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Research article

Asymmetry between the Dominant and Non-Dominant Legs in the Kinematics of the Lower Extremities during a Running Single Leg Jump in Collegiate Basketball Players

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Abstract

The present study aimed to clarify the asymmetry between the dominant (DL) and non-dominant takeoff legs (NDL) in terms of lower limb behavior during running single leg jumps (RSJ) in collegiate male basketball players in relation to that of the jump height. Twenty-seven players performed maximal RSJ with a 6 m approach. Three-dimensional kinematics data during RSJ was collected using a 12 Raptor camera infrared motion analysis system (MAC 3D system) at a sampling frequency of 500 Hz. The symmetry index in the jump heights and the kinematics variables were calculated as {2 × (DL – NDL) / (DL + NDL)} × 100. The run-up velocity was similar between the two legs, but the jump height was significantly higher in the DL than in the NDL. During the takeoff phase, the joint angles of the ankle and knee were significantly larger in the DL than the NDL. In addition, the contact time for the DL was significantly shorter than that for the NDL. The symmetry index of the kinematics for the ankle joint was positively correlated with that of jump height, but that for the knee joint was not. The current results indicate that, for collegiate basketball players, the asymmetry in the height of a RSJ can be attributed to that in the joint kinematics of the ankle during the takeoff phase, which may be associated with the ability to effectively transmit run-up velocity to jump height.

Key words: Jump height, symmetry index, bilateral difference, joint kinematics.

Introduction

In basketball, a running single leg jump (RSJ) is frequently used in various competitive activities such as rebounding, blocked shots and lay-up shots at a higher position. Hence, the ability of the RSJ is a determinant for achieving high competitive performances in this sport. It is known that basketball players have a dominant takeoff leg (DL), which is preferably used to perform the RSJ (Schiltz et al., 2009). For basketball players, however, it is critical to perform the RSJ at the same level regardless of the DL and non-dominant legs (NDL), because they must offend and defend from various directions and situations relative to the goal. In addition, Brumitt et al. (2013) and Schiltz et al. (2009) argued that limb asymmetry in performance over 10% increases the occurrence of sport-related injuries. For basketball players, lower extremities are the most frequently injured body area (Borowski et al., 2008; Decker et al., 2003; Ellapen et al., 2012; Messina et al., 1999; Nelson et al., 2007) because they frequently use each leg to jump, pivot or change directions, and are likely to overuse the takeoff leg as it enables them to jump higher. Thus, to reduce any asymmetry in the performance of the RSJ is essential, not only to achieve high performance, but also to prevent injury to the lower limbs.

Many studies have already investigated asymmetry between limbs in performance during different single leg jumps, which are started from a standing position (Hewit et al., 2012; Maulder and Cronin, 2005; Meylan ets al., 2010; Miyaguchi and Demura, 2010; de Ruiter et al., 2010; Schiltz et al., 2009; de Swearingen et al., 2011). Some studies (Meylan ets al., 2010; Miyaguchi and Demura, 2010; Swearingen et al., 2011) showed that the performance of a single leg vertical jump from standing was significantly higher in the DL than in the NDL. Meylan et al. (2010) also observed a similar phenomenon in the horizontal and lateral counter movement jumps. In addition, Schiltz et al. (2009) showed that professional basketball players jumped significantly higher with the DL than the NDL (12%) in drop jump. These studies focused on jumps from a standing position, and to our knowledge, no studies have tried to examine the asymmetry of performance in the RSJ.

Many studies have already investigated the kinematics during RSJ through comparing high jumping players with low or correlating the jump height with jump variables in basketball and jump events of track and field (Greig and Yeadon, 2000; Ritzdorf, 2009; Stefanyshyn and Nigg, 1998). Stefanyshyn and Nigg (1998) have reported that to exert a greater force by ankle angle compared with knee and hip joints is important to jump high in RSJ. Moreover, it has been shown that high jumpers kept knee joint to more extended position to jump high at takeoff phase (Greig and Yeadon, 2000). Considering these findings, it may be assumed that the asymmetry of performance in RSJ is attributable to that of the kinematics of takeoff leg.

The present study aimed to clarify the differences between the DL and NDL in the behavior of the lower extremity during RSJ in collegiate basketball players. To this end, we compared the kinematics of the lower limbs in the takeoff leg during the RSJ between the DL and NDL and examined how the asymmetry of the jump height can be associated to that in the kinematics of the takeoff legs. We hypothesized that the asymmetries of jump height in the RSJ can be associated to that in the kinematics of the takeoff leg, notably in the ankle joint.

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Methods

Subjects

Twenty-seven healthy male collegiate basketball players voluntarily participated in this study. Their means and standard deviations (SDs) of age, body height, and body mass were 21.1 ± 2.4 yr, 1.76 ± 0.05 m, and 71.4 ± 7.7 kg, respectively. Fifteen of the subjects were guard players, nine forward players and three center forward players except pure center playing near the rim. The subjects had experienced organized competitive basketball training for at least eight years and participated in domestic or inter-college competitive meetings. They were in good physical condition and without any history of injury to the lower limbs within the last year. On the basis of questionnaires, the DL was defined as the one used preferably for jumping with a single leg, as described in prior studies (Schiltz et al., 2009). In this study, all subjects could jump higher with the DL than the NDL during RSJ. The DL for 18 of the subjects was the left; therefor, for the remaining subjects was the right. This study was approved by the Ethics Committee of the National Institute of Fitness and Sports in Kanoya and was consistent with institutional ethical requirements for human experimentation in accordance with the Declaration of Helsinki. Prior to the measurement session, all subjects were fully informed about the procedures and possible risks involved as well as the purpose of the study. Written informed consent was obtained from all subjects.

Procedures

The participants were asked to perform a maximal RSJ that was similar to a condition in which basketball players rebound a ball close to the rim. The subjects approached for 6 m in which the distance was similar 3-point line when outside players started playing in the area at their own speed and jumped maximally in order to touch by hand a target set to the end of a ceiling 3.05 m in height. The experimental test was carried out without the ball to eliminate various constraint conditions. This allowed the participants to fully concentrate on performing the jump task itself. Execution of the RSJ was firstly demonstrated by an experimenter, and then the subjects were asked to practice the task to familiarize themselves with the testing procedure. In the measurements, the subjects were asked to jump four times with each takeoff leg alternated, with a sufficient rest interval which did not influence next jump performance. We calculated a symmetry index of jump height (symmetry index$_{JH}$) and index of each kinematics data as {2 × (DL – NDL) / (DL + NDL)} × 100 (Wong et al., 2007). The symmetry index$_{JH}$ was 6.3 ± 4.8 % (means ± SDs). In another experiment using the subjects examined here, we determined the mechanical power developed during a single leg squat vertical jump, which was without preparatory counter movements and with their arms akimbo, and confirmed that there was no significant difference in mechanical power between the two legs.

Measurements

The motions of the segments and contact time from touchdown to takeoff in the RSJ were recorded in three-dimensions using a 12 Raptor camera infrared motion analysis system (MAC 3D system, Motion Analysis, Corp., USA) at a sampling frequency of 500 Hz. The data was stored on a personal computer system through an A/D converter. Experimental 3-D error of capturing marks was less than 1 mm in all trials in the current study. Twenty-six reflective markers of 1.4 cm diameter were placed at specific landmarks of the body (Figure 1). Absolute coordinates of these markers were chosen to represent the joints of lower limb and to calculate the center of gravity (CG). The horizontal distance between the takeoff place and the vertical plane containing the target was adjusted for each participant so that they could jump with

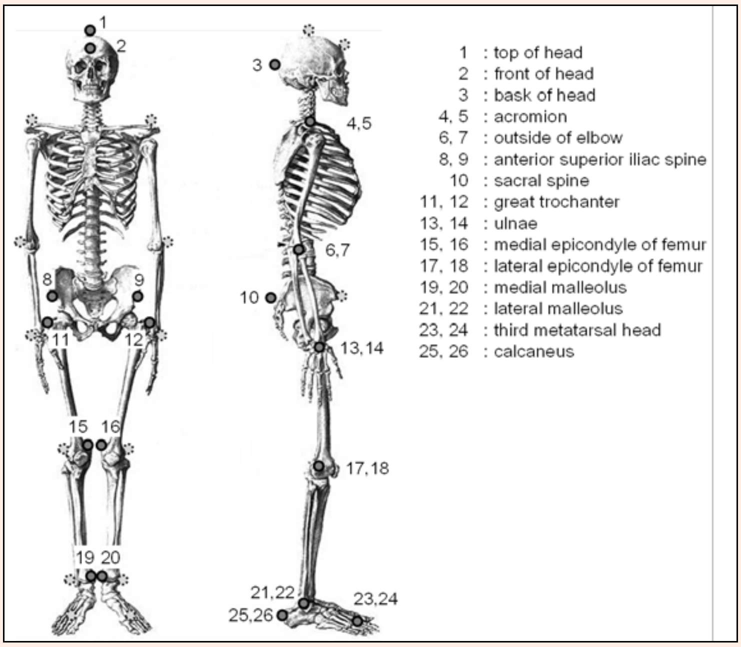

Figure 1. Markers on landmarks of the body.

Table 1. Descriptive data on jumping heights. Values are means (±SDs).

		DL	NDL	Symmetry Index (%)
Jump Height (m)		.722 (.068)***	.678 (.066)	6.275 (4.796)
Running Velocity ($m \cdot s^{-1}$)		7.925 (.492)	7.755 (.416)	2.106 (4.940)
Contact Time	CT (s)	.233 (.020) *	.238 (.023)	-2.355 (6.077)
	CT_{des} (s)	.054 (.011)	.055 (.012)	-3.042 (7.022)
	CT_{asc} (s)	.179 (.014)	.183 (.014)	-2.217 (6.081)

Running Velocity, maximal value of the running approach velocity. $CT_{des,}$ Contact time from touch-down to minimal vertical displacement of the center of gravity (CG_{zmin}). CT_{asc}, Contact time from CG_{zmin} to takeoff. * and * * * indicate that difference between the dominant (DL) and non-dominant leg (NDL) is significant p < 0.05 and 0.001, respectively.

maximal effort. A zero-lag, fourth-order, low-pass Butterworth digital filter with a cut-off frequency of 12 Hz was chosen as the best presentation of the raw positional data of the markers after a visual inspection of several frequencies. The cut-off frequency was selected in accordance with prior studies (Ae et al., 2008; Hay et al., 1999; Wang, 2011).

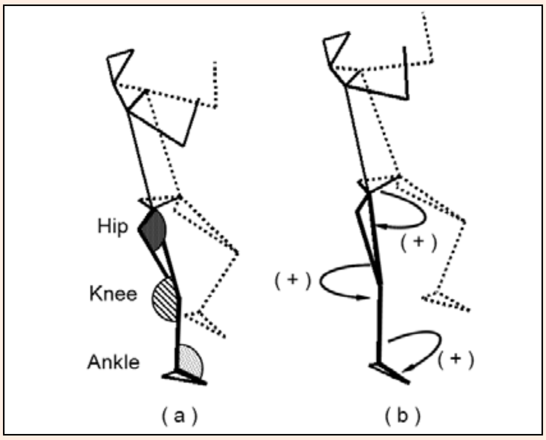

Figure 2. Joint angle and angular velocity of lower extremities. Joint angle **(a)** and angular velocity **(b)** of lower extremities in takeoff leg during takeoff phase. Angular velocity was defined as positive during extension in hip and knee joint and plantar-flexion, and negative during flexion and dorsiflexion.

Among the four trials carried out by the subjects, the highest jump trial in each of the DL or NDL was selected for further analysis. In this study, the jump height was calculated as the vertical height traveled by the marker attached to the sacral bone in the apex during the RSJ from a standing position. Joint angles and angular velocities of the lower extremities in the takeoff leg during takeoff phase, contact time (CT) to ground during the jump and maximal velocity in the running approach were calculated from the 3-D data (Figure 2). The CT was defined as from the landing of a heel to taking off from a toe, including the CG descent time (CT_{des}) and the CG ascent time (CT_{asc}) based on minimal vertical displacement of the CG (CG_{zmin}). The angle and angular velocity of the takeoff leg was analyzed for peak value in maximal (max), minimal (min), CG_{zmin} and average value of CG_{des} (Ave_{des}) and of CG_{asc} (Ave_{asc}).

Statistical analyses

Descriptive data are presented as means ± SDs. A Student's paired t-test was used to test the significance of the differences between the two legs in the measured variables. Using Pearson's product moment correlation analysis, linear correlation coefficients between the symmetry $index_{JH}$ and indices of kinematics data were calculated. The level of significance was set at $p < 0.05$. All data were analyzed using SPSS software (SPSS statistics 22, IBM, Japan).

Results

Jump height, running velocity and contact time

There was no significant difference in running velocity during approach to the RSJ between the trials of the DL (7.9 ± 0.5 $m \cdot s^{-1}$) and NDL (7.8 ± 0.4 $m \cdot s^{-1}$, Table 1). However, the jump height was significantly higher ($p < 0.001$) in the DL than in the NDL (Table 1). The CT for the DL was significantly shorter ($p < 0.05$) than that for the NDL (Table 1). The symmetry $index_{JH}$ was 6.3 ± 4.8 %, and it was over 11.1% (mean + 1 SDs) in 6 subjects, from 8.5 to 11.0% (mean + 0.5 SDs) in 5 subjects, from 1.5 to 3.9% (mean - 0.5 SDs) in 6 subjects, under 1.5% (mean - 1 SDs) in 5 subjects, and from 4.0 to 5.9% in the remainder (n = 5).

Joint angles and angular velocities

Table 2 summarizes descriptive data on joint angles for the DL and NDL. The min, Ave_{des}, Ave_{asc} and CG_{zmin} values of ankle angles were significantly larger in the DL than in the NDL (p < 0.05, 0.01). The min, Ave_{asc} and CG_{zmin} of knee angles were significantly larger in the DL than in the NDL ($p < 0.05$).

Table 3 summarizes descriptive data on joint angular velocity for the two legs. The Ave_{asc} of ankle joint angular velocity was significantly greater in the DL than in the NDL, and that of knee joint angular velocity was vice versa ($p < 0.05$).

Symmetry $index_{JH}$ and symmetry indices of kinematics

The symmetry $index_{JH}$ was not significantly correlated to those of running velocity and CT (Table 4). On the other hand, the symmetry $index_{JH}$ was positively correlated to the index of each of the min, Ave_{des} and Ave_{asc} values of the angle (p < 0.05, 0.01) and of the Ave_{asc} value of the angular velocity ($p < 0.05$) in the ankle joint (Table 5).

Discussion

The jump height and knee and ankle joint kinematics significantly differed between the DL and NDL. Furthermore, the symmetry $index_{JH}$ was positively correlated

Table 2. **Descriptive data on joint angle (degree) of lower extremities. Values are means (±SDs).**

		DL	NDL	Symmetry Index (%)
Hip Joint	Max	123.9 (8.9)	124.3 (6.3)	-.5 (7.6)
	Min	86.6 (9.7)	84.6 (9.2)	2.4 (8.5)
	Ave_{des}	88.0 (9.6)	86.3 (9.1)	1.9 (8.3)
	Ave_{asc}	103.4 (8.4)	102.5 (8.2)	.9 (7.1)
	CG_{zmin}	89.3 (9.7)	87.5 (9.2)	1.9 (8.3)
Knee Joint	Max	175.4 (3.2)	175.0 (3.2)	.3 (2.0)
	Min	139.2 (4.5) *	137.2 (5.6)	1.5 (3.7)
	Ave_{des}	158.7 (4.3)	157.5 (5.2)	.8 (2.4)
	Ave_{asc}	150.7 (4.2) *	148.9 (5.1)	1.3 (3.1)
	CG_{zmin}	152.4 (5.5) *	150.5 (6.3)	1.3 (3.4)
Ankle Joint	Max	124.9 (6.4)	123.5 (4.7)	1.1 (5.0)
	Min	96.9 (5.1) *	94.2 (5.0)	2.8 (6.7)
	Ave_{des}	107.4 (5.4) *	105.1 (5.4)	2.1 (4.9)
	Ave_{asc}	108.7 (5.2) *	106.4 (5.3)	2.1 (5.7)
	CG_{zmin}	112.7 (6.0) *	110.3 (6.2)	2.2 (5.2)

Max, maximal value; Min, minimal value; CG_{zmin}, value of minimal vertical displacement of the center of gravity; Ave_{des}, mean value from touchdown to CG_{zmin}; Ave_{asc}, mean value from CG_{zmin} to takeoff. * and * * indicate that difference between the dominant (DL) and non-dominant leg (NDL) is significant at $p < 0.05$ and 0.01, respectively.

with the index of each of the angle values, and angular-velocity, in only the ankle. These results support our hypothesis that the asymmetry of the RSJ performance can be associated with that of the behavior of the takeoff legs, notably in the ankle joint.

Table 4. **Descriptive data on correlation between the symmetry index $_{JH}$ and running velocity and contact time.**

		Symmetry Index	
		r	p
Running Velocity		.378	.083
Contact Time	CT	.315	.109
	CT_{des}	.171	.394
	CT_{asc}	.259	.191

Running Velocity, maximal value of the running approach velocity. $CT_{des,}$ Contact time from touchdown to minimal vertical displacement of the center of gravity (CG_{zmin}). CT_{asc}, Contact time from CG_{zmin} to takeoff. Symmetry index, symmetry index of the kinematics between the two legs. These values are correlations between the symmetry index$_{JH}$ and symmetry index of the kinematics. There were no significant correlations (N.S.) between the symmetry index$_{JH}$ and symmetry index of the running velocity or contact time.

For the knee joint, the min, Ave_{asc} and CG_{zmin} values of the angle were larger in the DL than in the NDL, although the Ave_{asc} of the angular velocity was greater in the NDL. This implies that, in the takeoff phase, the knee joint in the DL was in a more extended position as compared to the NDL. The jump height for high jumpers has been shown to be maximized when the knee joint of the takeoff leg is maintained in an extended position at touchdown (Greig and Yeadon, 2000). Knee kinematics at landing in a RSJ are an important factor affecting the ground reaction force (GRF) in vertical jumps (Wang, 2011). In jumps including a running or drop landing task, the decreased flexion of the maximal hip and knee angles at landing are linked to the increased vertical GRF (Decker et al., 2003; Yu et al., 2006). Taking these findings into account together with the current results, it may be assumed that the DL can produce a vertical impulse to the ground and effectively transmit the vertical GRF to the upper limb by keeping the leg straight (i.e., stiffen the knee joint) in order to jump high. However, it should be

Table 3. **Descriptive data on joint angular velocity (degree·sec^{-1}) of lower extremities. Values are means (±SDs).**

		DL	NDL	Symmetry Index (%)
Hip Joint	Max	307.1 (73.3)	322.7 (80.7)	-4.4 (28.7)
	Min	19.4 (32.2)	26.2 (49.8)	-6.8 (41.0)
	Ave_{des}	48.9 (37.0)	52.6 (47.7)	-2.1 (16.8)
	Ave_{asc}	191.7 (50.4)	201.4 (40.7)	-7.7 (27.3)
	CG_{zmin}	57.7 (37.3)	59.7 (42.7)	-5.4 (36.9)
Knee Joint	Max	525.4 (54.4)	520.0 (49.0)	.9 (11.0)
	Min	-326.0 (64.2)	-319.8 (38.2)	.9 (19.1)
	Ave_{des}	-198.9 (45.4)	-209.4 (49.3)	-4.9 (26.4)
	Ave_{asc}	122.1 (35.7) *	132.9 (31.3)	-9.7 (25.0)
	CG_{zmin}	-291.0 (41.8)	-303.5 (40.5)	-4.3 (15.8)
Ankle Joint	Max	481.6 (69.3)	473.0 (72.6)	1.6 (11.9)
	Min	-193.5 (32.5)	-196.3 (24.8)	-1.1 (14.2)
	Ave_{des}	272.9 (89.0)	257.8 (30.9)	16.8 (46.3)
	Ave_{asc}	81.6 (27.7) *	74.3 (24.1)	13.1 (66.9)
	CG_{zmin}	-14.0 (76.8)	-20.5 (71.0)	2.3 (55.1)

Max, maximal value; Min, minimal value; CG_{zmin}, value of minimal vertical displacement of the center of gravity; Ave_{des}, mean value from touchdown to CG_{zmin}; Ave_{asc}, mean value from CG_{zmin} to takeoff. * indicates that difference between the dominant (DL) and non-dominant leg (NDL) is significant at $p < 0.05$.

Table 5. **Descriptive data on correlation between the symmetry index $_{JH}$ and the joint angle and angular velocity of lower extremities.**

		Symmetry Index of Angle		Symmetry Index of Angular Velocity	
		r	p	r	p
Hip Joint	Max	-.036	.858	.014	.943
	Min	-.111	.580	-.118	.558
	Ave_{des}	-.145	.471	-.219	.273
	Ave_{asc}	-.166	.407	.137	.496
	CG_{zmin}	-.208	.297	-.175	.382
Knee Joint	Max	-.042	.835	.374	.055
	Min	-.255	.200	.328	.095
	Ave_{des}	-.357	.068	.297	.132
	Ave_{asc}	-.321	.102	.337	.085
	CG_{zmin}	-.373	.055	.170	.396
Ankle Joint	Max	.098	.628	.044	.828
	Min	.428 *	.026	.206	.303
	Ave_{des}	.412 *	.033	.077	.703
	Ave_{asc}	.522 **	.005	.406 *	.036
	CG_{zmin}	.349	.074	-.171	.393

Max, maximal value; Min, minimal value; CG_{zmin}, value of minimal vertical displacement of the center of gravity; Ave_{des}, mean value from touchdown to CG_{zmin}; Ave_{asc}, mean value from CG_{zmin} to takeoff. symmetry index, symmetry index of the kinematics between the two legs. These values are correlations between the symmetry $index_{JH}$ and symmetry index of the kinematics. * and * * indicate that correlation between the symmetry $index_{JH}$ and symmetry index of the kinematics is significant at $p < 0.05$, 0.01, respectively.

noted that, despite the significant differences between the two legs for the kinematics of the knee joint, their symmetry indices were not associated with the symmetry $index_{JH}$. This suggests that the observed bilateral differences in the kinematics of the knee joint are not a determinant factor for the symmetry $index_{JH}$ in RSJ.

For the ankle joint, the min, Ave_{des}, Ave_{asc} and CG_{zmin} values of the angle and the Ave_{asc} of angular velocity were also greater in the DL than in the NDL. This indicates that, in the takeoff phase, the ankle joint in the DL maintained a more plantar flexed position than that in the NDL, with a greater angular velocity in the push off phase. This may be linked to the result that the CT was significantly shorter in the DL than in the NDL, while the run-up velocity was similar in both legs because it is known that the stiffness of the ankle joint plays an important role in jumping high and taking off in a short time in the explosive jumps and drop jumps (about 0.2 sec, Yoon et al., 2007). Also, Stefanyshyn and Nigg (1998) reported that the ankle joint, as compared to the knee and hip, was the largest energy absorber and generator in RSJ and long jump. In the rebound jumps, the stiffness of the ankle during the eccentric phase is positively associated to the ankle joint torque at the turning point from an eccentric to a concentric activity (Yoon et al., 2007). The ankle torque also showed significant positive correlation with jump height (Yoon et al., 2007). Farley and Morgenroth (1999) reported that, during hopping in place, the stiffness of the ankle was 1.9 times greater while that of the knee was 1.7 times greater at the maximal height than in the preferred height jump (Farley and Morgenroth, 1999). Considering these findings, the stiffness of the ankle compared to the knee clearly plays an important role in explosive jumps including RSJ and standing jump. In the current results, therefore, the observed differences between the two legs in the angle and angular velocity of the ankle joint (i.e., a straightness of the ankle and explosive bounding from CG_{zmin}) suggest that the landing energy absorbed and the energy used for jumping are smaller in the NDL (vs. the DL), and consequently, this may have resulted in the difference in jump height for each leg. At the same time, the current result that the symmetry indices of min, Ave_{des} and Ave_{asc} for ankle angle, and of Ave_{asc} for the joint angular velocity, were significantly associated with the symmetry $index_{JH}$ suggests that the bilateral difference in the behavior of the joint directly influences the magnitude of the difference in the performance of RSJ.

It is known that basketball players have a leg which is used preferably for performing a RSJ (Schiltz et al., 2009). The DL for the players develops in the process of training to a professional level (Theoharopoulos and Tsitskaris, 2000). However, a limb asymmetry of over 10% can be considered a risk factor for inducing sport-related injuries (Brumitt et al., 2013; Schiltz et al., 2009). Considering this, it may be assumed that players with a large asymmetry in their performance have a greater risk of sport-related injuries, but this would be limited to regular players. In contrast, in the current study, only 3 of the 11 players who had an asymmetry of the symmetry $index_{JH}$ over 8.5% (+ 0.5 SDs) were regular players who were starters or replaced the starters in competitive games. All 11 players who scored less than 3.9% (- 0.5 SDs) were regular, while 8 players were non-regulars of those with asymmetry over 8.5%. Finally no one was less than 3.9%. These results refute the previous report (Theoharopoulos and Tsitskaris, 2000) cited above and indicate that, at least at the collegiate level, basketball players with a large asymmetry in their jump performances would be mainly judged as non-regulars.

Conclusion

The current results indicate that, for collegiate basketball players, the asymmetry in the height of a RSJ can be attributed to the joint kinematics of the ankle during the takeoff phase, which may be associated with the ability to effectively transmit run-up velocity to jump height. Additionally, basketball players who have a large asymmetry of the RSJ at the collegiate level could be assessed as non-regulars judging by the magnitude of asymmetry rather than jump height.

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Key points

- Asymmetry of height during running single leg jump between two legs is due to the behavior of the ankle joint (i.e. stiffer the ankle joint and explosive bounding).
- The dominant leg can transmit run-up velocity into the vertical velocity at takeoff phase to jump high compared with the non-dominant leg.
- Basketball players who have a greater asymmetry of the RSJ at the collegiate level could be assessed as non-regulars judging by the magnitude of asymmetry.

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