EFFECT OF LEG STIFFNESS DURING REBOUND JUMP ON SPRINT RUNNING KINEMATICS AND KINETICS

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We investigated the relationship between stiffness in rebound jump (RJ) and kinematics and kinetics of the support- and swing-leg in sprint running (SP). We included 13 male track and field athletes performing maximal effort SP and RJ. During the support phase, kinematics, kinetic, and leg stiffness parameters were calculated using a force platform and data from a high-speed video camera that recorded movement in the sagittal plane. A significant correlation was observed between SP and RJ for stiffness (r = 0.683). In SP, stiffness was significantly correlated with contact time (r = -0.659), mean joint torque at the ankle (r = 0.703) and knee (r = -0.726) joints, CG (center of gravity) -toe distance (r = -0.818), and the swing-leg angle (r = -0.676) at touch down. Based on our results, kinematics and kinetics correlated with stiffness in SP are affected by RJ stiffness.

KEYWORDS: kinematics, kinetics, support-leg, swing-leg, plyometric training.

INTRODUCTION: Sprint running (SP) is critical for high performance in many sports. It is necessary to increase the mechanical output of lower-limb muscles during the support phase to improve sprint performance. Plyometric training using jump exercises can increase mechanical output in SP (Kariyama and Zushi, 2016; Young, 2006). Typical jump exercises are bounce- or rebound-type double-leg jumping in the vertical direction including drop jump and repetitive rebound jump (RJ).

Our legs exhibit characteristics similar to those of the spring during SP and RJ. In particular, the spring-mass model, which consist of body mass and a linear leg spring supporting the body mass, is used to model the musculoskeletal structure (Blickhan, 1989). The stiffness of the leg spring is an important factor for sprint performance (Brughelli and Cronin, 2008). Plyometric training using jump exercises, such as RJ, increases stiffness in SP and sprint velocity. To our knowledge, no study has investigated the effect of stiffness in RJ on sprint motion, including kinematics and kinetics, in SP. We sought to assess the relationship between stiffness in RJ, and kinematics and kinetics of the support- and swing-leg in SP.

METHODS: Thirteen male track and field sprinters and jumpers (age, 22.0 ± 0.9 years; height, 1.76 ± 0.05 m; and mass, 68.19 ± 4.73 kg) performed SP and RJ at maximal effort. They were screened for injuries that could affect SP and RJ performance. All participants performed SP and RJ as part of their training programs and were familiar with all experimental trials. The Ethics Committee for the Institute of Health and Sport Sciences, University of Tsukuba, Japan approved all study procedures.

For SP, all participants wore their spiked shoes and performed 60-m sprints. A starting mark was used to allow the participants to strike the force plate without altering their technique immediately before contacting the force plate. Based on previous testing sessions, the mark was located approximately 45 m before the force plate. For the RJ, participants wore their training shoes without spikes, which they usually wore during plyometric training. The RJ consisted of five repeated rebound-type jumps in the vertical direction with a double-leg takeoff from a standing position. Participants were orally instructed to jump as high as possible and minimize ground contact time.

After warming-up, participants performed SP and RJ at least twice. Participants were recorded in the sagittal plane with a high-speed video camera (EX-F1, 300 fps; Casio, Tokyo, Japan). Ground reaction force was obtained using a one force platform (9287B 0.9 m × 0.6

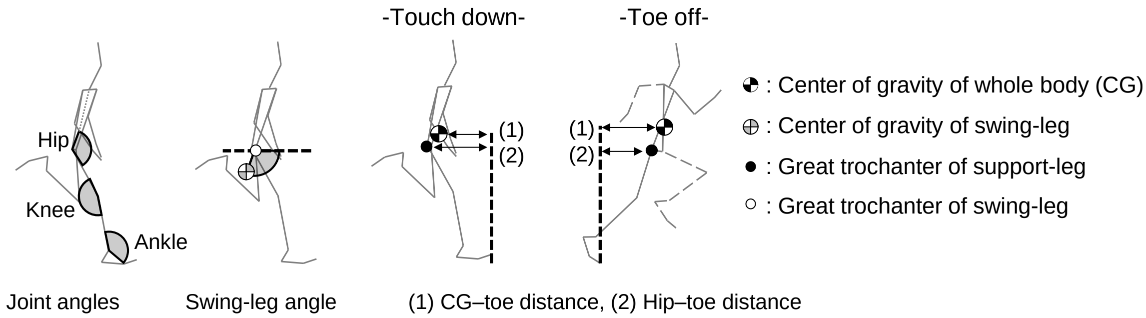

Figure 1: Definition of the angle and distance variables in sprint running.

m; Kistler Instrumente AG, Winterthur, Switzerland; 1,000 Hz) for the RJ and three force platforms (9287B, 0.9 m × 0.6 m; 9281A, 0.6 m × 0.4 m; 9281C, 0.6 m × 0.4 m; 1,000 Hz) for SP. The support phase was divided into two parts: the eccentric phase, from the point of touchdown to the lowest point of the center of gravity of the body (CG); and the concentric phase, from the lowest point of CG to toe-off.

Twenty-three body points and four calibration markers were digitized. The digitized coordinates were converted into real coordinates using four reference markers placed on the ground. Kinematics were calculated from the coordinates, and the joint torque of the support leg, using inverse dynamics. In SP, swing-leg angle, CG–toe distance, hip–toe distance, from the checkpoint of coaching for SP, were calculated (Fig.1). Leg stiffness was calculated using a spring-mass model, which consist of CG and ball of the foot. It was also calculated as the ratio of mean ground reaction force during eccentric phase to compression of the spring-mass model.

In SP, sprint velocity, step length, and frequency of a single step were calculated for each sprint trial using the information from the 300-fps camera. A step cycle was defined as the period from the moment of touchdown on the force plate by one foot until plate contact by the contralateral foot. Velocity was defined as the horizontal velocity at the CG at toe off. Step length was calculated as the distance between toe points at the force plate after touchdown in two consecutive steps, and step frequency was calculated by dividing the velocity by the step length.

The Pearson's correlation coefficient was used to determine the relationships between variables during SP and RJ. The significance was set to $P < 0.05$.

RESULTS: For SP, the sprint velocity was 9.63 ± 0.46 m/s (range: 8.86–10.50), step-length 2.28 ± 0.12 m (range: 2.06–2.49), and step-frequency 4.23 ± 0.29 Hz (range: 3.84–4.80). For RJ, the RJ index was 3.246 ± 0.448 (range: 2.585–3.991), jump height 0.502 ± 0.056 (range: 0.397–0.592), and contact time 0.156 ± 0.014 s (range: 0.138–0.189).

Fig. 2 shows the relationship between SP and RJ for stiffness. There was a significant positive correlation in stiffness. Table 1 shows the relationship between stiffness in SP and variables in SP. There was a significant correlation between stiffness and contact time, mean joint torque at ankle and knee joints in the eccentric and concentric phases, CG-toe distance at touch down, hip-toe distance at touch down, and swing-leg angle at touch down. Fig.4 shows the relationship between stiffness in SP and contact time in RJ. There was a significant negative correlation. Moreover, in RJ, there was a significant negative correlation between stiffness and contact time.

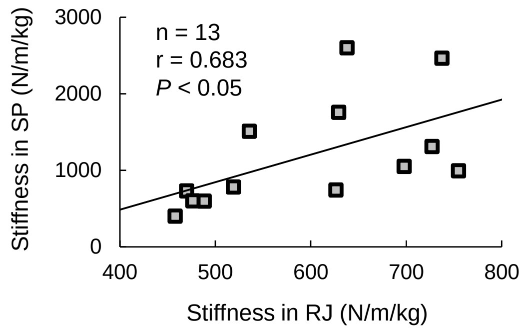

Figure 2: Relationship between sprint running and rebound jump for stiffness.

Table.1 Relationship between stiffness in sprint running and variables in sprint running.

Variables			Mean ± SD	Correlation coefficient vs stiffness
Sprint velocity (m/s)			9.63 ± 0.46	0.258
Step frequency (Hz)			4.23 ± 0.29	0.266
Step length (m)			2.28 ± 0.12	-0.076
Contact time (s)			0.10 ± 0.01	-0.659 *
Air time (s)			0.38 ± 0.03	0.036
Mean Joint torque (Nm/kg)	Eccentric	Hip	3.69 ± 1.19	0.048
		Knee	1.96 ± 0.68	-0.726 *
		Ankle	2.29 ± 0.70	0.703 *
	Concentric	Hip	0.88 ± 0.63	0.387
		Knee	1.64 ± 0.61	-0.646 *
		Ankle	2.56 ± 0.55	0.591 *
CG-toe distance (%)		Touch down	20.77 ± 2.68	-0.818 *
		Toe off	27.77 ± 2.86	-0.408
Hip-toe distance (%)		Touch down	24.00 ± 2.08	-0.641 *
		Toe off	23.11 ± 3.27	-0.179
Swing-leg angle (deg.)		Touch down	96.01 ± 13.51	-0.676 *
		Toe off	36.66 ± 10.37	-0.155

*: $P < 0.05$

DISCUSSION AND IMPLICATIONS: Stiffness was significantly correlated with SP and RJ (Fig.2). Stiffness in SP was affected by ankle joint torque. During SP, the ankle joint plays an important role in achieving high performance by producing a large vertical force (Stefanyshyn and Nigg, 1998), reducing ground contact time, and enhancing mechanical efficiency (Kuitunen et al., 2002). These findings indicate that the ankle joint is important for SP performance. In RJ, Kariyama and Zushi (2015) showed that stiffness was also affected by ankle joint torque. Performance in RJ is known to be primarily affected by the ankle joint (Yoon et al., 2007). Moreover, ankle-joint functions that are important for sprinting (enhancing mechanical efficiency and reducing ground contact time) are also important for RJ (Yoon et al., 2007). Collectively, these results explained the significant relationship observed between SP and RJ in stiffness.

In SP, contact time was significantly negatively correlated with stiffness, although sprint velocity was not significantly correlated with stiffness. Contact time is primarily dependent on the leg geometry and sprint velocity. Therefore, stiffness in these study participants was not directly important for SP but was indirectly important for SP since it shortened the contact time. Additionally, a significant

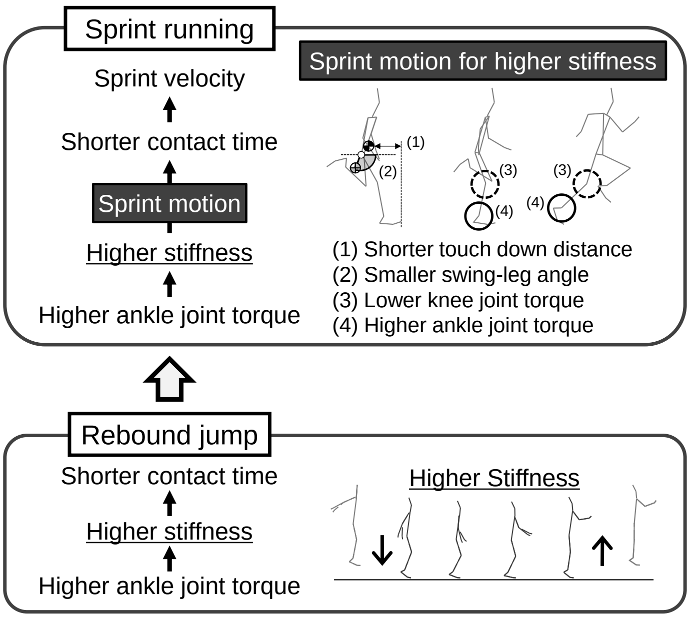

Figure 3: Hierarchical structure model between sprint running and rebound jump for stiffness.

correlation was also noted between stiffness and knee joint torque. However, the correlation coefficient was negative. In SP, knee extension is not necessary for achieving high velocity, because knee extension negatively affects sprint velocity (Ito et al., 2008). In addition, knee-joint torque does not contribute substantially to power generation during the latter part of the support phase (Bezodis et al., 2008). These data indicate that knee-joint torque may not be important for achieving a shorter contact time in SP. Moreover, CG-toe distance and the swing-leg angle at touch down were significantly negatively correlated with stiffness in SP. These results indicate that these movements are affected by stiffness characteristics.

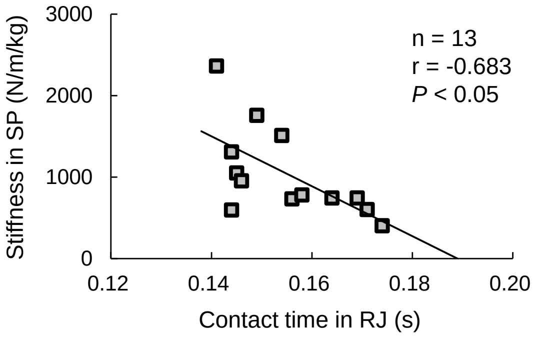

Figure 4: Relationship between stiffness in sprint running and contact time in rebound jump.

Our results indicate that plyometric training using RJ may be useful for improving kinematics and kinetics of support- and swing-leg by increasing stiffness during SP (Fig.3). Future studies are needed to test the effects of RJ on plyometric training, especially after considering our findings. In this study, we investigated the characteristics of SP by using stiffness. However, stiffness cannot be used in a field test because the calculation for stiffness needs an experimental instrument. Therefore, we investigated the relationship between stiffness in SP and contact time in RJ, which can be calculated using the jump-mat system in a field test. There is a significant relationship between stiffness in SP and contact time in RJ (Fig.4). Therefore, in a field test, contact time in RJ can estimate stiffness in SP.

CONCLUSION: We demonstrated a relationship between SP and RJ in stiffness. In SP, the kinematics and kinetics of the support-leg and swing-leg were associated with stiffness. Based on our results, the kinematics and kinetics correlated with stiffness in SP could also be affected by RJ stiffness. Understanding the characteristics of stiffness in RJ is important for plyometric training to change these kinematics and kinetics in SP. Moreover, stiffness in SP could be estimated using contact time in RJ during a field test.

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