THE EFFECT OF INCREASING JUMP STEPS ON THE TAKE-OFF LEG IN BOUNDING

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The purpose of this study was to clarify the effect of increasing jump steps in bounding in terms of three-dimensional joint kinetics for the take-off leg. Eleven male track and field athletes performed horizontal bounding from the standing posture. Kinematic and kinetic data were recorded using a Vicon T20 system (250 Hz) and force platforms (1,000 Hz). As jump steps increased, the joint kinetics characteristics are as follows: 1) ankle plantar flexion torque and knee extension torque and power increased, but hip extension torque and power did not increase; and 2) hip external torque and power (negative and positive) increased, particularly hip abduction torque and power. Therefore, in bounding initiated from the standing posture, ankle and knee joint kinetics from the sagittal plane and 3-dimensional hip joint kinetics increased, particularly on hip adduction-abduction axis.

KEY WORDS: plyometric training, joint kinetics, 3-dimentional motion analysis.

INTRODUCTION: In many sports, high power output of the lower extremity is important for improving performance. Plyometric training (PT) is widely used for enhancing power output. Single-leg take-off for horizontal direction is an important component of many skills in several sports. Hence, bounding exercises (single-leg jumps for the horizontal direction) are often used for PT. There are various types of bounding. In particular, bounding from the standing position is often implemented. Several studies have investigated the kinematics and kinetics with regard to bounding (Holm et al., 2008; Mero and Komi, 1989; Michael and Robert, 2009), but very few studies have studied the joint kinetics (Kariyama and Zushi, 2014). Moreover, no study has investigated joint kinetics of the effect of an increment jump step on the take-off leg in bounding from standing position. For proper execution and specificity of plyometric training, it is important to have an understanding of joint torque and power of the take-off leg. Plyometric training effects are affected by joint torque and power. The purpose of this study was to clarify the effect of jump step on take-off leg during bounding.

METHODS: Participants were 11 male track and field jumpers (age, 20.27 ± 1.35 years; height, 177.59 ± 6.04 cm; mass, 69.82 ± 4.92 kg). Informed written consent was obtained from all the participants' prior to participation. The Ethics Committee for the Institute of Health and Sport Sciences, University of Tsukuba, Japan approved all study procedures.

Participants performed bounding from the standing position. Bounding was started from a double-leg standing position, and the participants tried to cover the longest distance by performing a series of 7 forward alternating single-leg jumps. The 1st, 3rd, and 5th steps in bounding were performed for a minimum of three times to achieve successful trial that were analyzed in this study. In order to strike the force plate at each step, start position was adjusted between each trial. The trial was successful if the athlete was able to strike the force plate, and the highest jump distance from each step (1st, 3rd, and 5th step) was selected for further analysis.

The three-dimensional coordinates of 47 retro-reflective markers fixed on the body were collected by the Vicon T20 system (Vicon Motion System, Ltd.) using ten cameras operating at 250 Hz. The ground reaction force was measured with a force platform at 1,000 Hz. The joint angle and angular velocity of the take-off leg were calculated. The coordinates were smoothed by a Butterworth digital filter with optimal cut-off frequencies of 7.5–10.5 Hz, which were determined using the residual method. The location of the center of mass and inertia of each segment was estimated based on the body segment parameters for Japanese athletes, as described by Ae (1996).

The joint torque and joint power of the take-off leg were calculated using inverse dynamics. These were calculated around the plantarflexion-dorsiflexion axis in the ankle joint; around the extension-flexion axis in the knee joint; and around the extension-flexion, abduction-adduction, and external rotation-internal rotation axes in the hip joint. The time series data of all participants were normalized to the time of take-off phase 0%–100% and subsequently averaged.

A one-way multiple comparisons (repeated measure, Bonferroni) was used to determine the differences between the jump steps in each dependent measure. The significance was accepted at $P < 0.05$.

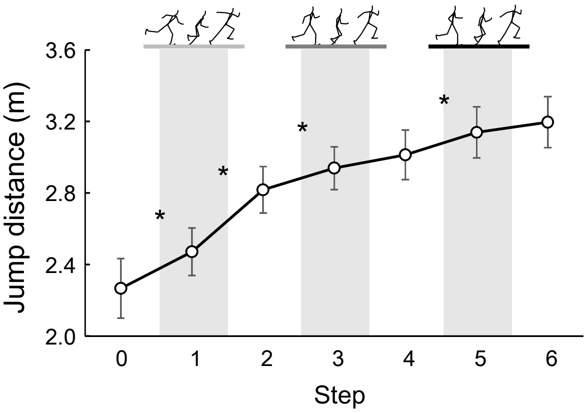

Figure 1: Change in jump distance with increasing jump steps.

RESULTS: Figure1 shows the changes in jump distance with increasing jump steps. Jump distance increased until the 6th step. Figure 2 shows the averaged patterns of the vertical, horizontal, lateral ground reaction forces. In the early phase, the ground reaction force in all directions increased with increasing jump steps and demonstrated a spike-shaped pattern. Table 1 shows the jump performances and ground reaction forces with increasing jump steps. Vertical impulse of the ground reaction forces during later phase did not increase. Moreover, horizontal negative impulse increased, and horizontal positive impulse and horizontal acceleration decreased. Figure 3 shows the averaged patterns of joint angular velocity, joint torque, and joint power. Table 2 shows the peak joint torque and power about the ankle, knee, and hip joint. As jump steps increased, the ankle joint torque and power significantly increased, knee joint torque and power significantly increased until 3rd step; however, the hip joint torque and power around the extension-flexion axis did not significantly change. Hip external torque and power around the external–internal axis increased and hip abduction torque and power increased. The effect size about the hip abduction-adduction axis was larger than that about the hip external–internal axis (Table 2).

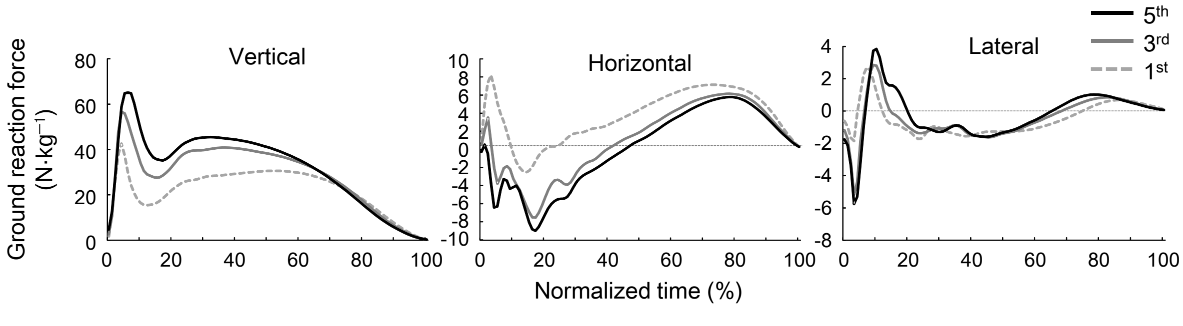

Figure 2: Averaged patterns of ground reaction forces.

DISCUSSION: Jump distance in bounding increased with increase in jump steps; however, this increment was stopped at the 6th step (Figure 1). This was caused by decrease in horizontal acceleration impulse (positive value), and increase in horizontal braking impulse (negative value). Therefore, horizontal acceleration was almost zero by the 5th step (Table 1). The above results along with the decreased contact time suggest that achieving the horizontal acceleration impulse became difficult with an increase in jump steps. Thus, jump distance demonstrated no increase by the 6th step.

It appeared that the sagittal plane movement, particularly in hip extension, directly affects the magnitude of the vertical and horizontal ground reaction forces. In the sagittal plane, on the take-off leg, the ankle plantar flexion torque and knee extension torque and power increased, but hip extension torque and power did not increase (Figure 2 & Table 2). These results indicate that ankle and knee joint kinetics are more important with respect to increasing bounding at high horizontal velocity, whereas the hip joint kinetics around the extension−flexion axis are important for getting the ground reaction force at all jump steps.

The hip external torque and power (negative and positive) exerted on the take-off leg increased, but the effect size was small (Table 2). Conversely, the hip abduction torque and power increased. Additionally, the patterns of hip abduction torque and power were similar to the vertical and lateral ground reaction force (Figure 2 & 3). In bounding at the 5th step, hip abduction torque and power may play an important role by resisting the impact force (ground reaction force) and maintaining the lateral balance (Kariyama and Zushi, 2013). These results suggest that although hip abductors are more important for horizontal high-speed take-off (5th step), they may also be important for low-speed take-off (1st and 3rd steps).

Table1 Comparison of jump performance and ground reaction forces (Mean ± S.D.)

	1stHSJ	3rdHSJ	5thHSJ	Difference	Effect Size (Partial η^2)
Jump distance (m)	2.47 ± 0.13	2.94 ± 0.12	3.14 ± 0.14	1st < 3rd < 5th	0.98
Contact time (s)	0.254 ± 0.013	0.201 ± 0.013	0.185 ± 0.015	1st > 3rd > 5th	0.96
Ground reaction force impulse ($N \cdot s \cdot kg^{-1}$)					
Vertical_former phase	2.67 ± 0.24	2.83 ± 0.21	2.86 ± 0.22	1st < 5th	0.43
Vertical_later phase	3.03 ± 0.17	3.03 ± 0.25	3.07 ± 0.29	n.s.	0.03
Horizontal_negative value	-0.08 ± 0.02	-0.32 ± 0.08	-0.41 ± 0.13	1st > 3rd > 5th	0.84
Horizontal_positive value	1.04 ± 0.13	0.53 ± 0.08	0.41 ± 0.07	1st > 3rd > 5th	0.97
Horizontal_accelaration	0.96 ± 0.14	0.21 ± 0.14	0.00 ± 0.17	1st > 3rd > 5th	0.97

<, >; *P* < .05

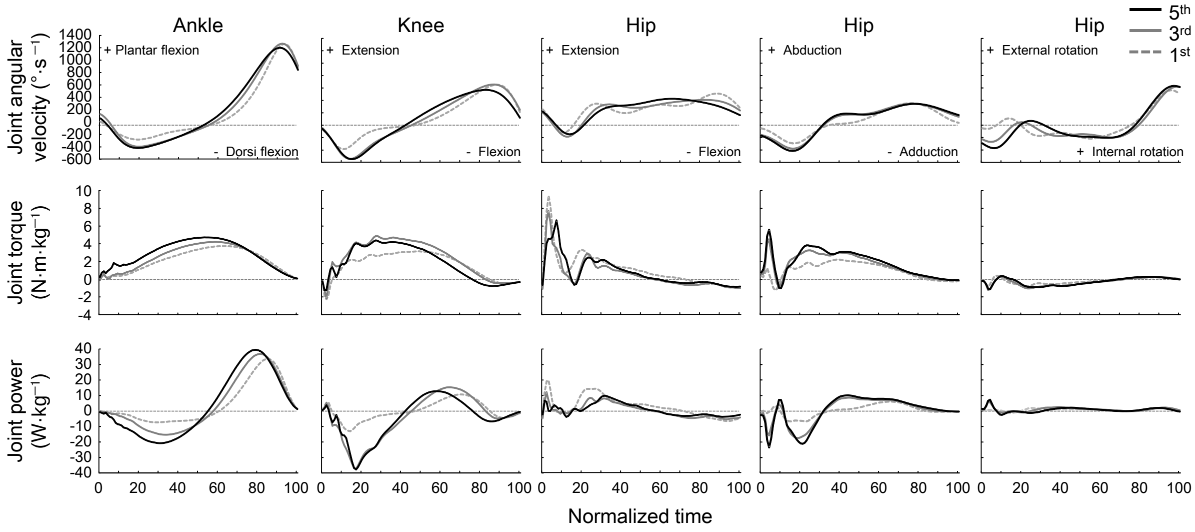

Figure 3: Averaged patterns of joint angular velocity, joint torque, and joint power about the ankle, knee, and hip joints.

Table2 Comparisons of joint torque and power (Mean ± S.D.)

	1^{st}HSJ	3^{rd}HSJ	5^{th}HSJ	Difference	Effect Size (Partial η^2)
Hip extension–flexion axis					
T_{peak} positive (N·m·kg^{-1})	11.95 ± 5.58	11.61 ± 4.86	11.88 ± 2.72	n.s.	0.00
P_{peak} negative (W·kg^{-1})	-11.42 ± 5.74	-12.71 ± 4.51	-13.04 ± 8.16	n.s.	0.02
P_{peak} positive (W·kg^{-1})	27.61 ± 12.97	19.69 ± 9.00	20.54 ± 9.35	n.s.	0.16
Hip abduction–adduction axis					
T_{peak} positive (N·m·kg^{-1})	2.67 ± 0.70	6.48 ± 2.14	8.10 ± 3.24	$1^{st} < 3^{rd} < 5^{th}$	0.72
P_{peak} negative (W·kg^{-1})	-9.87 ± 2.79	-28.07 ± 7.56	-37.25 ± 17.64	$1^{st} > 3^{rd} > 5^{th}$	0.68
P_{peak} positive (W·kg^{-1})	7.53 ± 3.29	13.50 ± 4.44	21.37 ± 9.93	$1^{st} < 3^{rd} < 5^{th}$	0.58
Hip external–internal axis					
T_{peak} negative (N·m·kg^{-1})	-1.15 ± 0.39	-1.72 ± 0.71	-1.64 ± 0.73	$1^{st} > 3^{rd}, 5^{th}$	0.34
T_{peak} positive (N·m·kg^{-1})	0.59 ± 0.23	0.60 ± 0.26	0.70 ± 0.27	n.s.	0.08
P_{peak} negative (W·kg^{-1})	-2.41 ± 2.57	-2.99 ± 1.85	-4.69 ± 2.86	$1^{st}, 3^{rd} > 5^{th}$	0.30
P_{peak} positive (W·kg^{-1})	3.76 ± 1.96	8.32 ± 5.05	9.34 ± 7.35	$1^{st} < 3^{rd}, 5^{th}$	0.43
Knee extension–flexion axis					
T_{peak} positive (N·m·kg^{-1})	3.35 ± 0.34	5.27 ± 0.85	5.03 ± 1.32	$1^{st} < 3^{rd}, 5^{th}$	0.71
P_{peak} negative (W·kg^{-1})	-14.85 ± 3.21	-40.39 ± 8.20	-42.56 ± 12.01	$1^{st} > 3^{rd}, 5^{th}$	0.86
P_{peak} positive (W·kg^{-1})	14.43 ± 4.94	17.13 ± 3.59	14.28 ± 2.86	$1^{st} < 3^{rd} > 5^{th}$	0.29
Ankle plantar–dorsi flexion axis					
T_{peak} positive (N·m·kg^{-1})	3.77 ± 0.37	4.24 ± 0.44	4.74 ± 0.45	$1^{st} < 3^{rd} < 5^{th}$	0.81
P_{peak} negative (W·kg^{-1})	-7.89 ± 1.78	-15.75 ± 2.77	-21.22 ± 2.93	$1^{st} > 3^{rd} > 5^{th}$	0.93
P_{peak} positive (W·kg^{-1})	34.14 ± 5.33	37.46 ± 4.45	40.11 ± 5.66	$1^{st} < 3^{rd} < 5^{th}$	0.53

T_{peak}; Peak joint torque, P_{peak}; Peak joint power, <, >; $P < .05$

CONCLUSION: With increasing jump steps in bounding from the standing posture, the joint kinetics characteristics are as follows: 1) the ankle plantar flexion torque and knee extension torque and power increased but hip extension torque and power did not increase; and 2) the hip external torque and power (negative and positive) increased, particularly hip abduction torque and power in response to ground reaction forces. Therefore, bounding with increasing jump steps is suitable for improving the force and power output of the ankle and knee extensor as well as the hip external–internal rotators, particularly on hip abductors in PT.

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