CHARACTERISTICS OF THREE LOWER LIMB JOINT KIMETICS DURING THE REBOUND JUMP IN FEMALE ATHLETES

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The aim of this study was to describe the lower limb muscle strength and power exertion characteristics of female athletes during the rebound jump (RJ) test. Forty-eight female soccer and basketball players performed the test, while the Quick Motion Analysis System was used to calculate joint kinetics (torque, power, and work of the three lower limb joints) in real time with high precision. A high correlation was found between the RJ index and contact time, jump height. In addition, a low correlation was found between jump height and contact time. However, the mechanical variables related to contact time and jump height were different. Therefore, for female athletes, the ability to shorten the contact time and the ability to obtain a jump height are considered independent abilities.

KEYWORDS: stretch-shortening cycle movement, joint kinetics, assessment, plyometrics.

INTRODUCTION: Sprinting and jumping movements in ball sports involve the stretch-shortening cycle (SSC) movement of the lower limb muscles. Thus, the ability to exert muscle strength and power during SSC (Bobbert, 1990) movements in the lower limbs is widely used in research and practice, and the rebound jump (RJ) test is a commonly used evaluation tool. The RJ test evaluates performance variables such as contact time and jump height, with results reported as the RJ index (Zushi et al., 1993), a measure of the exertion of force generated by the three joints of the lower limbs. Combining joint kinetics measures with the evaluation index, provides a more detailed assessment of lower limb muscle strength and power exertion ability (Zushi et al., 2017). To date, research on the use of RJ testing to measure lower limb muscle strength and power exertion ability has focused on male athletes (Bobbert et al., 1987). However, it is known that females have a larger knee valgus angle when jumping than males (Jacobs et al., 2007), and injuries to the knee joint during exercise are higher among female athletes (Myer et al., 2006). Therefore, the lower limb power exertion ability of female athletes merits separate assessment. The aim of this study was to clarify the lower limb joint kinetics characteristic of female athletes during the RJ test.

METHODS: Participants were 48 female college athletes (28 soccer players, 20 basketball players) with the following characteristics (age, 20.1±1.0 years; height, 164.6±7.2 cm; mass, 58.9±7.3 kg). After a warm-up, the participants performed a rebound jump (RJ) at least three times. RJ was repeated in a vertical direction using both legs in a standing position. The participants were orally instructed to shorten the ground contact time as much as possible and to jump as high as possible. The three-dimensional coordinates of 13 retroreflective markers affixed to the participant's body were collected using a Vicon T20 system (Vicon Motion System, Ltd.) with 10 cameras operating at 250 Hz. The ground reaction force was obtained with a force platform (Kistler, Inc. 9287C, 0.9m×0.6m) operating at 1000 Hz. The contact time and flight time were calculated with the point where the vertical ground reaction force was 10 N or less as the takeoff. The jump height (m) was calculated by substituting the flight time (tair, sec) and the gravitational acceleration ($g = 9.81$, m / s²) into the following equations. Jump height $= (g \cdot tair^2)\, 8^{-1}$. The RJ index was calculated by dividing the jump height by the contact time (Zushi et al., 1993). The trial with the highest RJ index was selected for further analysis. The ICC of the RJ index in trial was 0.938. Joint kinetics (joint torque, power, and work) of the lower leg (dominant leg) were calculated using inverse dynamics. The ankle joints were analyzed for plantar flexion and dorsiflexion, and the knee and hip joints were analyzed for extension and flexion. Joint kinetics were divided into a first half and a second half of take-off based on the lowest point of the center of gravity. In this study, we used the Quick Motion Analysis System. This system automatically calculates and reports the above-mentioned data immediately after the RJ movement. Relationships between variables were determined using Pearson's correlation test. Statistical significance was set at $p < 0.05$, 0.01.

RESULTS & DISCUSSION: The correlation coefficients between the RJ index and contact time, and RJ index and jump height were statistically significant, while a significantly negative correlation was noted between contact time and jumping height (Figure 1; *r = 0.889, -0.756, -0.384, respectively; p < 0.05*). In previous studies with male athletes, no significant relationship was found between jump height and contact time; therefore, we propose that the results of this study may indicate a sex-specific characteristic of female athletes.

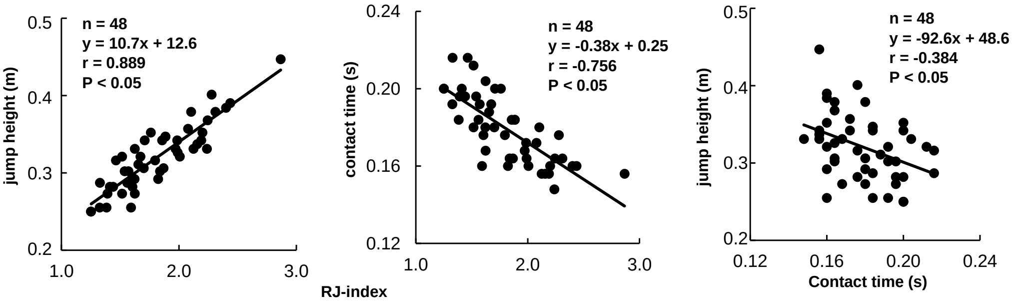

Figure 1. Relationship between performance variables on the rebound jump test.

Table 1 shows the relationship between performance variables and joint kinetics during RJ. For joint torque, significant correlations were found between the performance variables and eccentric ankle torque, concentric hip joint torque. In addition, for each performance variable, the eccentric ankle joint torque showed the highest correlation coefficient among the three joints, and the hip joint showed the highest correlation coefficient for RJ index among the three joints. Moreover, the correlation coefficient between each performance variable (RJ index, contact time, jump height) and negative ankle power was largest (*r = -0.703, 0.655, -0.532, respectively; p<0.05*), and there was also a significant correlation between each performance variable and positive ankle power. Conversely, a significant negative correlation was found between contact time and negative knee work (*r = -0.321, p <0.05*). On the other hand, jump height was significantly correlated with positive hip power and work (*r* = 0.560, 0.535, respectively; $p < 0.05$). Previous studies have shown that the ankle joint has the advantage of storing elastic energy by rapidly stretching the surrounding muscles and Achilles tendon and then reusing that energy during shortening to reduce exercise execution time (Zushi and Takamatsu, 1995). On the other hand, the hip joint has structural characteristics that are advantageous for exerting a large force when muscle groups with a large cross-sectional area, such as the gluteus maximus and hamstrings are activated (Zushi et al., 1998). While these results were obtained for male athletes, similar findings have been obtained for RJ performance in female athletes. In addition, a significant correlation coefficient was found between the performance variables and eccentric knee torque. A study including male athletes reported that a large knee joint angle may lengthen the contact time in RJ (Zushi and Takamatsu, 1996). On the other hand, although the movements are different, it has been reported that eccentric extensor muscle strength in the knee joint of female athletes measured during constant velocity training affects the shortening of the directional change speed in an 180° direction-change run, as well as the contact time at the time of the direction change. (Jones et al., 2019). Therefore, female athletes may be required to exert greater force not only in the ankle joint, but also in the knee joint in an eccentric manner in order to shorten the contact time during RJ. Table 2 shows the kinetic variables of the three joints of the lower limbs for the two athletes who showed similar RJ performance. The performance variables of the two athletes were higher than the average value, and among the participants, the athletes

Table 1. Relationship between the performance variables and joint kinetics.

		RJ-index		Contact time		Jump height	
		r	*p value*	r	*p value*	r	*p value*
ECC.torque (Nm/kg)	Hip	0.475	0.00**	-0.352	0.01*	0.426	0.00**
	Knee	0.530	0.00**	-0.352	0.01*	0.491	0.00**
	Ankle	0.616	0.00**	-0.565	0.00**	0.438	0.00**
CON.torque (Nm/kg)	Hip	0.542	0.00**	-0.368	0.01*	0.515	0.00**
	Knee	0.150	0.31	0.017	0.91	0.233	0.11
	Ankle	0.478	0.00**	-0.356	0.01*	0.438	0.00**
Negative power (W/kg)	Hip	-0.297	0.04*	0.196	0.18	-0.309	0.03*
	Knee	-0.150	0.31	-0.007	0.96	-0.223	0.13
	Ankle	-0.703	0.00**	0.655	0.00**	-0.532	0.00**
Positive power (W/kg)	Hip	0.531	0.00**	-0.255	0.08	0.560	0.00**
	Knee	0.055	0.71	0.003	0.99	0.092	0.54
	Ankle	0.577	0.00**	-0.499	0.00**	0.503	0.00**
Negative work (J/kg)	Hip	-0.004	0.98	-0.181	0.22	-0.155	0.29
	Knee	0.142	0.33	-0.321	0.03*	-0.024	0.87
	Ankle	-0.333	0.02*	0.038	0.80	-0.456	0.00**
Positive work (J/kg)	Hip	0.477	0.00**	-0.178	0.23	0.535	0.00**
	Knee	0.059	0.69	0.160	0.28	0.206	0.16
	Ankle	0.464	0.00**	-0.284	0.05	0.503	0.00**

ECC. ; Eccentric, CON.; Concentric *; p < 0.05: **; p < 0.01
r < 0.2; Few, 0.2 ≦ r < 0.4; Low, 0.4 ≦ r < 0.7; Moderate, r ≧0.7; High

Table 2. Joint kinetics of two athletes showing similar RJ performance.

		All Sub. (n=48)	Sub. A	Sub. B
Performance variable	RJ index	1.814 ± 0.357	2.125	2.157
	Jump height (m)	0.320 ± 0.043	0.331	0.337
	Contact time (s)	0.179 ± 0.018	0.156	0.156
ECC.torque (Nm/kg)	Hip	1.62 ± 0.75	3.38	0.80
	Knee	2.10 ± 0.52	2.22	3.05
	Ankle	2.46 ± 0.42	3.55	2.20
CON.torque (Nm/kg)	Hip	1.05 ± 0.47	1.60	0.33
	Knee	1.84 ± 0.41	1.33	2.05
	Ankle	2.21 ± 0.29	2.39	2.24
Negative power (W/kg)	Hip	-2.86 ± 1.73	-1.63	-5.13
	Knee	-7.99 ± 2.61	-5.53	-14.56
	Ankle	-16.53 ± 5.04	-32.89	-20.65
Positive power (W/kg)	Hip	3.43 ± 1.77	3.72	1.07
	Knee	10.35 ± 3.00	8.16	14.53
	Ankle	13.16 ± 2.54	15.99	13.25
Negative work (J/kg)	Hip	-0.16 ± 0.10	-0.04	-0.11
	Knee	-0.60 ± 0.23	-0.38	-0.98
	Ankle	-1.10 ± 0.20	-1.42	-0.88
Positive work (J/kg)	Hip	0.34 ± 0.20	0.35	0.08
	Knee	0.72 ± 0.20	0.69	0.92
	Ankle	1.34 ± 0.22	1.67	1.45

ECC.; Eccentric, CON.; Concentric
All.sub; the average value of the subjects in this study

each had an excellent RJ index. Participant A showed the same tendencies as the overall group, with eccentric torque of the three lower limbs, concentric torque of the hip and ankle, and ankle power and work, and positive hip work being higher than the average. On the other hand, in Participant B, the eccentric torque of the ankle joint, the positive power of the hip joint, and the positive work reported lower values than participant A and the overall group mean value, and the knee joint kinetic values were higher. Taken together, these results suggest that the knee joint may not be correlated to the RJ index. Unlike the overall tendency, participant B has characteristics suggesting that the muscles related to the knee joint were more engaged during RJ testing. We suggest that it is effective to use not only performance variables but also joint kinetics in order to assess the lower limb joint kinetics characteristics of athletes.

CONCLUSION: In this study, we provided additional detail on the lower limb joint kinetics characteristics of female athletes by lower limb joint kinetics and performance variables in RJ.

(1) We observed a relationship between contact time and jump height in female athletes; this has not been noted in male athletes yet.

(2) During the eccentric phase, female athletes showed characteristic use of the extensor muscles of the ankle and knee joint seemed to provide an advantage in contact time.

(3) Even when RJ performance is similar, the characteristics of the kinetics of the three joints of the lower limbs may differ between female athletes. Therefore, in order to assess a female athlete's ability to exert muscular strength and power, specific detail of the kinetics of the three joints is needed.

In previous studies, the assessment of lower limb joint kinetics characteristics by RJ has been conducted predominantly in male athletes. However, the findings of this study show that it is also possible to assess lower limb joint kinetics characteristics using RJ in female athletes. On the other hand, female athletes may have different performance variables results than male athletes, so it may be necessary to set standard values for sex-specific assessment in each variable in the future.

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ACKNOWLEDGEMENTS: This work was supported by a Grant-in-Aid for JSPS Research Fellow grant number 20K23310.