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Biomechanical Characteristics of Single Leg Jump in Collegiate Basketball Players Based on Approach Technique

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Abstract: Our study investigated the characteristics of the biomechanics of lower extremities during running single leg jump (RSJ) in collegiate basketball players. Twelve division III male basketball players voluntarily participated in this study. They performed three trials of the running single leg jump with two approach speeds (fast and preferred) randomly. The kinematic data were collected by motion analysis system (200 Hz), and kinetic data were collected using the AMTI force platform (1000 Hz), and electromyography (EMG) data were recorded by the Delsys surface Electromyography (EMG) system (2000 Hz). Kinematic, kinetic and EMG signal were synchronized using EvaRT 4.6. Peak Ground reaction force, eccentric loading rate (ELR), gastrocnemius (GA) of pre-activation phase, and tibialis anterior (TA) of push-off phase were found significantly larger in the fast approach speed ($p < 0.05$). RSJ improves muscle activation level and stretch reflex. Higher activation of TA and GA during RSJ may have the benefit of decreasing risk of injury and jump training. Thus, it is helpful in muscle stretch adaptation.

Keywords: sport biomechanics; jumping technical analysis; inverse dynamics; electromyography; muscle activation

1. Introduction

Jumping ability is one of the most important skills of basketball players [1]. Blocked shots and lay-ups are common skills in basketball competition, which is performed with a single leg. Differing from standing vertical jumps, the running single leg jump (RSJ) is generally preceded by an approaching and takeoff with one leg, [2,3] which is similar to the long jump and high jump. Hence, the ability of the RSJ is important for improving performance in sports. Moreover, a lot of the sports involve taking off from a single leg such as high jump, basketball, and handball [4,5].

The RSJ is a typical skill in sports competition. For example, such as being able to jump higher, faster, and farther, to break through the hostile or increase offensive opportunity in different circumstances. The ability of energy conversion from the horizontal-to-vertical explains the RSJ skill feature because the major joint power and work were generated by lower extremity [6]. Some studies reported horizontal kinetic energy of the center of mass (CoM) decreases to transformation a higher vertical kinetic energy and potential energy during the long jump and high jump touchdown phase [7,8] and the takeoff leg is main conversion pivoting. Ankle plantar-flexion, knee, and hip extension torques are believed to be the main contributors that generate the energy for the jumping height in RSJ [8,9].

Various studies investigated the biomechanical difference and functional application on RSJs movement through kinematic, kinetic and EMG. They included the training effect of RSJ [4,5,10], the difference in long jump [8], high jump [7,11,12], and approach drop jump [10,13]. None of them provide enough specific descriptions on RSJ of lower extremity work. As we know, jumping performance is achieved by the coordination, interaction and self-organization of the ground kinetic, body segments and muscles [14]. Hence, to understand how an external force triggers the stretch-shortening cycle (SSC) and stretch reflex is needed. In addition, we need to know how the body segment and joints respond. Some studies reported an approach that increases jumping movement activation level, thus improving the explosive power and coordination of the neuromuscular control of lower limbs [5,10]. Previous studies reported that the running movement can increase both the ground reaction force [15] and lower extremities' joint torque [7,10] while maintaining a shorter ground contact time [15,16]. Therefore, the feature of RSJ causes a faster and more powerful jump than a jump from a standing position. It is crucial to investigate the biomechanical characteristics of RSJ, as it can facilitate in determining the factor that improves jumping capability, decreasing risks of injury, or using RSJ as an optimized training method for explosive power.

Although studies were conducted based on the biomechanical parameters of RSJ between jumps for height and length, they are primarily used to compare the difference in parameters and are not applicable to athletes or coaches. To the best of our knowledge, none have examined the biomechanical characteristics of RSJ. Therefore, the present study aimed to clarify the biomechanical characteristics and muscle activation condition of the lower extremities during RSJ in collegiate basketball players. We hypothesized that RSJ performance will be affected by running speed and that the lower extremity biomechanical parameters may correspond with muscle activation, in which the ankle joint may be an essential factor.

2. Methods

2.1. Participants

Twelve division III male basketball plays volunteered in the study (age: 21.9 ± 1.3 years; height: 1.81 ± 0.07 m; mass: 75.1. ± 8.3 kg). All participants were free of any previous lower extremity injury, and they were familiar with RSJ. The testing procedures were explained to every participant, all participants provided their written consent before the study proceeded, and the study was approved by the ethics committee at the university.

2.2. Procedures

Participants wore standardized footwear (Mizuno K1GA140009, Lurng Furng, Inc., Taipei, Taiwan) to control the effect of differences in footwear properties. Prior to data collection, they performed a 15 min warm-up including a 5 min run on a treadmill followed by a 5 min dynamic stretching of the lower extremity muscles and 5 min RSJ practices. After the warm-up, they performed a fast and preferred RSJ in a randomized order. The fast RSJ implies that the approach run speed should be faster than the speed of the light-emitting diodes (LED) meteor light bar; the preferred RSJ implies that the participants run as their usual respectively. They were instructed to perform an approach run of 6 m, step onto a force platform, and jump as high as possible with the dominant leg. We suspended a sponge under the ceiling as an overhead target, and the target height was set as each participant's 125% countermovement jump height; they must jump to touch the overhead target. Three trials of each of the fast and preferred RSJ were collected.

2.3. Data Collection

A wooden runway (length: 10 m, width: 3 m) was set for the participants to perform the 6 m approach run. An AMTI force platform (Advanced Mechanical Technology Inc., AMTI Inc., Watertown, MA, USA) at 2000 Hz sampling rate was set at the end of the runway. A three-dimensional motion capture system (Motion Analysis Corporation, Santa Rosa, CA, USA) with 11 Eagle cameras at a 200 Hz sampling rate were set around the experimental site. EVaRT software (Version 5.0.1, Motion Analysis Corporation, Santa Rosa, CA, USA) was synchronized with the cameras and force platform. To calculate the moments and power outputs, the force data were resampled at 200 Hz. The joint moment was calculated from the kinematic and force data using inverse dynamics for each trial, as described by Winter [17]. A modified Helen Hayes marker set was used to measure the movement trajectories of the lower extremities. Total twenty-three retroreflective, spherical markers (19 mm in diameter) were placed on the sacrum and bilaterally on the shoulder, 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. More details regarding the segments can be found elsewhere [18]. A 9 m LED meteor light bar with a speed of 4 m/s was set beside the runway. Figure 1 shows the experimental site setting and instrumentation used in this study.

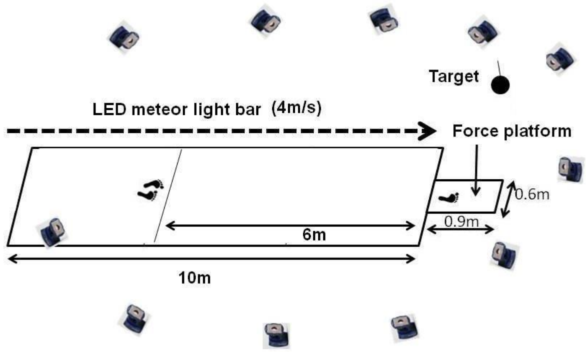

Figure 1. Experimental site setting and instrumentation used in this study.

A wireless surface electromyography (EMG) system (Delsys Inc., Boston, MA, USA) with a sampling rate of 2000 Hz was used to measure the muscle activity of the rectus femoris, biceps femoris, tibialis anterior, medial gastrocnemius, and soleus of the dominant leg. We assumed there was no bilateral different in this study. The dominant leg was defined as the leg typically used to kick a ball [19]. Each participant's skin was carefully shaved, abraded, and cleaned with alcohol prior to the attachment of the electrodes.

2.4. Data Analysis

RSJ was divided into three phases: (1) the pre-activation phase defined as 50 ms before touchdown [13]; (2) the downward phase defined from touchdown to the maximum knee flexion; (3) the push-off phase defined from the maximum knee flexion to push off [10,13]. Kinematic and kinetic variables were analyzed using the MotionMonitor (Version 8.0, Motion Analysis Corporation) software. A 10 N vertical ground reaction force (vGRF) threshold was used to identify touchdown and push-off from the ground. The kinematic variables were the jump height, touchdown velocity of center of mass (COM), time of downward and push-off phase, peak knee flexion angle, and change in knee angle. The jump height was calculated by the COM displacement from touchdown to the highest position. The horizontal-to-vertical velocity conversion rate (HVCR) was calculated using the following equation:

$$\text{HVCR} = \frac{H_{vtf} - H_{vtd}}{V_{vtf} - V_{vtd}}\% \quad (1)$$

where H_{vtf} and H_{vtd} are the horizontal COM velocities of take-off and touchdown, respectively; V_{vtf} and V_{vtd} are the vertical COM velocities of take-off and touchdown, respectively.

The kinetic variables were the peak horizontal ground reaction force (hGRF), vGRF, moment and powers of the hip, knee, and ankle joint, and eccentric loading rate (ELR) during RSJ. The net internal joint moments were calculated using the inverse dynamics approach. The joint powers were computed by multiplying the respective joint moment by the joint angular velocity. The ELR is a measure of the absorption of landing explosive strength calculated from the average slope of the eccentric loading portion of the vGRF-time curve in the downward phase [16]. The eccentric loading portion was determined from the vGRF exceeding the body mass to the peak vertical vGRF. The hGRF, vGRF, all force, and joint moment data were normalized by each participant's body weight.

Raw EMG signals were processed using a band-pass filter (20–450 Hz) to remove artifacts and calculate root mean square (RMS) with a 50 ms time interval. The EMG data of each muscle were normalized to a percentage of the highest RMS value of each muscle from trials of RSJ set as the reference voluntary contraction (RVC). The averaged %RVC of each phase of pre-activation, downward, and push-off was used to evaluate the recruited muscle activities [13].

2.5. Statistical Analysis

Descriptive data were expressed as the means (M) ± standard deviations (SD) of the measurements. The student's paired t-test was applied to all biomechanical variables to determine any significant effects during fast and preferred RSJs. Due to the sample size and participant's ability was limited in this research. Cohen's d of effect size (EZ) for the differences was calculated to indicate the practical relevance of the significance (Table 1). A Bonferroni correction was used to adjust the *p*-value for multiple comparisons in tests, the alpha level for the statistical tests was set at $\alpha = 0.005$ after Bonferroni correction adjust. Pearson product-moment correlation (r) of jump height with all the predictor variables were provided to understand the correlation of the biomechanical parameters to RSJ performance (Table 2).

Table 1. Descriptive data on biomechanical parameters of lower extremity. Based on means (M) and standard deviations (SD).

	Fast Approach		Prefer Approach		*t*	*p*	*r*	r^2	*Cohen's d*
	M	SD	M	SD					
Jump height (m)	0.78	0.08	0.77	0.09	0.57	0.583	0.74	0.55	0.161
Horizontal GRF (BW) *	1.58	0.24	1.36	0.24	−7.11	<0.000	0.91	0.82	2.139
Vertical GRF (BW)	3.46	0.31	3.27	0.34	2.40	0.035	0.65	0.42	0.695
Horizontal touchdown velocity (m/s)	4.31	0.17	3.96	0.28	−2.91	0.059	0.61	0.37	1.577
Vertical touchdown velocity (m/s)	0.32	0.17	0.30	0.17	−0.42	0.682	0.60	0.36	0.132
Concentric time (ms)	115	16	124	13	−3.25	0.008	0.82	0.67	0.983
Eccentric time (ms)	127	16	144	22	−3.15	0.009	0.56	0.32	0.914

* Indicates significant difference found between fast and prefer RSJ, $p < 0.005$.

Table 2. Pearson product-moment correlation (r) of jump height of fast and prefer approach.

Variables	Fast Approach		Prefer Approach	
	r	*p*	*r*	*p*
Horizontal GRF (BW)	0.082	0.801	0.480	0.114
Vertical GRF (BW)	0.229	0.474	0.200	0.533
Horizontal touchdown velocity (m/s)	0.358	0.253	0.223	0.486
Vertical touchdown velocity (m/s)	0.215	0.502	0.315	0.319
Concentric time (ms)	0.366	0.242	0.340	0.280
Eccentric time (ms)	0.574	0.051	0.221	0.490
ELR	0.188	0.558	0.167	0.604
GA%RVC in pre-activation (%)	0.278	0.382	0.125	0.699
TA%RVC in push-off (%)	0.213	0.506	0.255	0.424

3. Results

The horizontal GRF shows significantly higher in the faster approach ($p < 0.001$); No significant difference was found in the faster or preferred approach run during takeoff. Additionally, the HVCR indicated no difference between the faster (47.9 ± 12.3%) or preferred (52.3 ± 10.4%) approach run during the ground contact phase.

Figure 2 shows the averaged patterns of changes in the vertical and horizontal ground reaction forces during the ground contact phase. Table 1 shows that the biomechanical variables after the statistics. No significant difference in jump height ($p = 0.583$), vGRF ($p = 0.035$), touchdown velocity of vertical ($p = 0.682$) and horizontal ($p = 0.059$), duration of concentric ($p = 0.008$) and eccentric ($p = 0.009$) time, %RVC of TA ($p = 0.020$) and GA ($p = 0.032$), and ELR ($p = 0.010$) were found between the faster and preferred runs.

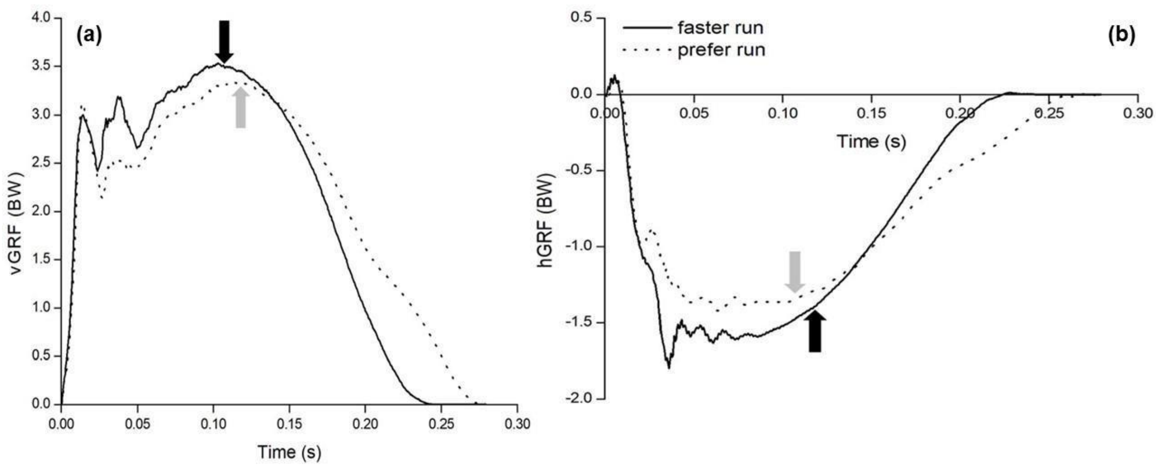

Figure 2. Averaged patterns of changes in the vertical (**a**) and horizontal (**b**) ground reaction force during the ground contact phase (bold line, faster run; dot line, prefer run); black arrow indicates the start of the push-off phase during the RSJ with the faster run approach; gray arrow indicates the start of the push-off phase during the RSJ with prefer run approach.

The GA muscle %RVC demonstrated an activation increase in the pre-activation phase of a faster run (47 ± 25%) compared to a prefer run (38 ± 22%), and the TA muscle %RVC increased in the push-off phase of a faster run (35 ± 31%) than in the preferred run (10 ± 6%).

4. Discussion

Biomechanical patterns and muscle activities during the pre-activation, downward and push-off phases of RSJ were examined in this study. The primary results are as follows: (1) an approach run did not increase the joint moment and power outputs during RSJ, and only a part increases in the GRF and ELR were observed; (2) the increasing approach speed was shorter in the downward and push-off time; (3) the faster approach run increased the muscle pre-activation level of the GA and activation level of the TA during the push-off phase. These results supported the hypothesis that biomechanical variables change with increased approach speed.

The faster approach runs increased the horizontal velocity of touchdown, but the preferred runs' condition exhibited a better HVCR. However, the HVCR in RSJ was still smaller compared to that in a high jump [20]. Our study indicated that a horizontal velocity of 60% (1.47 m/s) decreased from touchdown to takeoff and a conversion to vertical velocity at approximately 3 m/s. The movement duration of the RSJ was significantly shorter when the approach speed increased whether in eccentric or concentric time. This indicates that RSJ is a fast SSC movement that activates muscles to develop the maximum forces in a short time [21]. The result reflects the work efficiency of lower limb muscles that executed RSJs with fast SSCs [22]. However, a less eccentric time and a higher external force imply an increase in braking loading in the downward phase that may result in a muscular system activation with a high stretch reflex [23], thus enhancing muscle forces [24]. We found a phenomenon where the time delay between the eccentric and contraction phases was shorter. However, the participants did appear to benefit from the effect of a fast SSC in our final results.

The vGRF and ELR (Figure 3) were larger in the fast approach RSJ movement. Wang (2011) indicated that the GRF may be affected by knee joint range of motion (ROM) change. However, no significantly different knee ROM was found in the present study [25]. The knee joint angle trend decreased with increasing approach run speed. Our result indicates different patterns of the knee ROM with stop landing movement [26]; this may be because the RSJ focuses on follow-up jumping instead of landing. A higher ELR will shorten the downward phase and may create a beneficial situation for the SSC effect [15,16]; however, it did not reflect on the jumping performance and no difference was found in the joint moment and power output. These findings were different than those of previous studies indicating that the summed power, knee moment, and knee power increased with the approach speed [10]. The possible causes could be that previous studies involved performing an approach running drop jump (RDJ), while RSJ was performed in our study. Compared with RSJ, the 60 cm RDJ generated a higher mechanical output of the lower limbs.

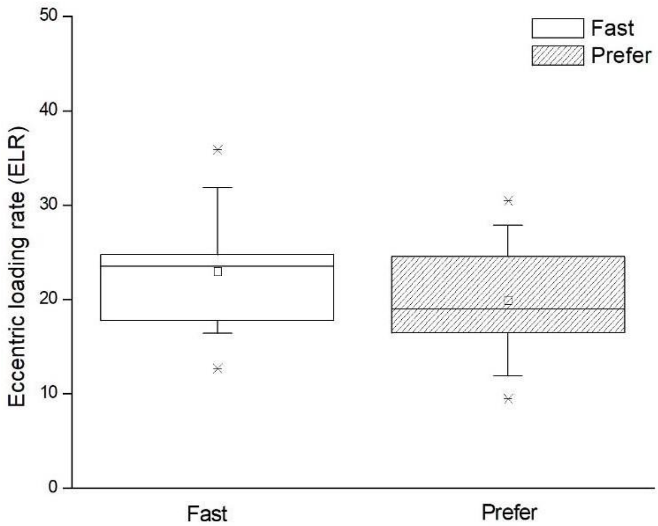

Figure 3. Box plot of ELR in fast and prefer approach conditions.

Figure 4 presents the averaged patterns of change in joint moments and powers of the hip, knee, and ankle joints of the dominant leg during the ground contact phase; the RSJ kinetic patterns of the lower extremity were presented. The knee flexor and hip extensor are important in supporting the body in the impact phase. The hip joint moment quickly increased in the initial part of the ground contact phase. The power was positive in the initial touchdown phase and became negative at the 55% point of the ground contact phase. The hip joint pattern indicated that the function of RSJ was to reduce the COM velocity and counteract collisions in the initial touchdown phase [27].

The knee flexor generated a large moment and a negative power of the dominant leg in the concentric phase. This pattern indicated that the knee joint resisted the impact force and absorbed the mechanical energy of the body during this phase. The knee joint moment was negative in the majority of the ground contact phase, but the power indicated two parts, i.e., positive and negative by peak knee flexion (43.1%). The knee flexor generated a large moment and a negative power of the dominant leg in the eccentric phase. This pattern indicated that the knee joint resisted the impact force and absorbed the mechanical energy of the body during this phase; simultaneously, the knee flexor had to exert a sufficiently large moment to support the body. In the concentric phase, the knee flexor continued to generate sufficient push-off moment by increasing the vertical COM velocity through the forward rotation of the body around the takeoff foot [9]. The mechanical work of the knee joint to the horizontal COM velocity indicate that the concentric contraction of the knee flexor would reduce the decrease in horizontal COM velocity during the concentric phase (Figure 5) [27]. In conclusion, the knee joint supported the body to optimize the effect of the horizontal-to-vertical movement over the dominant leg during the eccentric phase and extended the body during the concentric phase to increase the vertical COM velocity throughout the takeoff phase (Figure 5) [7].

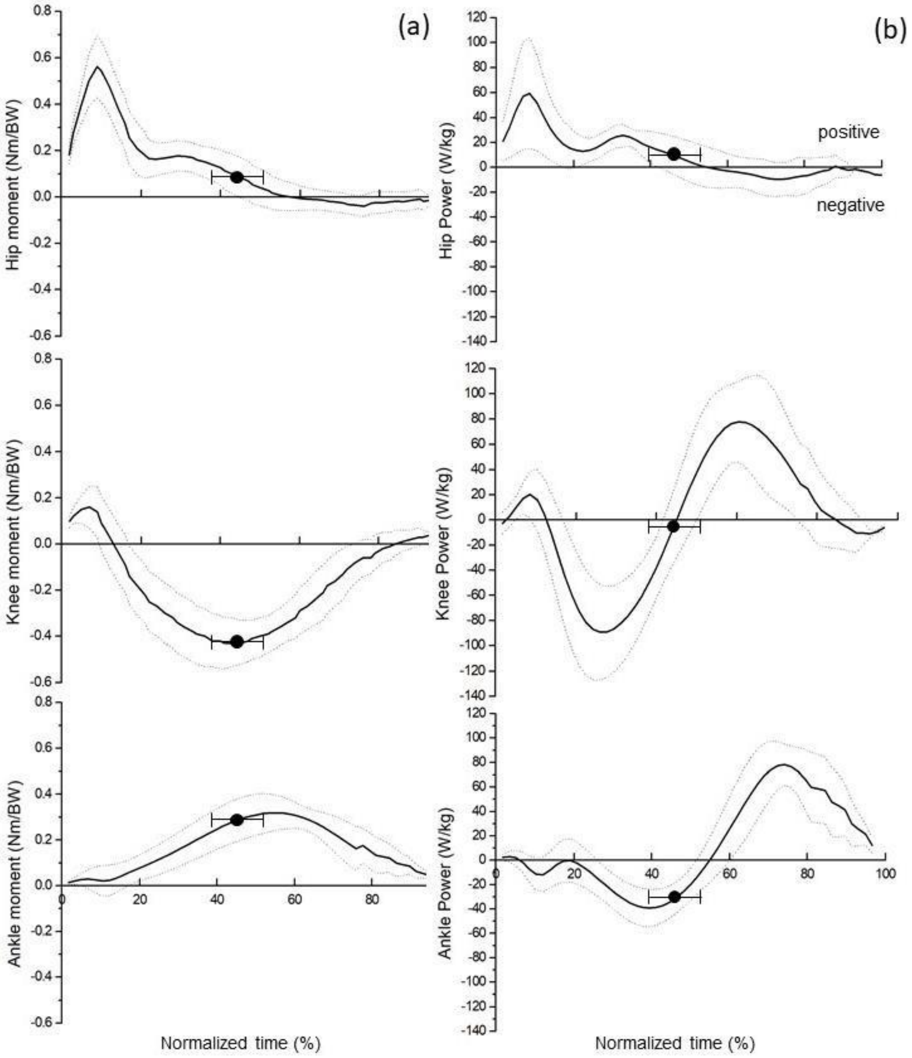

Figure 4. Averaged patterns of change in joint moments (**a**) and joint powers (**b**) of the hip, knee, and ankle joints of the dominant leg during ground contact phase (bold line, average; dot lines, range of ± SD). The averaged point of peak knee flexion of the dominant leg was presented (43.1%). Stick figures are drawn from touchdown to the toe-off at every 20% point. Where the positive value of the moment of hip and knee means extension, the negative value was flexion and plantar-flexion of the ankle joint was present as a positive value, the negative value was dorsi-flexion.

The ankle joint moment was positive throughout the ground contact phase; however, the power was negative in the initial touchdown phase and became positive at the 55% point of the ground contact phase. The ankle joint moment and power were substantial in the eccentric to concentric phase; this pattern indicated that the ankle dorsi-flexors were contracted eccentrically during the eccentric phase and that the ankle dorsi-flexors absorbed the mechanical energy of the body together with the knee flexors, particularly in the latter part of the eccentric phase. The plantar-flexors generated the most energy in the concentric phase (Figure 4). In addition, the plantar-flexors increased the mechanical energy and subsequently the COM velocity during the concentric phase. Therefore, the ankle dorsi-flexors act as an energy absorber in the eccentric phase, whereas the plantar-flexors act as an energy generator in the concentric phase that increases the vertical COM velocity throughout the takeoff phase [6]. The ankle joint is important in transmitting the force generated through the joints and other body parts to the ground [28]. This suggests that the jumper should exert a plantar-flexion moment in the early stages such that the positive work is larger during the concentric phase and the negative work duration is shorter.

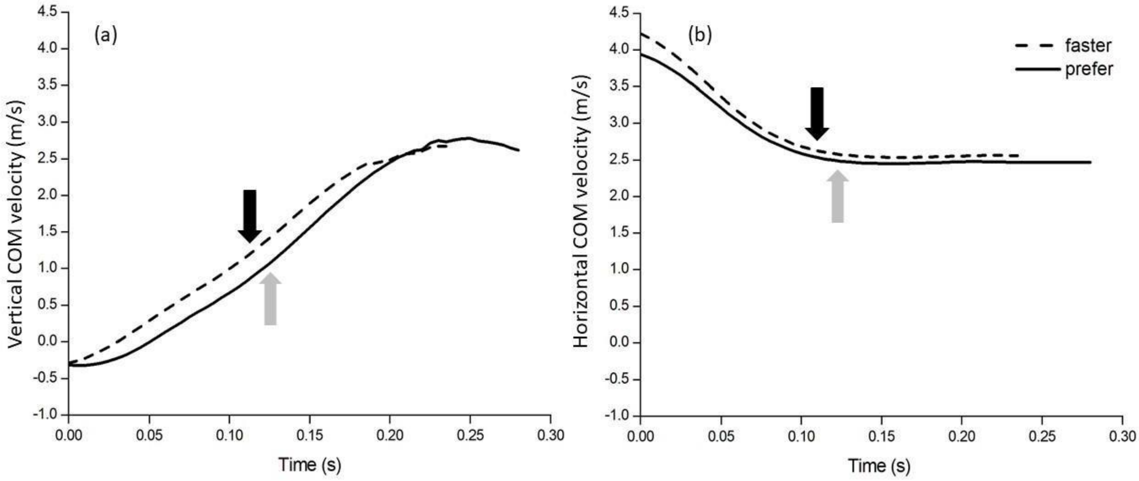

Figure 5. Averaged patterns of vertical (**a**) and horizontal (**b**) COM velocities during ground contact phase (bold line, prefer approach run; dot line, faster approach run); black arrow indicates the start of the push-off phase during the RSJ with the faster run approach; gray arrow indicates the start of the push-off phase during the RSJ with prefer run approach.

The GA muscle activities increased significantly in pre-activation and the TA muscle activities increased significantly in the push-off phase. Pre-activation was to increase the sensitivity of muscle spindles that enhanced stretch reflexes, which may increase tendomuscular stiffness and enhance force production [13]. In fact, we discovered that a higher ground reaction force corresponded to a faster approach run. When muscles are strongly pre-activated before touchdown, they will excitation dynamics to begin developing before landing. Owing to the specialized RSJ movement, the horizontal-to-vertical COM velocity transition caused a higher TA muscle activation in the push-off phase to stabilize the ankle joint.

In conclusion, the present study aimed to clarify the biomechanical characteristics and patterns of the lower extremity during an RSJ. We presented different biomechanical parameters form the faster and preferred approach runs, and described the kinetic patterns of the RSJ. Although we could not prove that the jump height is associated with the approach speed, we found that it was affected by the COM velocity of the horizontal-to-vertical transition. Furthermore, the joint power indicated that the ankle joint was important during the takeoff phase. These findings may be beneficial for training with running jumps for height movements. Additionally, we suggest that athletes process RSJ movements to practice performing a horizontal-to-vertical transition with a different approach speed to improve jumping performance and applications.

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Conflicts of Interest: The authors declare no conflicts of interest.

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