Dynamic Characteristics of Approach Spike Jump Tasks in Male Volleyball Players

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Abstract: The approach running spike-jump (RSJ) is a crucial technique in the sport of volleyball. Two types of RSJs are commonly used for the volleyball spike attack: (1) RSJ with one leg (RSJ-1L) and (2) RSJ with two legs (RSJ-2L). The purposes of the current study were to compare the kinematic and kinetic differences between the RSJ-1L and RSJ-2L. Ten male college volleyball players performed spike jumps by striking a stationary ball at maximal jump height. Data were collected by six infrared Qualisys motion-capture cameras (180 Hz), two AMTI force platforms (1800 Hz), and recorded by Qualisys Track Manager software. The RSJ-1L demonstrated the faster three-step approach running velocity, greater vertical GRF, and ankle, knee, and hip joint moment, but less jump height, shorter last step length and push-off time, smaller knee and hip joint flexion angles at the initial foot-contact, and knee range of motion compared to the RSJ-2L. The current study contributed to the understanding of biomechanical differences of the volleyball spike jumps and can be used to adapt to the volleyball training.

Keywords: volleyball; spike jump; kinematic; kinetics

1. Introduction

Spiking is a crucial technique in the sport of volleyball. Volleyball players usually perform volleyball spiking with combined movement of three-step approach running, countermovement jumping, and hitting the ball straight down on the other side of the net [1]. The approach running spike-jump (RSJ) is often practiced in volleyball training programs [1] to enhance jumping performances required for volleyball players. During the RSJ, volleyball players have to approach the target rapidly, jump off the ground, and smash the volleyball vigorously and accurately at the highest position in the air. Fundamental volleyball techniques, such as front-row spikes of a high set and short set ball in an attack tactic, are often practiced with the RSJ [2].

Previous researchers reported kinematic differences on duration of flight, jump height, and ball velocity in the front-row spike between the short set and high set ball [2] and indicated that the performance of the three-step approach RSJ was mainly influenced by vertical jump ability [1] and technical coordination [3]. The jump height demonstrated a positive correlation with the approach velocity, velocity transfer, upper-body lean, range of motion of the knee and ankle joints [4], and knee flexion angle [1]. Moreover, higher approach running velocity before a jump can enhance the stretch-shortening cycle (SSC) [5], make the subsequent neuromuscular force production and muscular concentric contraction.
more effective [6,7], and further improve the take-off velocity of the center of mass (COM) and jumping performance [8].

For a tactical purpose of the spike, both fast horizontal and vertical momentum of the COM during the RSJ are needed. The RSJ includes a three-step approach run where the last step is transitional to prepare for transferring horizontal momentum to vertical momentum, and a horizontal run to a vertical jump [9]. The last step of the approach run and take-off movement are important for the RSJ performance. Previous studies showed that the approach run can increase both ground reaction force and joint moment of the lower extremity [10–12] while maintaining shorter ground contact time [12,13], and improve explosive power and coordination of the neuromuscular control of the lower extremity [8,14].

Two types of RSJs are commonly used for the volleyball spike attack: (1) RSJ with one leg (RSJ-1L) and (2) RSJ with two legs (RSJ-2L). The RSJ-1L is usually performed in a quick spike of a short set ball with quick take-off movement and large body shift; while the RSJ-2L is usually performed in a block and spike of a high set ball with significant countermovement [1]. The coordination of the countermovement was crucial for a two-leg vertical jump performance [15], while Wilson et al. [16] reported that an optimal jumping performance was affected by the approach velocity before touchdown. Previous studies found that the RSJ-1L produced larger kinetic feedback and energy generation in simulation [17] but decreased joint angular displacement making the stiff lower extremity [12].

Although previous researchers have conducted certain biomechanical analyses on the RSJ-2L [1,4] and analyzed the RSJ-1L using kinematic [12] or simulation methods [16], respectively, limitations exist with no comprehensive comparison. Based on the aforementioned different practical characteristics between RSJ-1L and RSJ-2L, it is worth to further look into academic differences in kinetics combined with kinematics between RSJ-1L and RSJ-2L. Therefore, a comprehensive biomechanical analysis of RSJs is needed to extend knowledge of clarification of RSJ-1L and RSJ-2L. The purposes of the current study were to compare the kinematic and kinetic differences between the RSJ-1L and RSJ-2L, and identify the primary kinematic and kinetic parameters for the RSJ-1L and RSJ-2L performances. We hypothesized that there were significant differences between the RSJ-1L and RSJ-2L, and primary functional determinants for their performances.

2. Materials and Methods

2.1. Participants

Ten male Taiwan 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 were healthy and in good physical condition, and they were free from lower extremity injury in six months prior to testing. They were right-handed and practiced the spike by the right hand. All players provided informed consent prior to participation. The present study was approved by the Ethics Committee of the university.

2.2. Running Vertical Jump Tasks

The following tasks were arranged based on an understanding of volleyball spike-jump technique from the right-handed player. The RSJ-1L consisted of three steps running toward a set target, left leg landing on a platform, and take-off during the last step. The RSJ-2L consisted of three steps running toward a set target, two legs landing on two force platforms symmetrically, and two-leg take-off in the last step. The participants were required to perform the approach run as fast as possible and jump as high as possible. A suspended volleyball was set above the front side of the force platform on the ceiling as a target to simulate the actual volleyball spike on a court. The height was set as the greatest-effort spike-jump height of each participant. They were asked to perform the spike movement vigorously just like in a volleyball game, swinging their arms while jumping and smashing the target with the right hand.
2.3. Experimental Procedures

The participants wore their own training shoes and shorts, performed a series of dynamic stretches and warmed up for 20 min, and practiced the spike jumps several times. Then, the RSJ-1L and RSJ-2L were performed in a random order. Three trials of each spike-jump were collected for each participant. There was a 3 min rest between trials. Except for the sacrum, second metatarsal head, and heel, the retro-reflective markers were attached on the skin according to the Helen-Hayes Marker set and substituting regular markers for the wand markers [12].

2.4. Data Collection

Kinematic data were collected using six infra-red Qualisys motion-capture cameras (Oqus 100, Qualisys, Inc., Gothenburg, Sweden) with 21 reflective markers (19 mm diameter) at a sampling rate of 180 Hz. Kinetic data were collected using two AMTI force platforms (BP600900, AMTI, Inc., Watertown, MA, USA) at a sampling rate of 1800 Hz. Kinematic and kinetic data were recorded using Qualisys 64-channel A/D converter (Qualisys, Inc., Gothenburg, Sweden).

The calculations of segmental movements and kinetic analyses were performed via Qualisys Track Manager (QTM) system (Qualisys, Inc., Gothenburg, Sweden). Raw data were further imported into the MotionMonitor software (Innovative Sports Training, Inc., Chicago, IL, USA) for analysis.

2.5. Data Analysis

Kinematic and kinetics data were analyzed using the MotionMonitor software (Version 8; Innovative Sports Training Inc., Chicago, IL, USA). Kinematic data during each stop-jump trial were filtered through a low-pass Butterworth digital filter at a cutoff frequency of 12 Hz [18]. Kinetic data were filtered through a low-pass Butterworth digital filter at a cutoff frequency of 60 Hz. The sacrum velocity was defined as approach-run velocity. The last step length was defined as a distance of last step before take-off measured from the right toe to left heel. The following kinematic and kinetic data of the lower extremity were analyzed for the left leg since right-handed volleyball players use it as the support leg during the RSJ-1L. The support phase was defined as the duration from initial foot contact on the platform to the toe-off. It was separated into a landing phase (from the instant of foot contact on the platform to the peak knee flexion) and a push-off phase based by the peak knee flexion (from the peak knee flexion to the instant of toe-off). The threshold of the vertical ground reaction force (GRF) of force platform was set as 20N.

The lower extremity 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 inverse dynamic process was used to calculate the joint moments of the lower extremity in each trial as described in previous studies [19]. The joint power was calculated using the cross product of the joint moment and joint angular velocity vectors [20]. Joint stiffness was calculated from the quotient of the peak joint moments and peak joint angles [21]. Jump height was calculated using the formula:

\[ \text{Jump height} = \frac{gT^2}{8} \] (where \( g = 9.81 \text{m/s}^2 \); \( T = \text{flight time after take-off} \)).

The positive values of joint moments mean the extensors were concentrically contracted. We converted the knee moment to a positive value for consistency with the joint moment of the ankle and hip. The positive value of the power represented power generation; while the negative value of the power represented power absorption. The GRF, joint moment, and power were normalized to body weight (BW). Data were averaged across the three trials for each RSJ.

2.6. Statistical Analysis

Statistical analysis was performed using SPSS 14.0 for Windows (SPSS, Inc., Chicago, IL, USA). Mean data from three trials at each RSJ for all kinematic and kinetic dependent measures were used in the subsequent statistical tests. Descriptive statistics were presented...
as means and standard deviations with 95% confidence intervals (95% CI). The data were found to be normally distributed based on Kolmogorov–Smirnov tests. The Students’ paired t-tests were applied to all biomechanical variables to determine the significant difference between RSJ-1L and RSJ-2L. Pearson Product Moment correlation coefficient ($r$) was used to determine relationships between jump height and variables representing primary biomechanical elements of the RSJ-1L and RSJ-2L. The alpha level for the statistical tests was set at $\alpha = 0.05$. Cohen’s $d$ of effect size ($d$) for the differences was calculated to indicate the statistical magnitude of the significance. Cohen’s $d$ between 0.20 and 0.49, between 0.50 and 0.79, and for 0.80 and above indicated small, moderate, and large differences, respectively [22].

### 3. Results

Table 1 presents the approach run velocity, jump height, last step length, and joint kinematic variables of the leg and their correlation with the jump height during the spike jumps. The approach run velocity of the RSJ-1L was significantly faster than the RSJ-2L ($p = 0.028$; $d = 0.847$). The jump height and last step length of the RSJ-2L were significantly greater than the RSJ-1L (both $p < 0.001$; $d = 4.823$ and 1.936, respectively). The RSJ-2L showed significantly greater knee and hip flexion angles at initial foot contact than the RSJ-1L ($p = 0.023$ and 0.003; $d = 0.868$ and 1.286, respectively). The RSJ-2L showed significantly greater peak ankle, knee, and hip flexion angles than the RSJ-1L ($p < 0.001$; $d = 2.782$, 5.274, and 1.729, respectively). The angular range of motion of knee flexion angle of RSJ-2L was significantly larger than that of RSJ-1L ($p = 0.010$; $d = 1.019$). The peak knee and hip flexion angle showed significant, positive correlation to the jump height in the RSJ-2L ($p = 0.006$ and 0.008).

Table 1. The approach run velocity, jump height, last step length, and joint kinematic variables of the left leg and their correlation with the jump height during the spike jumps.

|                           | RSJ-2L (SD) | $r$ (p-Value of Correlation Coefficient) | RSJ-1L (SD) | $r$ (p-Value of Correlation Coefficient) | $p$-Value of $t$-Test | Cohen’s $d$ (95% CI) |
|---------------------------|------------|------------------------------------------|------------|------------------------------------------|-----------------------|---------------------|
| Peak approach run velocity (m/s) | 2.50 (0.22) | -0.123 (0.735) | 2.93 (0.56) | 0.550 (0.100) | 0.028 * | 0.847 (2.49, 2.95) |
| Jump height (BH) | 0.29 (0.03) | 0.19 (0.04) | 0.59 (0.04) | 0.258 (0.471) | $<0.001$ * | 2.823 (0.21, 0.27) |
| Last step length (BH) | 0.76 (0.07) | 0.088 (0.809) | 0.59 (0.04) | 0.258 (0.471) | $<0.001$ * | 2.982 (0.62, 0.72) |
| Flexion angle at contact (deg) | | | | | | |
| Ankle | -4.63 (13.45) | 0.518 (0.125) | -8.19 (7.86) | 0.266 (0.458) | 0.197 * | 0.440 (−11.50, −1.32) |
| Knee | 37.83 (11.36) | 0.290 (0.416) | 27.64 (5.79) | 0.269 (0.452) | 0.023 * | 0.868 (27.96, 37.52) |
| Hip | 39.35 (6.91) | 0.555 (0.100) | 33.59 (7.49) | 0.424 (0.222) | 0.003 * | 1.286 (32.91, 40.03) |
| Peak flexion angle (deg) | | | | | | |
| Ankle | 11.12 (4.93) | 0.468 (0.173) | -5.11 (4.44) | -0.203 (0.574) | $<0.001$ * | 2.782 (−1.44, 7.46) |
| Knee | 85.78 (6.97) | 0.793 (0.006) * | 63.17 (4.80) | 0.060 (0.869) | $<0.001$ * | 5.274 (68.40, 80.54) |
| Hip | 35.11 (5.83) | 0.779 (0.008) * | 25.06 (5.58) | -0.041 (0.091) | $<0.001$ * | 1.729 (26.53, 33.63) |

* Indicates significant difference found between the RSJ-1L and RSJ-2L, $p < 0.05$. $r$: correlation coefficient of jump height, BH: body height. The negative value of an ankle angle represents dorsiflexion.

Table 2 presents the landing, push-off, support time, peak GRF, and joint kinetic variables of the left leg and their correlation with the jump height during the spike jumps. The push-off time of the RSJ-1L was significantly shorter than the RSJ-2L ($p = 0.043$; $d = 0.745$). The peak GRF in the RSJ-1L was significantly larger than the RSJ-2L ($p < 0.001$; $d = 3.805$). The RSJ-1L produced a significantly greater peak plantar-flexion moment, knee, and hip extension moment compared to the RSJ-2L ($p < 0.001$; $d = 3.199$, 1.667, and 2.561,
respectively). The RSJ-1L produced significantly greater hip power absorption during push-off phase compared to the RSJ-2L ($p < 0.001; d = 3.458$).

Table 2. The landing, push-off, support time, peak GRF, and joint kinetic variables of the left leg and their correlation with the jump height during the spike jumps.

|                  | RSJ-2L (SD) | $r$ (p-Value of Correlation Coefficient) | RSJ-1L (SD) | $r$ (p-Value of Correlation Coefficient) | $p$-Value of t-Test | Cohen’s $d$ (95% CI) |
|------------------|-------------|-----------------------------------------|-------------|-----------------------------------------|---------------------|---------------------|
| Landing time (s) | 0.16 (0.02) | 0.498 (0.143)                           | 0.17 (0.02) | $-0.196$ (0.587)                       | 0.365 *             | 0.291 (0.16, 0.18)  |
| Push-off time (s)| 0.16 (0.01) | 0.479 (0.161)                           | 0.14 (0.02) | $-0.619$ (0.056)                       | 0.043 *             | 0.745 (0.14, 0.16)  |
| Support time (s) | 0.32 (0.03) | 0.587 (0.074)                           | 0.31 (0.04) | $-0.427$ (0.218)                       | 0.299 *             | 0.347 (0.30, 0.34)  |
| Peak ground reaction force (BW) | 1.63 (0.28) | $-0.360$ (0.307) | 3.00 (0.47) | $0.055$ (0.880) | $<0.001$ * | 3.805 (1.94, 2.68) |
| Peak joint moment (Nm/BW) | | | | | | |
| Ankle            | 0.24 (0.03) | 0.024 (0.948)                           | 0.31 (0.03) | $-0.064$ (0.861)                       | $<0.001$ *           | 3.199 (0.25, 0.29)  |
| Knee             | 0.35 (0.05) | 0.062 (0.865)                           | 0.53 (0.14) | 0.208 (0.564)                          | 0.001 *             | 1.667 (0.38, 0.50)  |
| Hip              | 0.15 (0.42) | $-0.016$ (0.965)                       | 0.26 (0.46) | 0.065 (0.858)                          | $<0.001$ *           | 2.561 (0.17, 0.23)  |
| Peak landing power (W/BW) | | | | | | |
| Ankle            | $-3.71$ (1.84) | 0.334 (0.346)                         | $-3.27$ (1.29) | 0.492 (0.149)                         | 0.204               | 0.429 ($-4.22$, $-2.76$) |
| Knee             | $-13.46$ (3.77) | $-0.565$ (0.089)                      | $-12.83$ (4.77) | 0.172 (0.635)                         | 0.725               | 0.113 ($-15.11$, $-11.18$) |
| Hip              | 0.77 (0.53) | $-0.013$ (0.972)                       | 1.26 (0.98) | 0.529 (0.116)                          | 0.217               | 0.445 (0.63, 1.40)  |
| Peak push-off power (W/BW) | | | | | | |
| Ankle            | 11.06 (2.03) | 0.270 (0.451)                           | 10.31 (2.09) | $-0.294$ (0.410)                       | 0.289               | 0.358 (9.73, 11.64) |
| Knee             | 13.78 (3.45) | 0.567 (0.087)                           | 14.65 (3.79) | 0.074 (0.839)                          | 0.319               | 0.334 (12.55, 15.88) |
| Hip              | 0.94 (0.61) | 0.032 (0.930)                           | $-1.67$ (0.81) | $-0.194$ (0.591)                       | $<0.001$ *           | 3.458 ($-1.07$, 0.34) |
| Joint stiffness (Nm/deg) | | | | | | |
| Ankle            | 12.8 (6.9) | $-0.033$ (0.928)                       | 37.6 (16.3) | $-0.539$ (0.108)                       | 0.001 *             | 2.319 (10.22, 39.38) |
| Knee             | 6.1 (1.8) | $-0.096$ (0.792)                        | 12.0 (3.0) | 0.344 (0.330)                          | $<0.001$ *           | 2.442 (3.58, 8.22)  |
| Hip              | 27.9 (16.9) | 0.383 (0.275)                           | 28.3 (13.4) | $-0.631$ (0.050)                       | 0.070               | 0.020 ($-13.93$, 14.73) |

* Indicates significant difference found between the RSJ-1L and RSJ-2L, $p < 0.05$. $r$: correlation coefficient of jump height. The positive value of power represents power generation, while the negative value of power represents power absorption.

4. Discussion

The major findings of the current study were (1) the RSJ-1L demonstrated the faster three-step approach running velocity, greater vertical GRF, and ankle, knee, and hip joint moment, but less jump height, shorter last step length and push-off time, smaller knee and hip joint flexion angles at the initial foot-contact, and knee range of motion compared to the RSJ-2L; (2) the peak knee and hip flexion angle were primary functional determinants for the jump height of the RSJ-2L.

Previous researchers reported that the faster approach running velocity resulted in the larger last step length, and it would be beneficial for the jump height only when there was successful vertical conversion for the horizontal approach running velocity at the take-off during the RSJ-2L [4]. Nevertheless, in the current study, the RSJ-1L demonstrated faster approach running velocity but smaller last step length and jump height compared with the RSJ-2L. Different jumping strategies were observed between the RSJ-1L and RSJ-2L. The RSJ-2L seemed to be able to utilize two legs to efficiently decelerate the horizontal approach running velocity and further convert it to vertical velocity for the higher jump height compared to the RSJ-1L. We suggested that the capacity to convert the horizontal approach running velocity to vertical velocity at take-off of the RSJ-2L would be better than the RSJ-1L.

The excessive approach running velocity and last step length could impede the full conversion from the horizontal approach running velocity to vertical velocity at take-off [4]. Nevertheless, other researchers indicated that the higher horizontal velocity may be favorable to achieve greater heights [1]. Previous researchers reported that national level volleyball players demonstrated 3.71 m/s approach run velocity during the RSJ-2L to reach 0.67 m jump height [1]. The approach run velocities during the RSJ-1L and RSJ-2L of the
current study were just 2.93 m/s and 2.50 m/s to reach 0.54 m and 0.35 m jump height, respectively, which were lower than those of the national level volleyball players found by Wagner et al. [1] The college-level players still have some room to improve their approach run velocity.

Previous studies reported that fast and high loading movement prior to a jump can induce high muscle preactivation and stretch reflex [23,24], and further increase the following muscle activation to result in the later improved performances [25,26]. The approach running was likely to increase the activation of the lower extremity muscles [8]. Furthermore, the muscle preactivation was proved to be positively correlated with the joint stiffness [24,27] that was crucial for the jumping performance [10,14] or injury prevention [27]. In the current study, the RSJ-1L demonstrated greater approach run velocity, ankle and knee joint stiffness than the RSJ-2L, which could infer that the RSJ-1L induced higher ankle and knee muscle preactivation and activation of the lower extremity than the RSJ-2L.

Moreover, due to the difference of take-off method and approach velocity, the RSJ-1L demonstrated greater peak vertical ground reaction force than the RSJ-2L in the current study. The finding was in accordance with previous studies reporting that the increase in the approach run velocity increased the vertical ground reaction force [10,28], and one-leg drop landing and stop-jump showed higher peak ground reaction force and smaller knee flexion angles compared to double-leg drop landing and stop-jump [29,30]. The great peak vertical ground reaction force found in the RSJ-1L was likely due to the smaller knee and hip flexion angles at the initial foot-contact with the ground, smaller peak hip, knee, and ankle flexion angles, and knee ROM during the support phase. The RSJ-1L involved greater ground impact for the lower extremity than the RSJ-2L.

Furthermore, the current study demonstrated that the RSJ-1L produced greater ankle, knee, and hip moment during the support phase than the RSJ-2L. This outcome was in accordance with previous studies that examined the kinetic during approach drop jump [10] and stop-jump [29]. The study of Ruan and Li [10] acknowledged that the approach running jump with one leg can increase the lower extremity loading and induce high joint moment production during jumping. Moreover, in the current study, the hip power demonstrated a significant difference between the RSJ-1L and RSJ-2L during the push-off phase. The hip power of the RSJ-1L showed the power absorption; while that of the RSJ-2L showed the power generation. We inferred that the greater ankle, knee, hip joint moment, and hip joint power absorption found in the RSJ-1L may contribute more muscular stimulation of the lower extremity than the RSJ-2L.

In the current study, correlation analyses revealed that only peak knee and hip flexion angle showed positive relationship with the jump height in the RSJ-2L. The outcome denoted the importance of the countermovement of the lower extremity in the RSJ-2L performance that was in accordance with previous studies of Wagner et al. [1] and Fuchs et al. [3]. They reported the importance of the countermovement through the knee flexion angle in male volleyball players and the knee and ankle range of motion in female volleyball players, respectively [1,3]. The RSJ-2L demonstrated distinct countermovement in greater ankle, knee, and hip flexion angle compared to the RSJ-1L as the aforementioned results of the current study showed. No significant correlation was found between the jump height and variables in the RSJ-1L. The reason could be that the RSJ-1L was usually practiced to move as quickly as possible to successfully finish the quick-set or short-set ball spike [1,2] rather than to jump as high as possible to successfully finish the high-set ball spike using the RSJ-2L [1,2].

There were some limitations in the current study. The subjects were male college Division III volleyball players; therefore, the outcomes may not be applicable to subjects of the other levels and female subjects. The muscle activation of the lower extremity was not measured. The muscle preactivation and activation were inferred from the kinematic and kinetic data and previous related studies. Future research should further investigate the electromyography of muscles.
5. Conclusions

The current results revealed that the RSJ-1L and RSJ-2L employed different strategies to perform a spike jump in the approach run velocity, last step length, push-off time, and certain joint kinematics and kinetics. The RSJ-1L can be considered as higher loading movement for the lower extremity compared to the RSJ-2L. The current study contributed to the understanding of biomechanical differences of the volleyball spike jumps and can be used to adapt to the volleyball training. Volleyball players and coaches should consider the loading of the RSJ-1L and RSJ-2L as practicing in volleyball training programs and their applications on the court depending on specific tactics.

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References

1. Wagner, H.; Tilp, M.; von Duvillard, S.P.; Mueller, E. Kinematic analysis of volleyball spike jump. *Int. J. Sports Med.* 2009, 30, 760–765. [CrossRef] [PubMed]
2. Mondal, P.; Bhowmick, S. A comparison of selected biomechanical parameters of front row spike between short set and high set ball. *Int. J. Phys. Ed. Fit. Sports.* 2013, 2, 1–5. [CrossRef]
3. Fuchs, P.X.; Menzel, H.K.; Guidotti, F.; Bell, J.; von Duvillard, S.P.; Wagner, H. Spike jump biomechanics in male versus female elite volleyball players. *J. Sport Sci.* 2019, 37, 2411–2419. [CrossRef] [PubMed]
4. Fuchs, P.X.; Fusco, A.; Bell, J.W.; von Duvillard, S.P.; Cortis, C.; Wagner, H. Movement characteristics of volleyball spike jump performance in females. *J. Sci. Med. Sport* 2019, 22, 833–837. [CrossRef] [PubMed]
5. Kyröläinen, H.; Avela, J.; Komi, P.V. Changes in muscle activity with increasing running speed. *J. Sport Sci.* 2005, 23, 1101–1109. [CrossRef]
6. Cormie, P.; McCaulley, G.O.; Triplett, N.T.; McBride, J.M. Optimal loading for maximal power output during lower-body resistance exercises. *Med. Sci. Sports Exerc.* 2007, 39, 340–349. [CrossRef]
7. Finni, T.; Komi, P.V.; Lepola, V. In vivo triceps surae and quadriceps femoris muscle function in a squat jump and counter movement jump. *Eur. J. Appl. Physiol.* 2000, 83, 416–426. [CrossRef] [PubMed]
8. Ruan, M.; Li, L. Approach run increases preactivation and eccentric phases muscle activity during drop jumps from different drop heights. *J. Electromyogr. Kines.* 2010, 20, 932–938. [CrossRef] [PubMed]
9. Prsala, J. Improve your spiking in volleyball. *Volleyb. Tech. J.* 1982, 7, 57–64.
10. Ruan, M.; Li, L. Influence of a horizontal approach on the mechanical output during drop jumps. *Res. Q. Exerc. Sport* 2008, 77, 1–9. [CrossRef]
11. Stefanyshyn, D.J.; Nigg, B.M. Contribution of the lower extremity joints to mechanical energy in running vertical jumps and running long jumps. *J. Sports Sci.* 1998, 16, 177–186. [CrossRef]
12. Tai, W.H.; Wang, L.I.; Peng, H.T. Biomechanical Comparisons of One-Legged and Two-Legged Running Vertical Jumps. *J. Hum. Kinet.* 2018, 64, 71–76. [CrossRef]
13. Laffaye, G.; Wagner, P.P.; Tombleson, T.I. Countermovement jump height: Gender and sport-specific differences in the force-time variables. *J. Strength Cond. Res.* 2014, 28, 1096–1105. [CrossRef] [PubMed]
14. Laffaye, G.; Bardy, B.G.; Durey, A. Leg stiffness and expertise in men jumping. *Med. Sci. Sports Exerc.* 2005, 37, 536–543. [CrossRef] [PubMed]
15. Bobbert, M.F.; van Ingen Schenau, G.J. Coordination in vertical jumping. *J. Biomech.* 1988, 21, 249–262. [CrossRef]
16. Wilson, C.; King, M.A.; Yeaton, M.R. The effects of initial conditions and takeoff technique on running jumps for height and distance. *J. Biomech.* 2011, 44, 2207–2212. [CrossRef]
17. Sado, N.; Yoshioka, S.; Fukashiro, S. Hip Abductors and Lumbar Lateral Flexors act as Energy Generators in Running Single-leg Jumps. *Int. J. Sports Med.* 2018, 39, 1001–1008. [CrossRef]
18. Bisseling, R.W.; Hof, A.L. Handling of impact forces in inverse dynamics. *J. Biomech.* 2006, 39, 2438–2444. [CrossRef]
19. Winter, D.A. (Ed.) *Biomechanics and Motor Control of Human Movement*, 4th ed.; Wiley: New York, NY, USA, 2009; pp. 107–138.
20. Sado, N.; Yoshioka, S.; Fukashiro, S. A non-orthogonal joint coordinate system for the calculation of anatomically practical joint torque power in three-dimensional hip joint motion. *Int. J. Sport Health Sci.* 2017, 15, 111–119. [CrossRef]
21. Hobara, H.; Muraoka, T.; Omuro, K.; Gomi, K.; Sakamoto, M.; Inoue, K.; Kanosue, K. Knee stiffness is a major determinant of leg stiffness during maximal hopping. *J. Biomech.* 2009, 42, 1768–1771. [CrossRef]
22. Cohen, J. *Statistical Power Analysis for the Behavioral Sciences*, 2nd ed.; Lawrence Erlbaum Associates: Hillsdale, NJ, USA, 1988.
23. Bobbert, M.F.; Casius, R.L.J. Is the effect of a counter movement on jump height due to active state development? *J. Med. Sci. Sports Exerc.* 2006, 37, 440–446. [CrossRef]
24. Kuitunen, S.; Ogiso, K.; Komi, P.V. Leg and joint stiffness in human hopping. *Scand. J. Med. Sci. Sport* 2010, 21, e159–e167. [CrossRef] [PubMed]
25. Komi, P.V.; Gollhofer, A. Stretch reflex can have an important role in force enhancement during SSC-exercise. *J. Appl. Biomech.* 1997, 13, 451–460. [CrossRef]
26. Kyröläinen, H.; Komi, P.V. The function of neuromuscular system in maximal stretch-shortening cycle exercises: Comparison between power- and endurance-trained athletes. *J. Electromyogr. Kines.* 1995, 5, 15–25. [CrossRef]
27. Needle, A.R.; Kaminski, T.W.; Baumeister, J.; et Higginson, J.S.; Falarquhar, W.B.; Swanik, C.B. The relationship between joint stiffness and muscle activity in unstable ankles and copers. *J. Sport Rehabil.* 2017, 26, 15–25. [CrossRef] [PubMed]
28. Yu, B.; Lin, C.F.; Garrett, W.E. Lower extremity biomechanics during the landing of a stop-jump task. *Clin. Biomech.* 2006, 21, 297–305. [CrossRef] [PubMed]
29. Wang, L.I. The lower extremity biomechanics of single- and double-leg stop-jump tasks. *J. Sport Sci. Med.* 2011, 10, 151–156.
30. Yeow, C.H.; Lee, P.V.S.; Goh, J.C.H. Sagittal knee joint kinematics and energetics in response to different landing heights and techniques. *Knee* 2010, 17, 127–131. [CrossRef]