THREE-DIMENSIONAL ANALYSIS OF THE TAKE-OFF PREPARATORY MOTION IN THE LONG JUMP

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The purpose of this study was to investigate three-dimensionally how long jumpers move during the take-off preparatory phase and what causes the lateral lean of the body of the touchdown. The subjects were six male university long jumpers. Three-dimensional coordinates and ground reaction forces (GRF) were collected by Vicon cameras and a force platform. The long jumpers placed support foot in the lateral position at L2on and L1on. The take-off foot nearly under the center of mass (COM) in the take-off phase resulted in the inward lean of the take-off leg and the outward lean of the trunk at the instant of touchdown of take-off foot. The lateral lean of the body helped to lower the COM at the touchdown of take-off foot and to use the hip abductors during the take-off phase.

KEY WORDS: running jump, motion analysis, inverse dynamics.

INTRODUCTION: Graham-Smith and Lees (2005) and Koyama et al. (2009) found that elite male long jumpers tended to laterally lean in the frontal plane at the instant of the take-off foot touchdown (trunk lean angle, 9.4 ± 6.2 deg; take-off leg lean angle, 1.3 - 4.7 deg). They speculated from the observation that the lean of the take-off leg would make hip abductors more involved in increasing the vertical center of mass (COM) velocity during the take-off phase. Shimizu and Ae (2013) revealed that the hip joint of the take-off leg exerted large abduction torque as well as the hip extension torque during the take-off of the long jump. Shimizu et al. (2014) suggested that the functions of the hip abductors were to transfer the horizontal COM velocity into the vertical one immediately after the foot strike and to control the body position during the take-off phase. Although it is clear that the body position during the take-off phase is affected by the preparatory motion, there is no investigation how the take-off preparatory motion relates to the lateral lean of the take-off leg and the trunk at the touchdown. The purpose of this study was to investigate three-dimensionally how long jumpers move during the take-off preparatory phase and what causes the lateral lean of the body of the touchdown.

METHODS: The subjects were six male university long jumpers (height, 1.75 ± 0.07 m; body mass, 68.6 ± 8.2 kg; personal best, 7.06 ± 0.29 m). All subjects started their approach run of 20m from a force platform (9287B, Kistler Instrument AG) in their own manner and jumped toward the landing area. One trial that each subject showed the best jump was selected for detailed analysis. Three-dimensional coordinates of 47 reflective markers fixed in the body were captured with a Vicon T20 system (Vicon Motion System, Ltd.) using twenty cameras operating at 250Hz. Ground reaction forces (GRFs) during the last stride were obtained with the force platform sampling at 1000Hz, which was time-synchronized in the Vicon system. The coordinate data were smoothed with a Butterworth low-pass digital filter with cut-off frequencies ranging from 12.5 to 25.0 Hz which were determined by the residual analysis proposed by Wells and Winter (1980).
The COM positions of the body segments were estimated from the body segment parameters of the Japanese athletes (Ae, 1996). The COM-toe distance in the X-axis and Y-axis were defined as shortest distance between the COM and the toe of the support foot at the touchdown during each support phase. The COM height change was obtained as a COM height difference from that of the touchdown in the second-to-last stride.
The trunk and take-off angles were defined as an angle between the segment and the vertical line. An inverse dynamics approach with a three-rigid-segment model consisting of

the foot, shank and thigh was used to calculate the hip joint torque of the take-off leg. The joint torque was divided by the subject's body mass.

The preparatory and take-off motions were divided into five motion phases: (1) L2-support phase, from the touchdown (L2on) to the toe-off (L2off) in the second-to-last stride (L2), (2) L2-flight phase, from the L2off to the touchdown (L1on) in the last stride (L1), (3) L1-support phase, from the L1on to the toe-off (L1off) in the last stride, (4) L1-flight phase, from the L1off to the touchdown of the take-off foot (TD) and (5) TO-support phase, from the TD to the toe-off of the take-off foot (TO). Time-series data during the L1-support phase were normalized by the L1-support phase time and then averaged at every 1%.

Pearson's product moment correlation coefficient was calculated to examine relationships between the parameters. The level of significance was set at 5%.

RESULTS: Figure 1 shows an overhead view of the locus of the COM from L2on to TO and the COM position of the support foot (circles) during each support phase. The solid line indicated support phase and the dotted line was flight phase. Although all jumpers placed their support foot laterally at L2on and L1on, they placed their take-off foot nearly under the COM in the take-off phase.

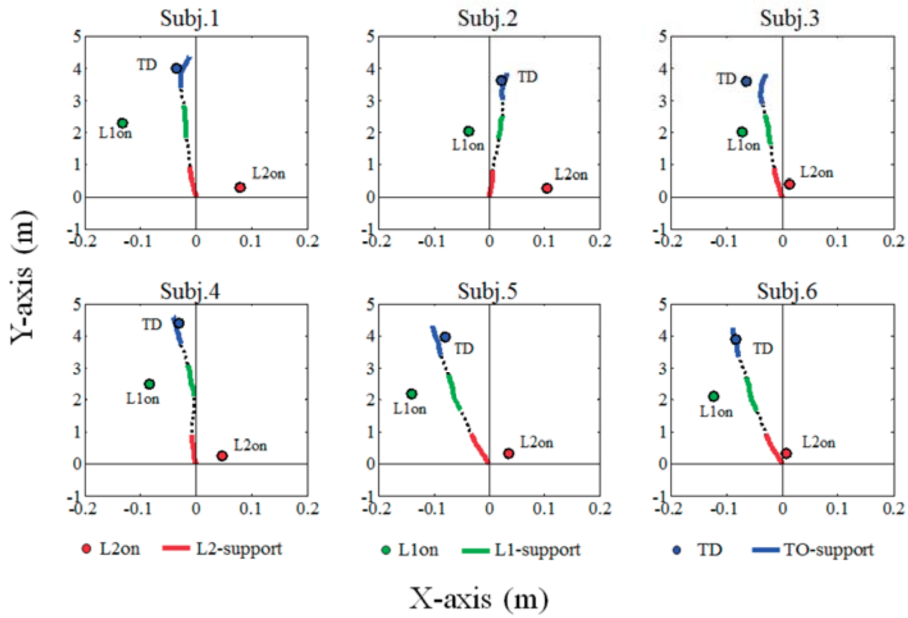

Figure 1: An overhead view of the locus of the COM from L2on to TO and the COM position of the support foot during each support phase.

Table 1 shows the COM-toe distance in X-axis and Y-axis during support phase, the COM height at L2off, L1on, L1off and TD and the take-off and trunk angle at TD. The average COM-toe distance in X-axis was 0.05 ± 0.04 m at L2on, 0.08 ± 0.02 m at L1on, 0.01 ± 0.01 m at TD, respectively. There was a significant relationship between the COM-toe distance in Y-axis at TD and the COM height at TD (r = -0.89, p < 0.05).

Table 1: The COM-toe distance in X- and Y-axis, the COM height and segment angle.

	COM - toe distance (m)						COM height (m)				segment angle (deg)	
	L2on		L1on		TD		L2off	L1on	L1off	TD	TD	TD
	X	Y	X	Y	X	Y	Z	Z	Z	Z	take-off leg	trunk
Subj.1	0.08	0.31	0.11	0.45	0.01	0.62	-0.06	-0.05	-0.06	-0.08	5.3	10.7
Subj.2	0.11	0.27	0.05	0.21	0.00	0.60	-0.02	0.00	-0.02	-0.05	4.2	6.3
Subj.3	0.01	0.40	0.05	0.42	0.03	0.70	-0.07	-0.03	-0.07	-0.09	5.7	5.4
Subj.4	0.05	0.26	0.08	0.39	0.00	0.66	-0.04	-0.03	-0.04	-0.07	1.8	8.8
Subj.5	0.04	0.32	0.09	0.50	0.01	0.58	-0.03	-0.04	-0.03	-0.04	5.5	6.1
Subj.6	0.01	0.33	0.08	0.46	0.01	0.53	-0.03	-0.03	-0.03	-0.04	5.1	5.9
mean	0.05	0.32	0.08	0.41	0.01	0.61	-0.04	-0.03	-0.04	-0.06	4.6	7.2
sd	0.04	0.05	0.02	0.10	0.01	0.06	0.02	0.01	0.02	0.02	1.5	2.1

Figure 2 shows the stick pictures and GRF vector in the frontal plane during the preparatory and take-off phases for a typical subject (Subj.1). The GRF vector was directed to the left of the COM during the L1support phase (20% time). His trunk leaned right from L1off to TO (L1off, 7.7 deg; TD, 10.7 deg; TO, 11.3 deg). The average outward angle of the trunk in the frontal plane for six jumpers were 1.5 ± 1.0 deg at L1on, 4.4 ± 2.1 deg at L1off, 7.2 ± 2.1 deg at TD and 8.3 ± 1.7 deg at TO, respectively. The average inward angle of the take-off leg in the frontal plane at TD was 4.6 ± 1.5 deg. There was a significant relationship between the COM-toe distance in X-axis at L1on and the trunk angle at TD ($r = 0.78$, $p < 0.05$).

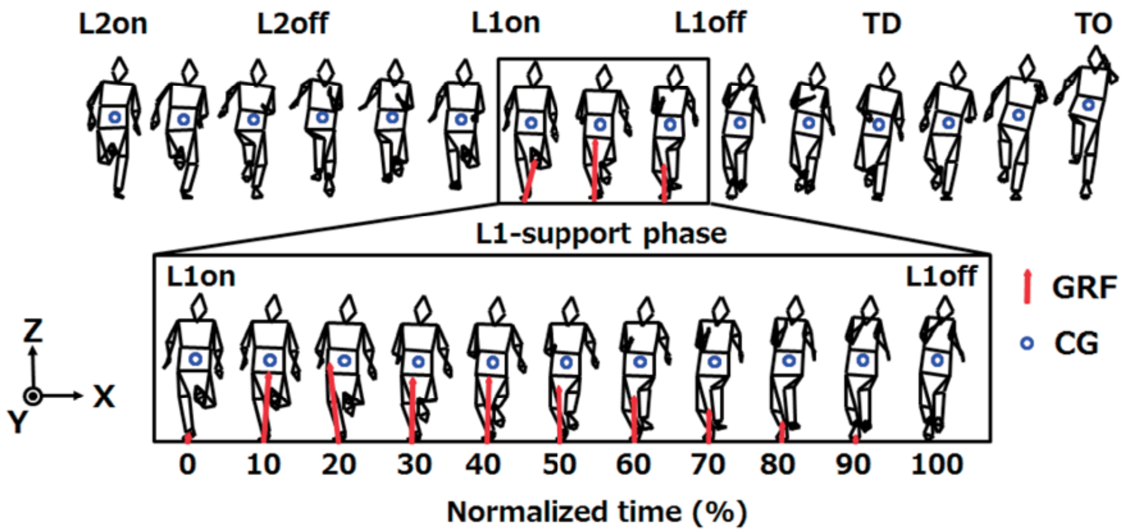

Figure 2: The stick pictures and GRF vector for the typical subject from L2on to TO in the back views.

Figure 3 shows the averaged patterns of joint torques of the hip extension (+) / flexion (−) and hip abduction (+) / adduction (−) of the support leg during the L1-support phase. The hip joint exerted the abduction torque during the L1-support phase. The hip extension torque was dominant in the first half and the hip flexion torque was exerted in the second half of the L1-support phase.

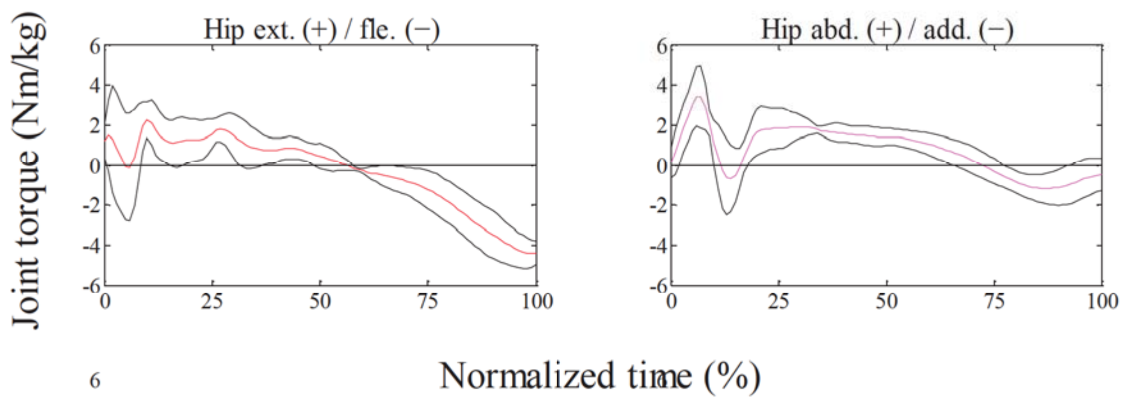

Figure 3: The averaged patterns of the hip joint torques of the support leg during the L1-support phase.

DISCUSSION: The present study was obtained similar result as Graham-Smith and Lees (2005) and Koyama et al. (2009). The trunk and take-off leg for the university long jumpers laterally leaned in the frontal plane at TD (trunk lean angle, 7.2 ± 2.1 deg; take-off leg lean angle, 4.6 ± 2.1 deg). All the long jumpers placed their support foot laterally at L2on and L1on, and they settled their take-off foot nearly under the COM in the take-off phase (Figure

1), which resulted in the inward lean of the take-off leg at TD. Shimizu and Ae (2013) and Shimizu et al. (2014) reported that the use of the hip abductors induced by the inward lean of the take-off leg and the outward lean of the trunk in the long jump helped to increase the vertical COM velocity and to support the body during the take-off phase.

The GRF vector acted left to the COM in the L1support phase and the trunk leaned right from L1off to TO (Figure 2). This result implied that the large right moment (clockwise in back view) about Y-axis of the body during the L1-support phase tended to rotate toward the trunk and body right side during the L1-flight phase. In addition, the large hip abduction torque of the support leg during the L1-support phase (Figure 3) would contribute to generate the GRF the left direction throughout the L1-support phase. The long jumpers leaned laterally by the placement of the support foot laterally and exerted the hip abduction torque of the support leg in the L1-support phase.

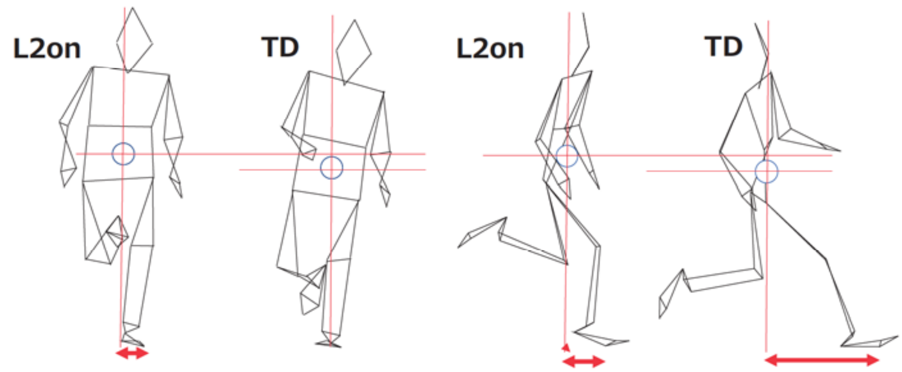

Figure 4: The body positions at the L2on and TD for the subject 1.

Long jumpers need to lower the COM during the preparatory phase to obtain the large vertical COM velocity by pivoting the body over the take-off foot during the take-off phase with a loss of COM velocity as less as possible (Hay, 1993). Figure 4 illustrates the difference in the body position between the L2on and the TD. The long jumper lowered the COM by placing their take-off foot in front of the body and leaning the body, as the Fosbury-flop high jumpers have employed.

CONCLUSIONS: The placement of foot laterally during the L1-support phase and the take-off foot nearly under the COM resulted in the inward lean of the take-off leg and outward lean of the trunk during the take-off phase. The lateral lean of the body helped to lower the COM at TD and to use the hip abductors during the take-off phase.

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