



Biomechanical Comparisons of One-Legged and Two-Legged Running Vertical Jumps

by

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The purpose of this study was to determine the differences in biomechanical characteristics between one- and two-legged running vertical jumps (1-LRVJ and 2-LRVJ). Ten male college volleyball players voluntarily participated in this study. Two running vertical jumps used in volleyball were randomly performed. Three trials for each type of the running vertical jump were recorded for each participant. Data were collected using six infra-red Qualisys motion-capture cameras at a 180-Hz sampling rate and two AMTI force platforms at an 1800-Hz sampling rate. Jump height in the 2-LRVJ was significantly higher than that in the 1-LRVJ ($p < 0.05$). In the take-off phase, knee and hip extension impulses for the 1-LRVJ were significantly greater than those for the 2-LRVJ ($p < 0.05$). These results suggest that the 1-LRVJ produced greater leg stiffness than the 2-LRVJ did. We found that the 1-LRVJ caused greater lower-extremity stiffness and impulse compared to the 2-LRVJ, which is beneficial in the stretch-shortening cycle, and thus the more focus on practicing 1-LRVJs is recommended for coaches and athletes.

Key words: volleyball, lower-extremity stiffness, training.

Introduction

One-legged and two-legged running vertical jumps are often practiced in training programs and performed in volleyball. They are important skills for the spike and block movements used in volleyball. Running vertical jumps involve the stretch-shortening cycle (SSC) (Bobbert et al., 1996; Mikołajec et al., 2012, 2017) and have been shown to be very effective neuromuscular exercises for increasing subsequent force production and concentric contraction before take-off (Cormie et al., 2007; Finni et al., 2000; Komi, 2000; Mikołajec et al., 2017). Additionally, they further improve take-off velocity, power, and vertical jump performance (McCaulley et al., 2007; Ruan and Li, 2010).

Both one- and two-legged running vertical jumps are performed with a high-approach running velocity to reach a great pre-activation level to increase muscle activation and tension (Ruan and Li, 2010). In order to improve the ability of tendons and muscles to store and release elastic energy, tendons and muscles have to be exposed to high stretching force movements, such as jump landing, drop jumping, or running vertical jumping, because the storage of elastic energy would be enhanced after high stretch speeds and eccentric force (Finni et al., 2000, 2001; Kyrolainen et al., 2003; Markovic et al., 2004). Previous studies suggested that stiffness of the lower extremity increased in accordance with the

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movement activities required (Seyfarth et al., 2002; Stefanyshyn and Nigg, 1998), and appropriate lower-extremity stiffness is needed for efficient utilization of the SSC for optimal performance (Latash and Zatsiorsky, 1993).

A previous study demonstrated differences in ground reaction forces between the one- and two-legged vertical jumps (Jakobi and Chilibeck, 2001). It showed that the ground reaction force of a one-legged vertical jump was greater than that of a two-legged vertical jump, indicating that the one-legged vertical jump receives more stretching force than does the two-legged vertical jump. However, there is an approach or run associated with the one- or two-legged vertical jump in volleyball games and training practices; and the contribution from an individual leg during the one- and two-legged running vertical jump in volleyball has not been revealed. In addition, information regarding the biomechanical characteristics of the different running vertical jump skills is limited.

Therefore, the purpose of this study was to compare the biomechanical variables of one- and two-legged running vertical jumps. It was hypothesized that one-legged running vertical jumps would have greater mechanical output compared to the two-legged running vertical jump.

Methods

Participants

Ten male college Division I volleyball players (age: 21.1 ± 2.2 years; body mass: 80.7 ± 7.6 kg; height: 1.85 ± 0.04 m) voluntarily participated in this study. All participants had no prior knee pain or any history of trauma to the lower extremities in the 6 months preceding the experiment. All participants were right-handed. This study was approved by the Ethics Committee of the University, and all athletes provided informed consent prior to participation.

Running vertical jump tasks

Based on the technique of the volleyball spike jump for the right-handed player, the one-legged running vertical jump (1-LRVJ) consisted of left-leg landing on a force platform and left-leg take-off. The two-legged running vertical jump (2-LRVJ) consisted of landing on the force platform with both legs symmetrically and a two-legged take-off. The participants were required to

perform the vertical jump following a three-step approach, to run as fast, and to jump as high as possible. In order to analyse the movement that the players would actually use for a spike in a volleyball game, they were allowed to swing their arms while jumping, just as they would in games. A suspended string with a target simulating a real ball was placed directly above the front edge of the force plate on the ceiling. Each participant was instructed to spike the target with his right hand when jumping up into the air and then to land on the force platform.

Experimental procedures

The participants performed a series of dynamic stretches and volleyball-specific warm-up activities for 20 min and practiced the running vertical jump several times. Thereafter, the 1-LRVJ and 2-LRVJ were completed by the participants in random order. Three trials of each running vertical jump were recorded for each participant. There was a 3-min rest between trials. Each participant wore his own training shoes.

Instrumentation and data collection

Kinematic and kinetic data were collected using six infra-red Qualisys motion-capture cameras (Oqus 100, Qualisys, Inc., Gothenburg, Sweden) at a 180-Hz sampling rate and two AMTI force platforms (BP600900, AMTI, Inc., Watertown, MA, USA) at an 1800-Hz sampling rate. The cameras and force platforms were synchronized using a Qualisys 64-channel A/D board (Qualisys, Inc., Gothenburg, Sweden).

The kinematic and kinetic data were recorded using the Qualisys Track Manager motion capture and analogue data acquisition system (Qualisys, Inc., Gothenburg, Sweden). Twenty-one retro-reflective, spherical markers (19 mm in diameter) were placed on the sacrum and bilaterally on the anterior superior iliac spine, greater trochanter, thigh, lateral femoral epicondyle, medial femoral epicondyle, shank, lateral malleolus, medial malleolus, second metatarsal head, and posterior aspect of the heel according to the modified Helen-Hayes configuration (substituting regular markers for the wand markers).

Data analysis

Three-dimensional trajectory data of the markers and raw analogue data of the force platforms were identified within the Qualisys Track Manager and exported to a C3D file format. The C3D files were further imported into the

MotionMonitor software (Innovative Sports Training, Inc., Chicago, IL, USA) for data analyses. The kinematic and kinetic data were filtered by a low-pass Butterworth digital filter at a cut-off frequency of 12 Hz (Bisseling and Hof, 2006; Ford et al., 2005).

Approach velocity was defined as the sacrum velocity. The duration from the initial foot-contact on the force platform to the toe-off was defined as the support phase. The support phase was separated into the landing phase and the take-off phase based on maximum knee flexion. The landing phase was defined from the initial foot-contact to maximum knee flexion, whereas the take-off phase was defined from maximum knee flexion to the toe-off. The initial foot-contact and toe-off were determined by the 20 N thresholds of the vertical ground reaction force (vGRF). Data from the left leg were used for analyses.

The hip, knee, and ankle flexion angles were calculated from a built-in joint coordinate system of the MotionMonitor software. Joint angles were defined as zero radians at full extension. The joint moment was calculated from the kinematic and force data using inverse dynamics for each trial, as described by Winter (2009). The moment was defined with positive values when the extensors were concentrically contracted. The joint impulse was calculated from the integration of the moment-time curve ($\int M dt$; M: joint moment; dt: duration time). Joint stiffness was calculated from the sagittal plane joint angle and moment using a rotational spring model (Farley et al., 1998; Stefanyshyn and Nigg, 1998). Mean joint stiffness throughout the support phase was defined as the slope of a least-square linear regression line of the joint moment-angle curve [$y = ax + b$ ($a =$ slope, ie. mean joint stiffness, $b =$ intercept)] (Butler et al., 2003; Ford et al., 2010). The coefficient of determination (r^2) was calculated to evaluate the linearity of the joint moment-angle curve (Ford et al., 2010). The knee moment was converted to a positive value for consistency with the joint moment-angle curve of the ankle and hip. Jump height was calculated using the formula: $gT^2/8$ ($g = 9.81 \text{ m/s}^2$; $T =$ flight time after take-off).

vGRF was normalized to body mass (BM). The joint moment and impulse were normalized to body mass \times body height (BM·BH). The jump height was normalized to the percentage of body height (%BH). Data were averaged across the

three trials for each running vertical jump.

Statistical analysis

Statistical analysis was performed using SPSS 14.0 for Windows (SPSS, Inc., Chicago, IL, USA). Descriptive statistics (mean \pm standard deviation, SD) were used to determine characteristics of participants. The normality of continuous data was assessed with the Kolmogorov-Smirnov test. Comparisons of the one- and two-legged running vertical jump differences in biomechanical variables were performed using analysis of covariance (ANCOVA) adjusted for the approach velocity. Significance was set at $\alpha = 0.05$.

Results

Approach velocity, peak vGRF, vGRF impulse for the landing and take-off phases; ankle plantar flexion, knee extension, and hip flexion impulse for the landing phase; knee extension and hip flexion, impulse of the landing phase, knee and hip extension impulse of the take-off phase of the 1-LRVJ were significantly greater than those of the 2-LRVJ. Nevertheless, the jump height for the 1-LRVJ was significantly smaller than that for the 2-LRVJ (Table 1). Additionally, ankle, knee, and hip joint stiffness for the 1-LRVJ was significantly greater than that for the 2-LRVJ (Table 2).

Discussion

The purpose of this study was to compare the biomechanical characteristics of one- and two-legged running vertical jumps. The major finding was that the approach velocity, peak vGRF, vGRF impulse of the landing and take-off phase, joint impulse and joint stiffness of the leg during the one-legged running vertical jump were greater than those of the two-legged running vertical jump. However, jump performance for the one-legged running vertical jump was lower than that for the two-legged running vertical jump.

Results of the current study suggested that a one-legged running vertical jump, on the dominant leg, could induce greater muscle activation than a two-legged running vertical jump. Previous research indicated that high approach velocity was associated with increased stiffness of the lower extremity during jumping (Seyfarth et al., 2002; Stefanyshyn and Nigg, 1998). Moreover, the muscle activation level can be increased with increased leg stiffness (Ruan and Li, 2008).

Table 1*Kinematic and kinetic data*

	1-LRVJ	2-LRVJ	p
Approach velocity (m/s) *	2.93 (0.56)	2.50 (0.22)	0.044
Jump height (%BH) *	0.19 (0.03)	0.29 (0.04)	< 0.001
Peak GRF (BM) *	3.02 (0.38)	1.63 (0.19)	< 0.001
GRF impulse of landing phase (BM·s) *	60.14 (4.37)	37.69 (4.42)	< 0.001
GRF impulse of take-off phase (BM·s) *	46.80 (6.22)	36.34 (4.30)	0.004
Ankle plantarflexion impulse of landing phase [(BM·s)/BH]	1.55 (0.49)	1.21 (0.50)	0.186
Knee flexion impulse of landing phase [(BM·s) /BH] * ^a	-4.26 (0.60)	-3.33 (0.66)	0.007
Hip flexion impulse of landing phase [(BM·s) /BH] *	2.49 (1.02)	1.44 (0.41)	0.010
Ankle plantarflexion impulse of the take-off phase [(BM·s) /BH]	2.77 (0.49)	2.52 (0.40)	0.243
Knee flexion impulse of the take-off phase [(BM·s) /BH] * ^a	-3.41 (0.49)	-2.78 (0.44)	0.015
Hip flexion impulse of the take-off phase [(BM·s) /BH] * ^a	-0.03 (0.58)	0.55 (0.33)	0.020

*significant difference found ($p < 0.05$); ^a negative flexion impulse values denote an extension impulse. Data are presented as the mean (standard deviation). 1-LRVJ, one-legged running vertical jump; 2-LRVJ, two-legged running vertical jump; BH, body height; BM, body mass; GRF, ground-reaction force.

Table 2*Mean joint stiffness throughout the support phase*

	1-LRVJ	2-LRVJ	p
Ankle			
a [(N·m)/(BM·BH·rad)] *	0.18 (0.06)	0.12 (0.03)	0.015
b	180.60 (38.40)	103.43 (23.89)	
r ²	0.33 (0.18)	0.46 (0.28)	
Knee			
a [(N·m)/(BM·BH·rad)] *	0.43 (0.10)	0.20 (0.02)	< 0.001
b	300.93 (86.00)	169.51 (32.48)	
r ²	0.90 (0.05)	0.91 (0.05)	
Hip			
a [(N·m)/(BM·BH·rad)] *	0.20 (0.03)	0.11 (0.03)	< 0.001
b	-49.41 (21.61)	-43.02 (17.43)	
r ²	0.71 (0.18)	0.65 (0.10)	

*significant difference found ($p < 0.05$). Least-square linear regression line of the joint moment-angle curve [$y = ax + b$ (a = slope, ie. mean joint stiffness, b = intercept)]; r^2 = coefficient of determination. Data are presented as mean (standard deviation). BH = body height; BM = body mass.

Significant stiffness may cause an increase in the stretch speed before touchdown and improve stretch reflex, storage and re-utilization of elastic energy, thereby increasing potentiating of the contractile machinery (Kallio et al., 2004).

Combined with the present results of approach velocity and joint stiffness, it can be surmised that the approach for the one-legged running vertical jump increased lower-extremity stiffness before take-off. Joint stiffness in the one-legged running vertical jump seemed to be beneficial to the SSC for the leg as compared to that of the two-legged running vertical jump. Laffaye et al. (2005) indicated that optimal stiffness could increase jumping performance, whereas low joint stiffness with too much knee and/or ankle flexion during take-off would decrease the effect of the SSC. Greater joint stiffness came from the higher muscle activation level because leg extensor muscles worked more rapidly to finish the eccentric contraction (Comyns et al., 2007) with a greater stretch reflex.

Moreover, a one-legged running vertical jump produced a greater vGRF impulse and joint angular impulses of the dominant leg than did the two-legged running vertical jump during landing and take-off phases. Bobbert et al. (1987) indicated that the impulse during the landing phase was for deceleration, whereas the impulse during the take-off phase was for the push-off. The one-legged running vertical jump may require more effort for deceleration; however, it can induce greater exertion for the take-off. This provided the rationale for a greater SSC effect and could be the reason that there may have been greater muscle activation on the one-legged running vertical jump. Although higher vGRF and joint angular impulses during one-legged running vertical jumps might induce greater muscle activation than the two-legged running vertical jump for the

leg, jump performance of a two-legged running vertical jump was better than that of a one-legged running vertical jump. The reason could be that both legs together can generate greater vertical ground reaction force and joint angular impulse to lift the body higher than one leg only.

There were some limitations in this study that should be acknowledged. We did not control the approach velocity among participants in the design of the study. However, this was examined via an analysis of covariance (ANCOVA) in SPSS where the approach velocity was the covariate. Moreover, we did not measure muscle activation in these participants; therefore, we could not quantitatively determine the association among the muscles during the running vertical jump. A study with electromyography is needed for such analysis.

Conclusions

The findings of the current study suggest that a one-legged running vertical jump causes increased lower-extremity stiffness and impulse that would be beneficial to the SSC. It is recommended to practice one-legged running vertical jumps during training. Differences in approach velocity and jump performance reflected the unique skill requirement in a volleyball game in which one-legged running vertical jumping would be beneficial to a quick attack, whereas two-legged running vertical jumping would be beneficial for spike blocking and spiking.

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