A Comparison of Vertical Ground Reaction Forces in Single-leg Jump Take-offs and Double-leg Jump Take-offs in Indoor Collegiate Volleyball Players

Biomechanics & Motion Analysis Laboratory

Margaret E. Latchford, Maggie McDermott, Austin Deshner, Moroni de Moors, Will W. Peveler

Allied Health Professions

Liberty University

A Comparison of Vertical Ground Reaction Forces in Single-leg Jump Take-offs and Double-leg Jump Take-offs in Indoor Collegiate Volleyball Players

TABLE OF CONTENTS

Abstract

The purpose of this study was to determine if differences in vertical ground reaction forces (vGRFs) exist between single-leg take-off approaches (SL) and double-leg take-off approaches (DL) and if sex or positional differences existed in vGRFs in SL- or DL-style approaches. It was hypothesized that DL jumps would generate greater vGRFs, males would generate greater vGRFs in both styles, and middle blockers would have higher SL vGRFs while pin hitters would have higher DL vGRFs. Nine collegiate volleyball players (4 female; 5 male) (age: 20.44 $\pm$ 1.42 years; height: 186.02 $\pm$ 6.44 cm; body mass: 78.21 $\pm$ 10.63kg; body fat: 11.66 $\pm$5.62%) were tested. An AMTI force plate collected vGRFs with three recorded trials per approach style per subject with randomization of jump-style order. The level of significance was set at $p \leq 0.05$. No significant differences were found between vGRFs and position or SL and DL vGRFs. Males had significantly higher vGRFs overall compared to females (p=0.007). Male SL vGRFs were significantly larger than females (p=0.017). DL, relative SL, and relative DL vGRFs were not significantly different between genders. Height, mass, and body fat percentage had at least moderate correlations to combined vGRFs, and height moderately correlated to DL vGRFs. These results suggest that both takeoffs have similar enough force load to be interchangeable. Strength coaches may use both styles to train their athletes and improve neural integration. Positional jump loads during practice or games may be tracked interchangeably in style regarding the take-off phase.

Key words: *sport, ground reaction forces, force platform, acute load*

INTRODUCTION

Volleyball is a dynamic sport characterized by rapid transitions between offensive and defensive strategies while each team attempts to score a point. The most aggressive, terminal offensive strategy occurs when a player completes an attack by using a coordinated approach to be in position to swing at the ball with the intention of scoring a point (1). Volleyball approach-jump height is an important differentiating characteristic for attackers since higher levels of competition correlate to height in vertical jump values (20,28). The coordinated approach begins with an approach phase as the athlete develops horizontal speed and translates this motion into a vertical direction using a plant step and explosive arm swing while recruiting a stretch-shortening cycle in the lower limbs which enhances the athlete’s ability to influence impulse and jump acceleration (5,25).

As the game of volleyball continues to increase in speed and complexity of game strategy, the traditional approach has developed from a simple two-step jump to a four-step jump incorporating a countermovement half-drop jump and a “step-close” planting technique (3,6,17). However, different approach styles like the “hop-close” and “step-close” have not been found to be significantly different in take-off velocities or jump heights (2,3,7,17,28). In addition to the traditional approach, a modified, one-foot approach termed a “slide” has been incorporated, as it creates more complicated play combinations and it provides a hitter with a wide variety of attacking angles and deceptive shots (10). A distinct difference between the traditional approach and the slide approach, besides the plant prior to takeoff, is that the ball and the hitter travel in the same plane before contact rather than in an oblique or perpendicular plane (10). In a four-step, self-paced jump overall jump height, reach height, and loss height have not been found to be different between single-leg and double-leg jump styles, but the 1-foot jump carried more horizontal velocity into the flight phase of the jump ($p<0.0042$) (26). With the greater horizontal velocity, 1-foot jumps might have greater kinetic energy distribution during the support phase which would be advantageous to sport performance (26). The typical volleyball approach requires two feet; however, single-foot jumps are more likely to occur with faster trajectory sets (11,22).

Based on the four positions of volleyball (pins, middle blockers, liberos, and setters), receivers demonstrate the highest maximal jumping ability in males and females while male middles have the highest jumping frequency relative to playing time followed by setters (15,17,19,20). When comparing gender, professional Austrian men's players demonstrated greater approach speed and vertical velocity compared to female players with a traditional approach which was most likely caused by different muscle recruitment patterns during the planting angle in the dominant leg revealed through EMG (5). Strategically, both genders see increases in hitting efficiency when faster tempo setting trajectories are used (15). Several differences in playing style occur between men's and women's volleyball (15). The men's game emphasizes the highest point of contact and maximal ball velocity when attempting to score, while the women's attack style relies more heavily on deception and 'surprise' techniques to score points (16).

Volleyball-specific jumping research has been focused on a three-step vertical approach jump that translates the athlete's body from a horizontal power output to a vertical power output (2,5,6, 27). However, coaching and game strategy has evolved to implement a four-step approach rather than a three-step approach for a traditional "attack". Volleyball also utilizes an alternative “slide” approach that has not been examined in detail in research; especially in considering potential differences in gender. In addition, most research has focused on the landing phase of an attack rather than the take-off phase (8,9,14,23). Consequently, the aim of the current study was to determine 1) if differences exist in vertical ground reaction forces (vGRFs) between single-leg (SL) and double-leg (DL) approaches and 2) if sex or positional differences in vGRFs in SL and DL exist.

It was hypothesized that DL jumps would generate greater vGRFs, but SL jumps would have relatively equal magnitude when considering limb application. Regarding the study’s secondary focus, it was hypothesized that males would have higher SL and DL vGRFs. Positionally, it was hypothesized that middle blockers would have higher SL vGRFs, and pin hitters would have significantly higher DL vGRFs.

METHODS

Experimental approach to the problem

A randomized, repeated-measures experimental design was used to determine the effect of volleyball approach take-off style on biomechanical outcomes. The dependent biomechanical variable was vertical ground reaction forces (vGRFs). The independent variable was the style of take-off : the single leg take-off (SL) typically used to perform a “slide” and a double-leg take-off (DL) typically performed in a traditional volleyball “spike” . The independent variable was randomly assigned during the experimental session. A minimum of 15 participants was required with a statistical significance set at 0.05, a power of greater than 0.80 and an effect size of 0.8.

Subjects

A total of 9 collegiate-level volleyball players participated in this study. The subjects were male (n=5) and female (n=4) between the ages of 18 and 24 years. The subjects' anthropometric measures can be found in Table 1. All of the participants were members of either an NCAA Division I Women's Indoor Volleyball team or Club Men's Volleyball team during the 2019 to 2020 season. For full inclusion in the research, subjects had to have experienced no injuries or illnesses for 30 days or were cleared by a doctor or athletic trainer as "fit-for-full" practice participation. This standard was verified using a health history questionnaire completed prior to testing. Subjects met ACSM's minimum activity guidelines to participate in this study. The subjects self-identified positions as pin hitters (PINS, n=3), middle blockers (MB, n=3), liberos (LIBS, n=2), and setters (S, n=1).

[Insert Table 1]

All participants were fully informed about the nature and demands of the study and the possible health risks. Written information and oral instructions were given to each participant, and all the participants provided signed consent to participate. Approval for this study was obtained through the local Institutional Review Board.

Procedures

Testing was completed in the Biomechanics and Motion Analysis Laboratory at Liberty University in Lynchburg, Virginia. It was conducted in a closed, ventilated facility typically between 2:00 PM and 7:00 PM EST. These times correlated to typical in-season practice times. Before testing, subjects were directed to be well rested and adequately hydrated. Each subject underwent all testing during one session. Anthropometric measures of height, weight, and body fat percentage of the participants were completed prior to the warm-up using a stadiometer and In-Body 770. For the rest of testing, the subjects wore athletic shorts and shirts and volleyball shoes. After a 5-minute progressive cycling warm-up on a cycle ergometer (828E Monark ®, Varberg, Sweden), subjects performed 4 lower extremity dynamic stretches and 3 sport-specific motions (Figure 1).

[Insert Figure 1]

Each subject performed 8-10 familiarization jumps during a 3 to 5-minute time window with 3-5 jumps per approach style. After 1 minute of rest, each subject performed 3 recorded trials for each of the two styles of approach jump with 20 seconds of rest between each repetition and 2 minutes of rest between approach styles. All the jumps were measured using an AMTI Force plate at a sampling frequency of 1000 Hz (AMTI, Watertown, MA).

The DL technique used a four-step approach with a “step-close” technique occurring in the last two steps (3). The SL technique used a four-step approach described to the subjects as a “running approach where the last step is used to jump as high as possible.” A DL trial was deemed unacceptable if a “step-close” was not used in the last two steps while a SL trial was unacceptable if a single-foot plant was not used in the final step. Technique was observed for accuracy to protocol by an expert with twelve years of experience in the sport. Subjects were instructed to move “slow to fast” during their steps in both techniques.

The subjects were instructed to perform the jumps in the way that they found most comfortable and similar to their personal technique during a volleyball game or practice. It was necessary to acknowledge that each of the tested players had characteristic individual movement patterns (length of approach, foot positioning, arm swing, etc.) Since all tested subjects were collegiate-level athletes, further standardization would most likely have negatively influenced jumping performance during these tests.

Statistical Analysis

Statistical analysis was conducted using IBM Statistical Package for the Social Sciences (SPSS Inc., Chicago, IL, USA). Descriptive statistical parameters (means ± SD) were calculated for each subject's three trials and for the overall results of the conducted test. Using data from nine participants, the reliability of dependent measures was assessed using intraclass correlation coefficients. These coefficients ranged from 0.74 to 0.95, indicating acceptable reliability; therefore, the average values from the three recorded trials were used. Body mass (N) was also used to calculate relative vGRFs for SL and DL jumps (rSL and rDL). Prior to statistical analyses, normality was verified for each dependent variable and for differences between gender and position using skewness and kurtosis coefficients and Shapiro-Wilk normalcy tests. A one-way analysis of variance (ANOVA) was used to detect any statistical differences between combined vGRFs & position with a Bonferroni post hoc adjustment. Dependent t-tests compared SL & DL and rSL & rDL. Independent t-tests were conducted comparing vGRFs x gender, SL & gender, DL & gender, rSL x gender, and rDL & gender. Pearson's correlation coefficient was used to examine correlations between anthropometric measures to jumping styles. Levene's test of equality of error variances was calculated to consider between subject effects. The level of significant was set at 95% ($p \leq 0.05$) for all statistical procedures.

RESULTS

Individual subject means and standard deviations are shown in Table 2 and overall jumping means standard deviations are shown in Table 3.

[Insert Table 2 & Table 3]

The one-way ANOVA (combined vGRFs x position) gave an *f* -value of 2.58 with a significance of 0.095, and the Bonferroni post-hoc analysis revealed no statistically significant differences between positions regarding combined vGRFs ($p>0.05$). The dependent t-tests between SL and DL vGRFs as well as rSL and rDL vGRFs revealed no statistically significant differences between take-off style and vGRFs generated.

Significant independent t-test results are shown in Tables 4 and 5.

[Insert Table 4 & 5]

Table 6 displays significant Pearson correlations between anthropometric measures and vGRFs.

[Insert Table 6]

DISCUSSION

The primary purposes of this investigation were to determine if differences exist in vGRFs between SL and DL takeoffs and to determine if sex or positional differences in SL and DL takeoffs exist. Compared to existing literature, this study has similar mean vGRFs values to those sampling from athletic populations using an explosive jumping approach and higher values than studies examining a stationary countermovement jump (4,12,13,21). In contrast to the hypothesis that DL will be greater than SL, the data demonstrates that there is no statistically significant difference between mean SL and DL at take-off. This result parallels that of Polish national players, where the slide attack landing/take-off vGRFs ratio and the attack line spike landing/take-off VGRFS ratio had no significant difference (8). Although landing vGRFs were included in addition to the take-off vGRFs, the lack of a statistical difference between the landing/take-off ratio supports that the take-off and landing loads are similar enough to compare to the present study (8). Most studies examine the landing phase of the volleyball attack sequence as most injuries occur in this phase due to the dynamic loads placed upon the body with all attacking variations; however, investigations of the take-off phase of the approach provide greater insight into sport-specific performance (9). The greater the force an athlete applies into the ground before take-off, the more the athlete accelerates his/her center of mass which results in a higher take-off velocity and greater jumping height. Additionally, the results of this study demonstrate that a volleyball player may generate equal amounts of force regardless of approach style (24).

The secondary hypothesis that males have greater vGRFs for both SL take-off and DL take-off is partially supported by the results of this study as the combined vGRFs and SL vGRFs demonstrated statistically significant differences between males and females with male means being larger in both cases; however, the $\eta^2_{parital}$ values (0.374; 0.582 respectively) indicate small effects. Previous studies have also found that males produce higher ground reaction forces during jumping take-off and landing, and this has been attributed to differences in planting angles between male and female approaches (5,14). Additionally, no statistically significant differences occur when rSL and rDL are compared to gender indicating that gender differences did not occur when normalized for body mass (N) which further suggests that males and females use different jump kinematics to perform a given approach (21). The analysis of these kinematic differences is beyond the scope of this study.

The research results fail to support the secondary hypothesis that middle blockers would have higher SL values while pin hitters would have higher DL values. The one-way ANOVA between combined jumps and positions revealed no significance between vGRFs and position ($p>0.05$) which was further confirmed by the Bonferroni post-hoc analysis. This finding of no difference between positions contradicts previous research which has found differences in jumping characteristics between PINS and S, PINS and LIB, and MB and all other positions (17). An ANOVA differentiating between SL and DL means could not be conducted as only one setter participated (S=1) which limits the results of this study.

Combined vGRFs was significantly correlated to height (cm), mass(kg &N), and BF% (r=0.750 ‘strong positive’; 0.565 ‘moderate positive’; and -0.566 ‘moderate negative’ respectively). Therefore, as height and mass increase, combined vGRFs increases as well while as BF% increase combined vGRFs decreases. This can be related back to potential gender differences as male volleyball players tend to be taller and have greater body mass than female volleyball players while female volleyball players have larger BF% (21,17). DL vGRFs was also significantly correlated to height (r=0.876 ‘strong positive’). No other vGRFs variables significantly correlated to height, mass, or BF%, and this again could potentially be attributed to gender differences in height (17).

PRACTICAL APPLICATION

This study suggests that an SL and DL takeoffs have similar enough load to be interchangeable. This is due to the similar vertical forces generated during SL and DL volleyball take-offs. Also, it is possible that male volleyball athletes could experience greater vertical force loads when approaching; especially when using a SL technique. From a load management perspective, “slide” attacks and “regular” attacks may be counted equally with take-off loading. Together, these findings highlight the importance of training both SL and DL jumping techniques since volleyball players need to coordinate force application and joint acceleration for optimal skill performance (18). Further, jumps are time limited, training SL jumps in addition to DL jumps will help improve neural activation and can increase the athlete’s capacity for force generation and improve jump height (24). Jump height has been proven to be a skill-separating characteristic in volleyball, so integrating SL and DL training into the athlete’s program may help him/her compete at a higher competition level (20,28).

Future research may choose to examine potential differences in rate of force development and center of mass acceleration between different volleyball approach styles. Furthermore, constructing a visible net within the testing facility could improve the jump performances as the subjects could utilize the net as a visual reference when performing the approach.

ACKNOWLEDGEMENTS

The authors thank all the athletes who volunteered to participate in the study for their enthusiasm and effort. The authors have no outside funding or conflicts of interest to disclose.

Table 1. Subject anthropometrics

	Female (n=4)	Male (n=5)	Total (n=9)
Age (years)	21.75 ± 0.50	19.40 ± 0.89	20.44 ± 1.42
Height (cm)	181.93 ± 3.59	189.30 ± 6.56	186.02 ± 6.44
Body Mass (kg)	74.06 ± 12.05	81.54 ± 9.28	78.21 ± 10.63
Body Mass (N)	726.53 ± 118.16	799.89 ± 91.06	767.29 ± 104.29
Body Fat (%)	17.28 ± 2.59	7.16 ± 1.14	11.66 ±5.62

Table 2. Individual subject vGRFs means ± standard deviations

Subject	Gender	Position	SL (N)	Dl (N)	rSL	rDL
1	M	LIB	2736.67±174.84	2733.67±453.26	4.03±0.26	4.03±0.67
2	M	LIB	2974.67±256.29	2423.33±278.78	3.74±0.32	3.04±0.35
3	M	MB	2517.67±55.41	2630.00±383.15	2.90±0.06	3.03±0.44
4	M	MB	2955.67±144.47	4079.67±93.77	3.26±0.16	4.50±0.10
5	F	PIN	2174.67±88.96	2174.33±255.74	2.81±0.12	2.81±0.33
6	F	S	2265.00±75.90	2394.67±104.99	3.44±0.12	3.64±0.16
7	F	PIN	2035.33±143.20	1978.33±24.58	3.36±0.24	3.27±0.04
8	F	MB	2516.67±111.36	2465.00±238.54	2.90±0.13	2.84±0.27
9	M	PIN	2439.67±36.67	2660.67±16.77	3.25±0.05	3.54±0.02

Table 3. Overall vGRFs means and standard deviations

	Female (n=4)	Male (n=5)	Total (n=9)
Combined (N)	2250.50 ± 196.31	2815.17 ± 482.83	2564.20 ± 471.86
SL (N)	2247.92 ± 202.55	2724.87 ± 244.99	2512.89 ± 329.52
DL (N)	2253.08 ± 221.09	2905.47 ± 666.43	2615.52 ± 598.85
rSL	3.13 ±0.32	3.43 ± 0.45	3.30 ± 0.41
rDL	3.14 ± 0.39	3.63 ± 0.63	3.41 ± 0.57

Table 4. Independent t-test

	t	df	Sig.	Mean Difference	St. Error Difference	$\eta^2_{parital}$
Combined x gender	3.094	16	0.007**	564.67	182.48	0.374

*equal variances assumed
**significant at p≤0.05

Table 5. Independent t-tests

	t	df	Sig. (2-tailed)	Mean Difference	St. Error Difference	$\eta^2_{parital}$
SL x gender	3.122	7	0.017**	476.95	152.79	0.582
DL x gender	1.855	7	0.106	652.38	351.61	0.330
rSL x gender	1.160	7	0.284	0.309	0.26	0.161
rDL x gender	1.343	7	0.221	0.491	0.37	0.205

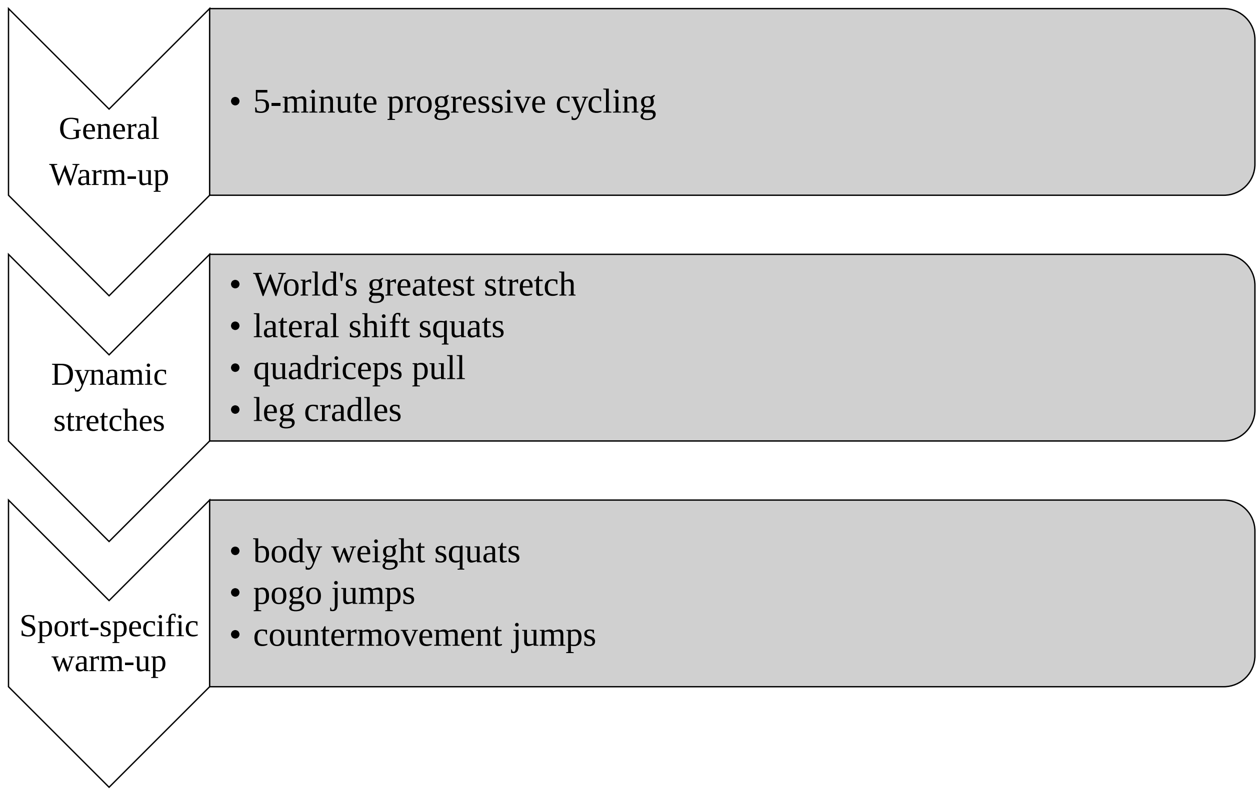
*equal variances assumed
**significant at p≤0.05

Table 6. Significant Pearson correlations

		Height (cm)	Mass (kg)	Mass (N)	BF%
Combined	**Pearson (r)**	.750	0.565	0.565	.-.566
	Sig (2-tailed)	0.00	.014	.014	.014
	N	18	18	18	19
DL	**Pearson (r)**	0.876			
	Sig (2-tailed)	0.002	No significant interactions		
	N	9			
SL, rSL, rDL	**Pearson (r)**				
	Sig (2-tailed)	No significant interactions			
	N				

r < 0.3 : very weak; 0.3 < r < 0.5 : weak; 0.5 < r< 0.7 : moderate; r>0.7 : strong

Figure 1. Warm-up procedures



REFERENCES

1. Bagley, C, Ware, B. Bump, set, spike: using analytics to rate volleyball teams and players. *SSAC*, 2017.
2. ChengTu, H, Christiansen, CL. The effect of approach on spike jump height for female volleyball players. *Int J Sports Sci Coa* 5: 373-380, 2010.
3. Coutts, KD. Kinetic differences of two volleyball jumping techniques. *Med Sci Sports Exerc* 14: 57-59, 1982.
4. DiStefano, LJ, Padua, DA, Brown, CN, Guskiewicz, KM. Lower extremity kinematics and ground reaction forces after prophylactic lace-up ankle bracing. *J Athl Train*, 43(3): 234-241, 2008.
5. Fuchs, PX, Menzel, H-J K, Guidotti, F., et al. Spike jump biomechanics in male versus female elite volleyball players. *J Sports Sci* 37: 2411-2419, 2019.
6. Huang, KC, Hu, LH, Huang, C, Sheu, TY, Tsue, CM. Kinetic and kinematic differences of two volleyball-spiking jumps. *ISBS*: 148-151, 2002.
7. Ikeda, Y, Sasaki, Y, Hamano, R. Factors influencing spike jump height in female college volleyball players. *J Strength Cond Res* 32: 267-273, 2018.
8. Kabaciński, J, Dworak, LB, Murawa, M, Rzepnicka, A. Dynamic load indicators for take-off-landing sequence in blocks and attacks in elite female volleyball players. *Acta Bioeng Biomech* 18(1): 41- 46, 2016.
9. Kabaciński, J, Murawa, M, Dworak, LB, Mączyński, J. Differences in ground reaction forces during landing between volleyball spikes. *Trends in Sport Sci* 2(24): 87-92, 2017.
10. Landvatter, S. Slide into your attack. *Coach and Athletic Director* 67: 28-31, 1997.
11. Lobietti, R, Coleman, S, Pizzichillo, E, Merni, F. Landing techniques in volleyball. *J Sports Sci* 28: 1469-1476, 2010.
12. Martins, S, Carvalho, J, Conceição, F. Insights of take-off of ground reactions force in high jump. *Conference: XXVIII ISBS*: 1-2, 2010.
13. McElveen, MT, Riemann, BL, Davies, GJ. Bilateral comparison of propulsion mechanics during single-leg vertical jumping. *J Strength Cond Res* 24(2): 375-381, 2010.
14. McNair, PJ, Prapavessis, H. Normative data of vertical ground reaction forces during landing from a jump. *J Sci Med Sport* 2(1): 86-88, 1999.
15. Palao, JM, Santos JA, Ureña A. Effect of the manner of spike execution on spike performance in volleyball. *Int J Perf Anal Spor* 7: 126-138, 2007.
16. Palao, JM, Manzanares, P, Ortega, E. Techniques used and efficacy of volleyball skills in relation to gender. *Int J Perf Anal Spor* 9: 281-293, 2009.
17. Sattler, T, Sekulic, D, Hadzic, V, Uljevic, O, Dervisevic, E. Vertical jumping tests in volleyball: reliability, variability, and playing-position specifics. *J Strength Cond Res* 26: 1532-1538, 2012.
18. Shan, X. Biomechanical analysis of vertical jump performance of volleyball players. *18 ISBS* : 1-6, 2000.
19. Shepphard, JM, Gabbet, TJ, Stanganelli, L-CR. An analysis of playing positions in elite men's volleyball: considerations for competition demands and physiologic characteristics. *J Strength Cond Res* 23: 1858-1866, 2009.

20. Skazalski, C, Whiteley, R, Bahr, R. High jump demands in professional volleyball-large variability exists between player and player positions. *Scand J Med Sci Sports* 28: 2293-2298, 2018.
21. Stephens, TM, Lawson, BR, DeVoe, DE, Reise, RF. Gender and bilateral differences in single-leg countermovement jump performance with comparison to a double-leg jump. *J Appl Biomech 23*: 190-202, 2007.
22. Taylor, JB, Kantor, JL, Hockenjos, TJ, Barnes, HC, Dischiavi, SL. Jump load and landing patterns of collegiate female volleyball players during practice and competition. *J Sport Med Phys Fit* 59: 1892-1896, 2019.
23. Tillman, MD, Hass, CJ, Brunt, D, Bennett, GR. Jumping and landing techniques in elite women's volleyball. *J Sports Sci Med* 3(1): 30-36. 2004.
24. Tilp, M. Chapter 3: The biomechanics of volleyball. In: *Handbook of Sports Medicine and Science: Volleyball.* JC Reeser and R Bahr, eds. Hoboken: John Wiley & Sons, Inc., 2017. pp. 29-37.
25. Vaverka, F, Jandačka, D, Zahradnik, D, et al. Effect of an arm swing on countermovement vertical jump performance in elite volleyball players. *J Hum Kinet* 53: 41-50, 2016.
26. Vint, PF, Hinrichs, RN. Differences between one-foot and two-foot vertical jump performances. *J Appl Biomech* 12 : 338-358, 1996.
27. Zahálka, F, Malý, T, Malá, L, Ejem, M, Zawartka, M. Kinematic analysis of volleyball attack in the net center with various types of take-off. *J Hum Kinet* 58(1): 261-271, 2017.
28. Ziv, G, Lindor, R. Vertical jump in female and male volleyball players: a review of observational and experimental studies. *Scand J Med Sci Sports* 20(4): 556-567, 2010.

.