008; Kipp *et al*., 2016).

In practice, these parameters are most commonly assessed using the Countermovement jump (CMJ), a standardized test that enables simple, reliable, and precise quantification of jump force, power, and temporal characteristics (Markovic *et al*., 2004; McMahon *et al*., 2018). CMJ is particularly useful because it allows differentiation between various aspects of explosive abilities and can detect subtle differences among players of the same competitive level. In addition to the traditional RSI (the ratio of jump height to contact time), in recent years RSImod (the ratio of jump height to time to take-off) has been increasingly applied, as it better reflects the specific demands of volleyball jumps and allows for a more precise analysis of neuromuscular efficiency (Wang *et al*., 2015; Suchomel *et al*., 2016; Beckham *et al*., 2019). Nevertheless, research indicates that these indices are not interchangeable and that their interpretation depends on the type of jump, training experience, and the level of the athletes (Louder *et al*., 2021). Previous studies have also emphasized the existence of sex differences in neuromuscular abilities (Sole *et al*., 2018; Lehnert *et al*., 2020), but findings regarding elite female volleyball players remain inconsistent. While some studies report clear differences between starters and non-starters in professional teams (Harata & Lanesman, 2025), others find no significant differences in force–time metrics (Cabarkapa *et al*., 2024). These inconsistencies are often attributed to small sample sizes, a focus on male athletes or adolescent populations, as well as insufficient attention to individual variations within elite female squads. Consequently, the research gap lies in the lack of data linking stiffness, explosive power, and RSI in elite female volleyball players, particularly in the context of the Balkan region, where systematic scientific research in this area remains scarce. A precise understanding of individual differences in these parameters could contribute to the development of personalized training protocols, performance optimization, and injury risk reduction.

Therefore, the aim of this study was to examine the morpho-functional capacities of the muscle–tendon system (lower limb stiffness), explosive power and the RSI in elite female volleyball players, with a special focus on individual variations and their impact on CMJ performance, as well as on overall competitive performance.

MATERIAL AND METHOD

Sample of Participants. The study included 18 elite female volleyball players from the Volleyball Club Jahorina, a member of the Premier League of Bosnia and Herzegovina, with a mean age of 19.11 ± 2.63 years, body height of 173 ± 8.77 cm, body mass of 66.04 ± 9.09 kg, and body mass index (BMI) of 22.03 ± 2.19 kg/m^2. All participants were healthy, physically fit, and free from injuries during the previous six months. The inclusion criteria comprised being an active member of Volleyball Club Jahorina, being in good health without chronic diseases or injuries that could affect test performance, and voluntary signing of informed consent. The exclusion criteria referred to injuries or health problems in the past six months, refusal to participate or withdrawal of consent during the study, and inability to perform the required tests for physical or technical reasons. Before the start of the study, all participants were thoroughly informed about its purpose and procedures and voluntarily signed informed consent. The study was approved by the Ethics Committee of the H.S. Skovoroda Kharkiv National Pedagogical University, in accordance with the Declaration of Helsinki of the World Medical Association on ethical principles of research involving humans (No. KhNPU/PhES/EC/3/5/2021).

Research Design

Measured Variables. The following parameters were assessed: body height, body mass, BMI, lower-limb stiffness, explosive power, jump height, and the RSI. Lower-limb stiffness was evaluated using the MRSJT, which reflects the ability of the muscle–tendon complex to store and release elastic energy. This parameter indicates the balance between force absorption during landing and force generation during take-off, which is crucial for volleyball performance. Explosive power, expressed relative to body mass, was assessed during vertical jumps and represents the ability of the lower limbs to generate maximal force within a short time, which is essential for both offensive and defensive volleyball actions.

Experimental Design. The study was conducted as a cross-sectional design using standardized anthropometric instruments in accordance with the methodology of the International Society for the Advancement of

Kinanthropometry (ISAK). Body height was measured with a SECA 206 stadiometer (Germany), and body mass with a Tefal digital scale (0–160 kg), following standardized protocols (Malousaris *et al*., 2008). Jump performance, explosive power, and stiffness were measured using the GLOBUS Ergo Tester Jump System (Codognè, Italy), consisting of a contact mat connected to a handheld microcontroller. The system recorded flight time with a 1-ms temporal resolution, and jump height was calculated using the standardized formula (Pueo *et al*., 2020):

$$h = \frac{t^2 \times g}{8}, = 9.81\ m/s^2$$

Test Protocol. The MRSJT was applied as a valid method for assessing reactive strength and lower-limb stiffness (Pueo *et al*., 2020). Warm-up (10–15 min): Dynamic stretching, hip and ankle mobility drills, and 3–5 submaximal adaptation jumps. Testing procedure: Each athlete stood on the contact mat and performed six consecutive maximal vertical jumps on signal, executed explosively with minimal ground contact time and no pauses between jumps. Hands were placed on the hips, and the objective was to achieve maximum jump height with the shortest possible contact time. The system recorded the following parameters: contact time (CT), flight time (FT), jump height (JH), RSI; ratio of flight time to contact time, and explosive power. Both individual and mean values across all jumps were included in the analysis. All testing was carried out during regular training sessions in April 2021, under controlled indoor conditions (18–22 °C).

Statistical analysis. Data were processed using STATISTICA 10.0 software. For all variables, descriptive statistics were calculated, including mean (M), minimum (Min), maximum (Max), range (R), standard deviation (SD), 95 % confidence interval (95 % CI), coefficient of variation (CV %) and Standard Error (SE). Both individual and mean values of lower-limb stiffness and explosive leg power were included in the analysis. The normality of data distribution was verified using the Shapiro–Wilk test. To examine the relationships between anthropometric parameters (body height, body mass, and BMI) and performance variables (explosive power, stiffness, and RSI), Pearson's correlation coefficients (r) were calculated. The level of statistical significance was set at $p < 0.05$.

RESULTS

The results of the female volleyball players are presented in the form of Tables I to III and Figures 1 to 3. The obtained results (Table I) provide a detailed insight into the anthropometric characteristics and explosive strength parameters of the volleyball players. Considering parameters such as Body Height (cm), Body mass (kg), BMI (kg/m∑), Stiffness Test results, (height six vertical jumps - HJ in cm), RSI, and average explosive power (expressed in W/kg), it is possible to examine not only the average values but also the differences within the group, which may have practical implications for individualized training. The data are presented through mean values, minimum and maximum values, range, standard deviation (SD), 95 % confidence interval of the SD (CI), coefficient of variation (CV %), and standard error (SE), allowing for a comprehensive evaluation of homogeneity and variability within the group, as well as the identification of individuals with pronounced deviations from the average.

The average height of the participants is 173.3 cm, with a minimum of 150.5 cm and a maximum of 187 cm, resulting in a range of 36.5 cm. The standard deviation of 8.77 cm, with a 95 % confidence interval of 6.54 to 13.15 cm, indicates that most participants are close to the mean, while some are significantly shorter or taller than the average. The relatively low coefficient of variation (CV 5.07 %) confirms the uniformity of height within the group, suggesting homogeneity in anthropometric composition regarding height.

Table I. Descriptive statistics of anthropometric parameters and stiffness test in volleyball players (n=18).

Variables		Mean ± SD	Min	Max	Range	95 % ± CI SD	CV %	Standard-Error
	Body Height (cm)	173.30±8.77	150.5	187.0	36. 50	6.54 - 13.15	5.07	2.07
	Body mass (kg)	66.04 ± 9.09	49.90	84.90	35.00	6.82 - 13.63	13.77	2.14
	BMI (kg/m^2)	22.03 ± 2.19	18.68	27.10	8.42	1.65 - 3.29	9.96	0.52
Stiffness test [illegible]	**1. HJ (cm)**	31.03 ± 4.43	20.00	36.50	16.50	3.32 - 6.64	14.27	1.04
	2. HJ (cm)	31.00 ± 3.43	25.60	37.20	11.60	2.57 - 5.15	11.06	0.81
	3. HJ (cm)	31.14 ± 3.69	25.60	37.20	11.60	2.76 - 5.53	11.85	0.87
	4. HJ (cm)	31.41 ± 4.13	25.50	38.90	13.40	3.10 - 6.19	13.15	0.97
	5. HJ (cm)	31.99 ± 3.28	27.40	36.10	8.70	2.46 - 4.92	10.25	0.77
	6. HJ (cm)	31.48 ± 4.70	19.70	37.00	17.30	3.52 - 7.05	14.93	1.10
Average Height jumps (cm)		31.81 ± 3.10	27.00	36.50	9.50	2.33 - 4.65	9.74	0.73
Average Power (W/kg)		46.34 ± 7.06	31.65	56.10	24.45	5.30 - 10.59	15.23	1.66
RSI		2.66 ± 0.46	1.77	3.44	1.67	0.38 - 0.59	17.53	0.11

This height homogeneity can be important for planning joint training sessions and game tactics, as similar height facilitates team formation coordination and task distribution on the court. The average body mass is 66.04 kg, ranging from 49.9 to 84.9 kg, with a standard deviation of 9.09 kg. The SD confidence interval (6.82–13.63 kg) and a CV of 13.77 % indicate slightly greater individual variability in body mass, which is expected due to differences in muscle mass and body composition among participants. This variability highlights the need to tailor conditioning programs, as players with lower or higher body mass may require different approaches to develop explosive power and agility. BMI ranges from 18.68 to 27.1 kg/m^2, with an average of 22.03 kg/m^2, showing moderate variability (CV 9.96 %) and a low standard error (0.52), suggesting that most participants fall within the normal weight category. This indicator is useful for assessing fitness status, but when combined with body mass and height data, it allows for a more detailed analysis of body composition and potential for power development.

Analysis of the results from the MRST (Table I; Fig. 1) shows relatively stable average values within the group. The height first jump (1st HJ) has a mean of 31.03 cm, a range of 16.5 cm (20–36.5 cm), and a CV of 14.27 %, representing the highest relative variability among the jumps and possibly indicating inconsistency in the initial performance or adaptation to the test. The standard deviation of 4.43 cm and SD confidence interval (3.32–6.64 cm) confirm a moderate dispersion of results. This initial variability highlights the importance of proper warm-up, technical preparation, and mental focus before the jump series, as the first jump can significantly influence the overall average and perception of individual potential. The height second and third jumps (2nd HJ and 3rd HJ) show means of 31.0 and 31.14 cm, with a smaller range of 11.6 cm and CVs of 11–11.85 %, suggesting adaptation and greater consistency in performance. The fourth and fifth jumps (4th HJ and 5th HJ) have means of 31.41 and 31.99 cm, ranges from 8.7 to 13.4 cm, and CVs of 10.25–13.15 %, indicating stable performance for most participants with lower individual variability. This mid-series stability reflects good technical preparation and the ability to maintain explosive power across multiple efforts. The sixth jump (6th VJ) records a mean of 31.48 cm, but the largest range (17.3 cm) and highest variability (CV 14.93 %), potentially reflecting fatigue, reduced concentration, or technical imprecision on the final attempt. These findings suggest the need to consider endurance capacity and recovery within the series to maintain optimal performance in the final stages of play. The overall average jump height (Total AH) is 31.81 cm, with relatively low variability (CV 9.74 %) and a low standard error (0.73), confirming stable average performance within the group.

The average explosive power (AW) is 46.34 W/kg, ranging from 31.65 to 56.1 W/kg, with a standard deviation of 7.06 and the highest relative variability (CV 15.23 %). The SD confidence interval (5.3–10.59) indicates significant individual differences in the ability to generate explosive power. The standard error (1.66) shows that the averageestimate is reliable, but the range reflects varying levels of muscle mass, neuromuscular efficiency, and technical coordination among participants. Graphical representations of these results show that some players achieve high performance in both jump height and explosive power, while others exhibit discrepancies, confirming that explosive power is not the sole determinant of jump height. Technical precision, coordination, tactics, and movement efficiency significantly influence overall performance.

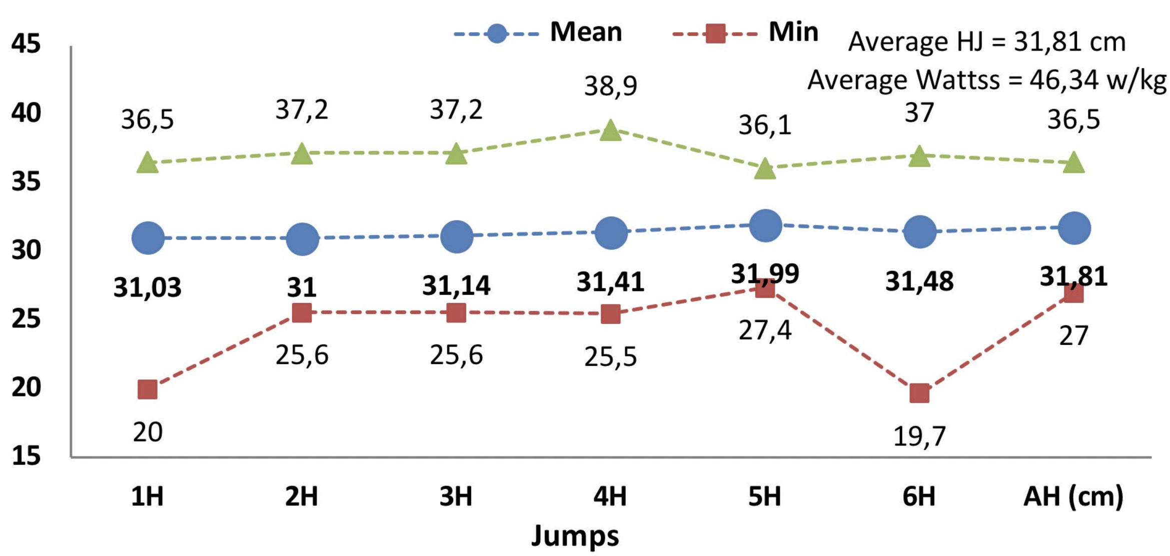

Fig. 1. Multiple repeated stiffness jump test females.

Table II. Pearson correlation coefficients between jump height and anthropometric characteristics.

Height jump (cm)	Body height (cm)	Body mass (kg)	BMI (kg/m²)
1. jump	0.216; p=0.389	-0.069; p=0.783	-0.280; p=0.260
2. jump	0.397; p=0.102	0.080; p=0.752	-0.264; p=0.289
3. jump	0.392; p=0.107	0.111; p=0.659	-0.219; p=0.381
4. jump	0.388; p=0.111	0.067; p=0.790	-0.277; p=0.265
5. jump	0.138; p=0.583	-0.143; p=0.570	-0.312; p=0.207
6. jump	0.151; p=0.549	0.010; p=0.967	-0.137; p=0.588

Analysis of the average RSI values for 18 players shows a mean RSI of 2.66, indicating a good level of lower-limb reactive strength. The lowest average value was 1.77, while the highest reached 3.44, demonstrating some diversity in player performance. The range of results is 1.67, with a standard deviation of 0.47, indicating moderate variability within the group. The coefficient of variation (17.5 %) confirms a moderate dispersion around the mean, and the standard error of 0.11 indicates a precise estimation of the average. The 95 % confidence interval for the standard deviation ranges from 0.38 to 0.60, further confirming the reliability of the variability estimate. These results provide a solid basis for monitoring individual player performance and adjusting training programs to enhance reactive strength and reduce injury risk.

The volleyball players demonstrate homogeneity in height and BMI, while body mass and explosive power reflect moderate to considerable individual variability. Jump height results confirm stable average performance, but extremes are present in the first and last jumps, likely due to adaptation, motivation, or acute fatigue. Given the pronounced differences in explosive power, individualized conditioning and technical training are recommended. Special emphasis should be placed on developing power in players with lower values, optimizing the execution of jump series, managing fatigue, and refining technical precision. Implementing such measures may contribute to greater group homogeneity, improved overall competitive efficiency, and optimized performance in volleyball, which is a key objective in training planning and tactical task management within the team.

Correlation analysis (Table II) between jump height (1st–6th jumps), average jump height (cm), and average explosive power per kilogram of body mass (W/kg) with basic anthropometric parameters (height, weight, BMI) showed that none of the examined relationships were statistically significant ($p > 0.05$). This indicates that variations in jump height and explosive power cannot be reliably explained by differences in basic body characteristics. Correlations between jump height and body height ranged from weak to moderate ($r = 0.138–0.397$), with the strongest association observed for the 2nd jump ($r = 0.397$; $p = 0.102$). Although this relationship is not statistically significant, there is a trend suggesting that taller players may achieve higher jump heights. This aligns with biomechanical expectations, as greater body height can provide longer lever arms and higher potential for generating vertical explosive power. Correlations between jump height and body mass were generally weak and inconsistent ($r = -0.143$ to 0.111), with high p-values ($p > 0.05$), indicating that body mass alone does not significantly influence jump height in these volleyball players. Similarly, correlations between jump height and BMI were weak and negative ($r = -0.137$ to -0.312), suggesting that higher BMI does not predict better jump performance, likely because BMI does not differentiate between muscle mass and fat tissue. Overall, the correlation analysis indicates that basic anthropometric parameters (body height, body mass, BMI) do not significantly explain variability in jump height or average explosive power among these 18 elite female volleyball players. While there is a non-significant trend of a positive association between body height and jump height, the result is not statistically confirmed. These findings emphasize that neuromuscular coordination, technical execution, lower-limb power, and specific training preparation are likely more important determinants of vertical jump performance than anthropometric characteristics alone.

Table III and Figures 2 and 3 presents a detailed analysis of lower limb stiffness, vertical jump height, explosive power, and RSI in the elite female volleyball players, highlighting clear individual differences. The team averages are 24.93 N/m for stiffness, 31.37 cm for jump height, 46.34 W/kg for explosive power, and 2.66 for RSI, while individual values range from 13.37 to 43.02 N/m, 26.63 to 36.48 cm, 31.65 to 56.10 W/kg, and 1.77 to 3.44 for RSI, indicating substantial variability in biomechanical efficiency, body mass, and explosive capabilities among the players. Most players (14 out of 18) achieve an average RSI greater than 2.2, indicating a high capacity for rapid execution of reactive jumps with minimal ground contact time. Players 5 (32.59 N/m, 33.85 cm, 56.10 W/kg, RSI 3.44) and 17 (43.02 N/m, 33.85 cm, 56.10 W/kg, RSI 3.03) combine above-average stiffness, jump height, and relative explosive power, enabling highly efficient tendon energy storage and release, which plays a key role in attacks and blocks. These players demonstrate an optimal synergy of biomechanical stiffness, explosive power, and jump height, with a high capacity for repeated reactive jumps.

Table III. Leg stiffness, jump height, explosive power and RSI in volleyball players.

PLAYERS	STIFFNESS MEAN	JUMP MEAN	POWER	RSI
1	29.61	27.01	47.57	2.74
2	41.78	29.17	44.67	2.54
3	28.77	33.45	48.94	2.88
4	24.12	36.48	48.93	2.73
5	32.59	33.85	56.1	3.44
6	18.01	30.52	36.21	1.90
7	29.74	32.07	49.76	2.91
8	21.22	32.67	46.08	2.68
9	27.13	35.00	51.43	2.97
10	21.29	36.48	48.93	2.73
11	22.29	28.45	40.55	2.57
12	13.37	26.63	31.65	1.77
13	17.17	27.67	37.85	2.53
14	30.24	35.48	51.43	2.72
15	16.46	28.28	38.88	2.39
16	15.37	28.93	54.56	2.60
17	43.02	33.85	56.1	3.03
18	17.50	30.82	41.49	2.70
MEAN	**24.93**	**31.37**	**46.34**	**2.66**

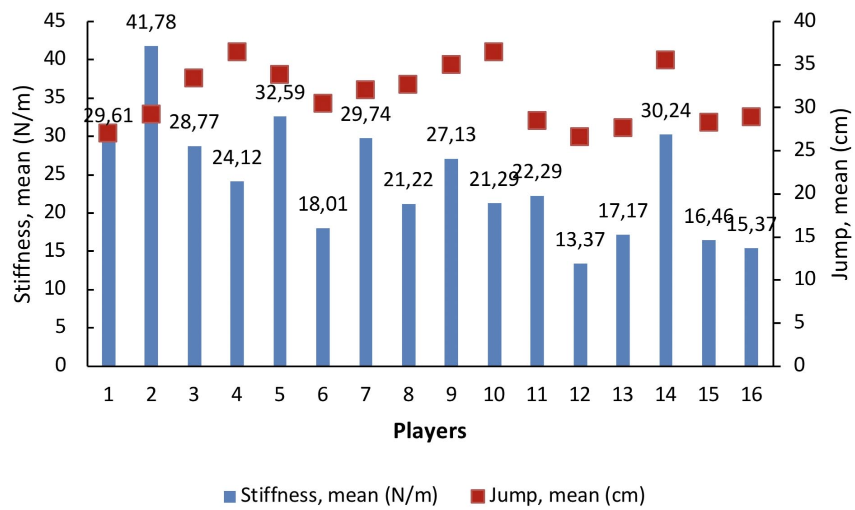

Fig. 2. Individual Variability of females volleyball (Stiffness vs. Jump).

Fig. 3. Individual Variability of females volleyball players (Power vs. RSI).

Players with average RSI values (2.53–2.97), including numbers 3 (28.77 N/m, 33.45 cm, 48.94 W/kg, RSI 2.88), 4 (24.12 N/m, 36.48 cm, 48.93 W/kg, RSI 2.73), 7 (29.75 N/m, 32.07 cm, 49.76 W/kg, RSI 2.91), 9 (27.13 N/m, 35.00 cm, 51.43 W/kg, RSI 2.97), 10 (21.29 N/m, 36.48 cm, 48.93 W/kg, RSI 2.73), and 14 (30.24 N/m, 35.48 cm, 51.43 W/kg, RSI 2.72), exhibit a stable balance between stiffness, jump height, and power, enabling a consistent capacity for reactive jumps. Their performance confirms that efficient coordination and biomechanical synergy play a key role in maintaining high reactive strength.

Players with lower RSI (below 1.9) and lower stiffness, such as numbers 6 (18.01 N/m, 30.52 cm, 36.21 W/kg, RSI 1.90) and 12 (13.37 N/m, 26.63 cm, 31.65 W/kg, RSI 1.77), require additional development of plyometric abilities and eccentric strength. Players 15 (16.46 N/m, 28.28 cm, 38.88 W/kg, RSI 2.39) and 16 (15.37 N/m, 28.93 cm, 54.56 W/kg, RSI 2.60) demonstrate that relative explosive power and lower body mass can partially compensate for lower stiffness. Players 8 (21.22 N/m, 32.67 cm, 46.08 W/kg, RSI 2.68), 11 (22.29 N/m, 28.45 cm, 40.55 W/kg, RSI 2.57), and 13 (17.17 N/m, 27.67 cm, 37.85 W/kg, RSI 2.53) with lower stiffness and jump height show average RSI, indicating the need for targeted tendon training, plyometric exercises, and explosive power development to enhance reactive movement efficiency.

Player 1 (29.61 N/m, 27.01 cm, 47.57 W/kg, RSI 2.74) exhibits above-average stiffness and solid RSI but lower jump height, while player 2 (41.78 N/m, 29.17 cm, 44.67 W/kg, RSI 2.64) with extremely high stiffness achieves an average jump, highlighting the influence of body mass, coordination, and execution technique on performance. Player 4 (24.12 N/m, 36.48 cm, 48.93 W/kg, RSI 2.73) demonstrates efficient tendon energy storage and release, enabling greater vertical jump despite average stiffness.

Analysis of parameter interrelationships indicates that high stiffness and greater jump height often contribute to higher explosive power and RSI, but relative power per kilogram, execution technique, and muscle contraction speed modulate this relationship. For example, player 16, with lower stiffness (15.37 N/m), achieves high relative power (54.56 W/kg) and solid RSI (2.60), showing that mass and muscle contraction speed significantly contribute to reactive strength even when biomechanical stiffness is not optimal. Monitoring RSI values throughout jump series is essential, as a significant drop (over 20 %) may indicate fatigue or reduced capacity to maintain explosiveness, directly affecting performance during matches or training.

DISCUSSION

The aim of this study was to examine the morpho-functional capacities of the muscle–tendon system (lower limb stiffness), explosive power, and RSI in elite female volleyball players, with a special focus on individual variations and their impact on CMJ performance, as well as on overall competitive performance. The analysis of these parameters is important because the vertical jump represents a key element of success in volleyball, influencing the quality of attack, block, and defense (Sheppard *et al*., 2007; Ziv & Lidor, 2010).

The results showed a relatively homogeneous structure of anthropometric characteristics but significant variability in biomechanical abilities. The stiffness test and RSI indicated pronounced differences among players in explosive strength (AW = 46.34 W/kg; CV 15.23 %) and RSI (2.66 ± 0.47; CV 17.53 %), confirming previous research findings that within the same team, there may be players with clear biomechanical advantages while others lag behind in force-generation capacity and jump performance (Sole *et al*., 2018; Cabarkapa *et al*., 2024, Harat & Lanesman, 2025).

CMJ height depends on the impulse that an athlete generates against the ground, with lower-limb strength, reactive ability, and rate of force development significantly affecting performance (Ham *et al*., 2007; McBride *et al*., 2010; Suchomel *et al*., 2016). Our findings show that jump height and explosive strength are not determined by anthropometric parameters, as correlations with height, weight, and BMI were weak and statistically insignificant ($p > 0.05$), confirming that coordination, contraction speed, tendon stiffness, and technical precision play a greater role (Sole *et al*., 2018; Beckham *et al*., 2019). Lower limb stiffness analysis showed an average value of 24.93 N/m, with a wide range (13.37–43.02 N/m).

Players with higher stiffness and RSI values (e.g., players 5 and 17) achieved optimal synergy of biomechanical and neuromuscular factors, while those with lower values (e.g., players 6 and 12) required specific programs for eccentric strength development and plyometric abilities. Some results (e.g., player 16) indicate that lower stiffness can be partially compensated for by relatively high explosive strength, confirming the findings of Sole *et al*. (2018) and Kipp *et al*. (2016).

Analysis of individual jumps indicated stability in mean values but greater variability in the first and last attempt, which may suggest adaptation or fatigue. Monitoring RSI during jump series can serve as an indicator of acute fatigue and assist in training load planning (Bailey *et al*., 2014; Suchomel *et al*., 2015).

Our results confirm that RSI is a reliable and practical indicator of lower-limb explosive power in volleyball players (Suchomel *et al*., 2015; Kipp *et al*., 2016). Most players in this study (14 out of 18) demonstrated RSI > 2.2, which indicates good capacity for fast and repeatable jumps. Individual differences in lower limb stiffness, explosive strength, and RSI emphasize the need for personalized training and continuous monitoring to optimize performance and reduce injury risk.

CONCLUSION

This research shows that individual variations in lower limb stiffness, explosive strength, and RSI significantly affect volleyball players' performance. The relative homogeneity of anthropometric parameters facilitates coordination in play, but variability in functional abilities highlights the need for personalized training and precise progress monitoring, targeting individual weaknesses, and optimizing overall biomechanical efficiency. These findings contribute to the understanding of physiological, biomechanical, and neuromuscular factors of success in volleyball and provide a foundation for further research in the Balkan region, with a special focus on training optimization and injury risk reduction.

Practical Implications. The results of this study have direct practical value for planning the volleyball training process. The observed individual differences in lower limb stiffness, explosive strength, and RSI indicate the need for a personalized approach. Players with lower RSI and lower tendon stiffness should focus on plyometric and eccentric exercises to improve reactivestrength, while those with higher RSI should maintain their current level and focus on technical precision and fatigue management. Including lower limb stiffness and RSI testing in regular monitoring enables coaches to track players' readiness, optimize workloads, and reduce injury risk during long seasons.

Limitations of the Study and Recommendations for Future Research. The study has several limitations that affect its interpretation. First, the sample size was relatively small (n = 18) and included players from only one club, which limits the ability to generalize the findings to a broader population of volleyball players. Second, measurements were conducted in controlled conditions using the CMJ test, without including other relevant indicators such as force analysis in real game situations or long-term training adaptations. Third, the study design was cross-sectional, so it was notpossible to establish cause-and-effect relationships between the tested parameters and sports performance. Future research should include larger and more diverse samples of volleyball players from different competition levels, as well as longitudinal studies that monitor changes in lower limb stiffness, explosive strength, and RSI during different phases of training and competition. It would also be beneficial to integrate additional assessment methods, such as isometric and isokinetic measurements or biomechanical analysis in real competition settings, to provide a more comprehensive picture of the factors influencing performance. This would allow for more precise recommendations for personalized training and injury prevention in volleyball players.

PAVLOVIC, R.; KOZINA, Z.; JOKSIMOVIC, M.; RADULOVIC, N. & MUNTEAN, R. I. Características morfofuncionales relacionadas con la rigidez de los miembros inferiores, la potencia explosiva y el índice de fuerza reactiva (RSI) en jugadoras de voleibol: Variabilidad individual e implicaciones en el rendimiento. *Int. J. Morphol., 43(6)*:2129-2137, 2025.

RESUMEN: En voleibol, la capacidad de realizar saltos verticales explosivos es crucial para el éxito tanto en ataque como en defensa. Los principales factores que determinan la altura del salto son la rigidez de los miembros inferiores, la potencia explosiva y el índice de fuerza reactiva (RSI), que reflejan la eficiencia neuromuscular, la elasticidad tendinosa y la capacidad de generar fuerza rápidamente. El objetivo de este estudio fue analizar la rigidez de los miembros inferiores, la potencia explosiva y el RSI en jugadoras de voleibol, así como evaluar las diferencias individuales y sus implicaciones en el rendimiento. El estudio incluyó a 18 jugadoras de voleibol de élite. Los parámetros antropométricos registrados fueron la altura, la masa corporal y el índice de masa corporal (IMC). La rigidez de los miembros inferiores y la potencia explosiva se midieron mediante la Prueba de Salto con Rigidez Repetida Múltiple (MRSJT) con el Sistema de Salto Globus Ergo Tester, a través de seis saltos verticales máximos consecutivos. Se analizaron los valores medios, los rangos y los coeficientes de variación, y se utilizaron correlaciones de Pearson para examinar las relaciones entre los parámetros antropométricos y el rendimiento del salto. La rigidez media dede los miembros inferiores fue de 24,93 N/m, la altura media del salto fue de 31,37 cm, la potencia explosiva fue de 46,34 W/kg y el RSI medio fue de 2,66. Los valores individuales mostraron una variación considerable (rigidez 13,37–43,02 N/m, altura de salto 26,63–36,48 cm, potencia explosiva 31,65–56,10 W/kg, RSI 1,77–3,44). Las jugadoras con mayor RSI demostraron una sinergia óptima entre rigidez, altura de salto y potencia explosiva. No se observaron correlaciones estadísticamente significativas entre el rendimiento del salto y los parámetros antropométricos, lo que sugiere que los factores neuromusculares y técnicos tienen una mayor influencia. El estudio destaca la presencia de diferencias individuales en la rigidez de los miembros inferiores, la potencia explosiva y el RSI entre las jugadoras de voleibol de élite. Se recomienda un enfoque de entrenamiento individualizado centrado en la potencia explosiva de los miembros inferiores y en la mejora de la fuerza reactiva.

PALABRAS CLAVE: Jugadoras de voleibol; Prueba de rigidez; RSI; Potencia explosiva; Rendimiento del salto.

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