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THREE-DIMENSIONAL ANALYSIS OF THE TAKEOFF MOTION IN THE LONG JUMP

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The purposes of this study were to investigate why long jumpers laterally leaned at the touchdown of the takeoff using the three-dimensional kinetics analysis and to obtain suggestions for long jumpers' training. The subjects were twelve male university long jumpers. Three-dimentional coordinates and ground reaction forces (GRF) were collected by Vicon cameras and a force platform. The results in this study were revealed that the hip joint of the takeoff leg exerted the large abduction torque during the takeoff as well as hip extension torque (peak hip abduction torque, 4.24±3.28 Nm/kg). The hip abductors seemed to help to bear the body against the GRF and to contribute to obtain the vertical CG velocity. These imply why the long jumpers laterally leaned the body at the touchdown of the takeoff.

KEY WORDS: running jump, three-dimensional motion analysis, inverse dynamics.

INTRODUCTION: A long jumper transfers the horizontal velocity obtained in the approach into the vertical velocity during the takeoff phase (Hay, 1986). Many investigations have been performed on the kinematics of the takeoff motion (e.g., Lees, et al., 1994; Ae, et al., 1999). These have indicated that there are three factors in the takeoff techniques to transfer the horizontal velocity to the vertical one during the takeoff phase: (1) a pivoting of the body over the takeoff foot, (2) a swinging of the free limbs, and (3) an extension of the takeoff leg joints. However, most of the previous studies on the long jump discussed the takeoff techniques, based on the analysis in the sagittal plane. On the other hand, Graham-Smith and Lees (2005) and Koyama, et al. (2009) investigated the three-dimensional kinematics of the takeoff techniques for the elite male long jumpers. These studies pointed out that long jumper tended to laterally lean in the frontal plane at the instant of the touchdown of the takeoff foot. However, they did not mention why the long jumpers laterally leaned at the touchdown of the takeoff foot. Although a three-dimensional kinetic analysis of the takeoff techniques is mandatory, there seems no three-dimensional kinetic investigation on the takeoff techniques of the long jump to answer our question. Therefore, the purposes of this study were to investigate why long jumpers laterally leaned at the touchdown of the takeoff foot using the three-dimensional kinetics analysis and to obtain suggestions for long jumpers' training.

METHODS: The subjects were twelve male university long jumpers (Age, 22.3±3.3 years; Height, 1.74±0.05 m; Body mass, 67.6±5.8 kg; Personal best, 7.13±0.33 m). All subjects started the approach run of the approximately 20m from a force platform (9287B, Kistler Instrument AG) in their own manner and jumped to the landing area. The trial in which each subject showed the best jump was selected for detailed analysis. Three-dimensional coordinates of 47 retro-reflective markers fixed in the body were captured with a Vicon T20 system (Vicon Motion System, Ltd.) using twenty cameras operating at 250Hz. The ground reaction forces (GRF) were obtained with the force platform at 1000Hz. These data were collected simultaneously and time-synchronized in the Vicon system. The coordinate data were smoothed with a Butterworth low-pass digital filter. The optical cut-off frequencies with cut-off frequencies, ranging from 12.5 to 25.0 Hz, were determined by the residual analysis proposed by Wells and Winter (1980).
Segment angles in the frontal and sagittal planes were defined as shown Figure1. The center of gravity (CG) coordinates were estimated often from the body segment parameters of the Japanese athletes (Ae, 1996) and then differentiated for the CG velocity and the CG

acceleration. The GRF and its moment about the CG integrated to calculate the impulse of GRF and the angular impulse. The mass, location of the center of mass, and the moment of inertia for body segments were used to calculate joint kinetics. An inverse dynamics approach with a three-rigid-segment model consisting of the foot, shank, and thigh was used to calculate the joint torques at the ankle, knee, and hip of the takeoff leg. The joint torque was divided by the subject's body mass. Time-series data were normalized by the time of the takeoff phase and then averaged at every 1%. Takeoff motion was divided into two phases: The first half began at the instant of the takeoff foot touchdown (TD) and ended at the instant of the maximum knee flexion (MKF) of takeoff leg, and the second phase was from MKF to the instant of the toe-off (TO). Each phase was set as 50%, respectively.

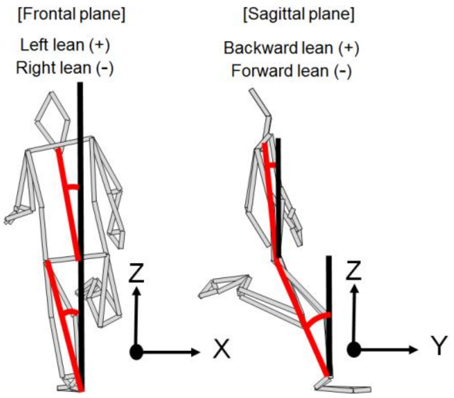

Figure 1. The torso and takeoff leg angles in frontal and sagittal planes.

RESULTS: The horizontal and vertical CG velocities at the TO of the experimental long jump were 6.35±0.54 m/s and 3.22±0.29 m/s, respectively. The decrease in the horizontal CG velocity during the takeoff phase was -1.16±0.28 m/s and the increase in the vertical CG velocity was 3.75±0.36 m/s. The torso angles in the frontal and sagittal planes at the TD were 8.5±2.4 deg and 5.9±4.5 deg, which indicated left lateral and backward lean. The takeoff leg angles at the TD were 4.2±1.2 deg in the frontal plane and 30.2±2.2 deg in the sagittal one.
Figure 2 shows the stick pictures and GRF vector during the takeoff phase for the typical subject who obtained the largest vertical CG velocity at the TO (3.76 m/s). His torso and takeoff leg were leaned left lateral (torso, 7.7 deg; takeoff leg, 4.4 deg) and backward lean (torso, 3.9 deg; takeoff leg, 30.0 deg) at the TD. The GRF vector acted to the left direction after TD and the backward direction in the 20-70%.

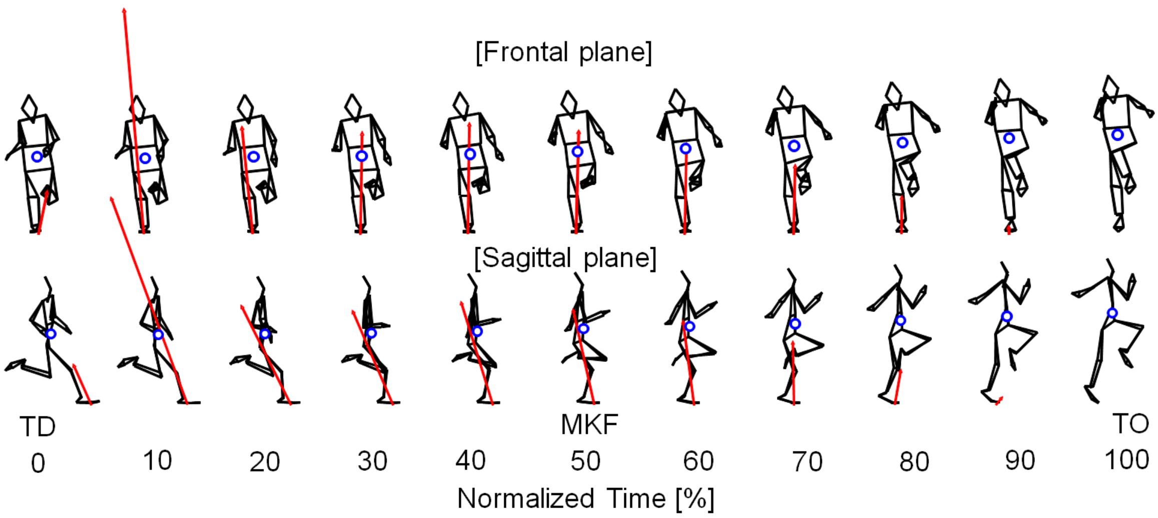

Figure 2. The stick pictures and ground reaction force vector for the typical subject during the takeoff phase.

Table 1. The impulse of the GRF and the angular impulse of the moment about CG during the takeoff phase.

	positive	negative
Impluse_Xcomponent (Ns/kg)	0.07±0.05	-0.17±0.06
Impluse_ycomponent (Ns/kg)	0.08±0.03	-1.28±0.24
Impluse_Zcomponent (Ns/kg)	4.65±0.28	-0.00±0.00
Angular Impluse_Xaxis (Nms/kg)	0.12±0.03	-0.27±0.03
Angular Impluse_yaxis (Nms/kg)	0.14±0.01	-0.05±0.01
Angular Impluse_Zaxis (Nms/kg)	0.04±0.01	-0.02±0.01

Table 1 shows the impulse of the GRF and the angular impulse during the takeoff phase. The negative impulse of the brake component was -1.28±0.24 Ns/kg, and the positive impulse of the vertical component was 4.65±0.28 Ns/kg. The negative angular impulse of the forward rotation component was -0.27±0.03 Nms/kg, and the positive angular impulse of the right rotation component was 0.14±0.01 Nms/kg.

Figure 3 shows the averaged patterns for twelve subjects of the joint torques of the hip abduction (+) / adduction (-), hip extension (+) / flexion (-), knee extension (+) / flexion (-), and ankle plantar flexion (+) / dorsal flexion (-) of the takeoff leg during the takeoff phase. The hip joint exerted the large abduction torque during the takeoff phase. The peak hip abduction torque which appeared around the 10% time was 4.24±3.28 Nm/kg. The hip extension torque was dominant in the first phase and the hip flexion torque was dominant in the second phase. The knee and ankle joint exerted the large extension and plantar flexion torques throughout the takeoff phase. The large variation was seen in the hip abduction and extension torques during the initial period, i.e. 0-20% time.

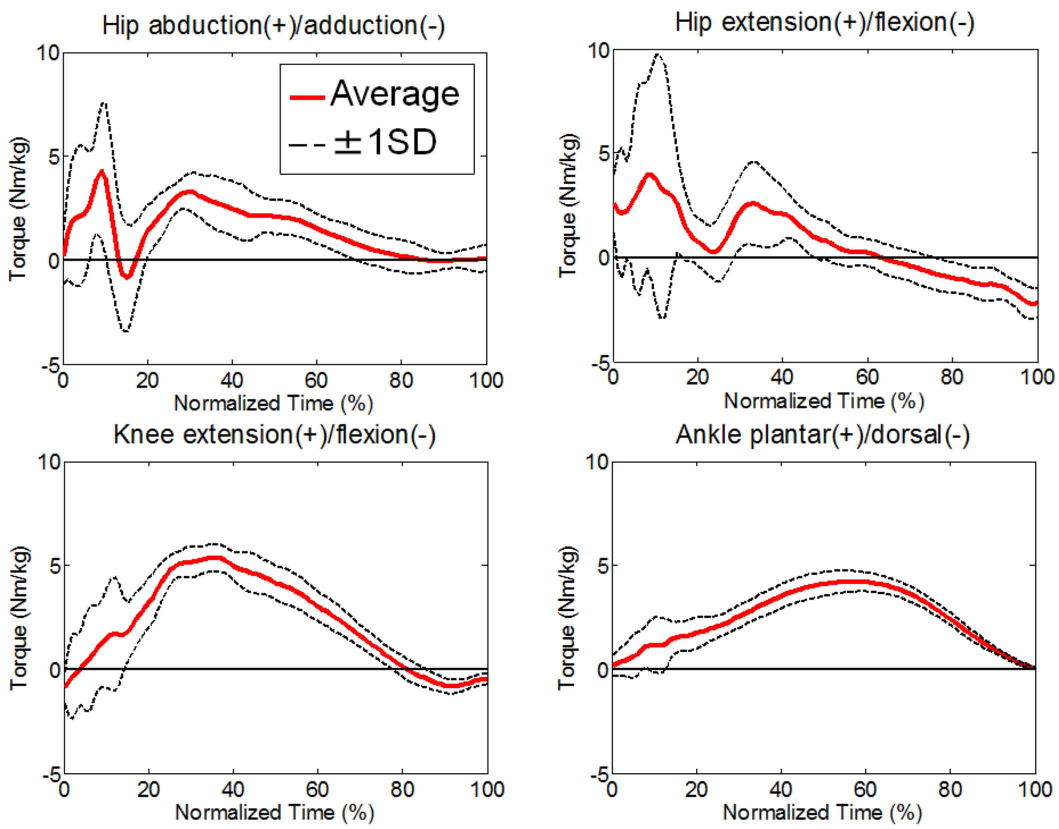

Figure 3. Averaged patterns for twelve subjects of the joint torques of the takeoff leg during the takeoff phase.

DISCUSSION: Koyama, et al. (2009) found that the elite long jumpers tended to laterally lean in the frontal plane at the TD of the takeoff, and speculated that the hip abductors might be helpful to obtain the vertical CG velocity during the takeoff phase. In the present study, the torso and takeoff leg for the university long jumpers laterally leaned in the frontal plane at the TD, as the jumpers of Koyama's study. The hip abduction torque was exerted as much as the hip extension torque, although it was smaller than the knee extension and the ankle plantar flexion torques. Therefore, the hip abduction torque should be considered as important torque during the takeoff of the long jump.

Okuyama (2003) pointed out that the hip abductors helped to bear the body against the GRF during the first half of the takeoff phase and contributed to obtain the vertical CG velocity during the second phase in the Fosbury-flop. It seemed that effects of the joint torques of the takeoff leg in the long jump were similar to those of the high jump as follows.

The hip abductors exerted the large torque immediately after foot strike. The GRF vector and the its adduction moment at the hip joint were large around the 10%. Therefore, the hip abduction torque had to be exerted to prevent the hip joint from collapsing and bear the body against the GRF. During the second phase, the GRF vector acted through the CG around the 40-70% time (see Figure 2 top). If a long jumper had not laterally leaned the body at the touchdown of the takeoff, the large right lateral moment about Y-axis would have been generated almost the takeoff phase and the body would have largely leaned right direction. To prevent these unprofitable motions, the jumpers exerted the hip abduction torque and obtained the vertical CG velocity thought the takeoff phase.

These results imply that the hip abduction torque plays an important role to bear the body during the first phase and to obtain the vertical CG velocity during the second phase and that leaning the body laterally at the instant of the touchdown renders the hip to exert abduction torque during the takeoff phase. These findings suggest that long jumpers may have to consider their strength training of the hip abductors to effectively utilize the benefit.

CONCLUSIONS: The hip joint of the takeoff leg exerted the large abduction torques during the takeoff in the long jump. The functions of the hip abductors were to bear the body during the first phase and to obtain the vertical CG velocity effectively during the second phase. The lateral lean of the long jumpers observed at the touchdown of the takeoff induces the hip joint of the takeoff leg to exert the large hip abduction torque, suggesting the necessity of the hip abductors strength training.

REFERENCES:

Ae, M. (1996). Body segment inertia parameters for Japanese children and athletes (in Japanese). *Japanese Journal of Sports Sciences*, 15, 155-162.

Ae, M., Omura, I., Kintaka, H., Iiboshi, A., Yamada, A., Ito, N., and Ueda, T. (1999). A biomechanical analysis of the takeoff preparation motion by elite long jumpers (in Japanese), *Research of Sports and Science of the Japan Sports Association,* 22,183-186.

Graham-Smith, P.,Lees, A. (2005). A three-dimentional kinematic analysis of the long jump take-off. *Journal of Sports Sciences*, 23(9), 891-903.

Hay, J.G. (1986). The biomechanics of the Long Jump. In K.B. Pandolf (ed.), *Exercise and Sports Sciences Reviews* (Volume 14) (pp. 401-446). New York: Macmillan Publishing Co.

Koyama, H., Ae, M., Muraki, Y., Yoshihara, A., and Shibayama, K. (2009). Biomechanical analysis of men's and women's long jump. *Bulletin of studies in Athletics of JAAF*, 5, 107-118.

Okuyama, K., Ae, M., and Yokozawa, T. (2003). Three dimensional joint torque of the takeoff leg in the fosbury flop style. *International Society of the Biomechanics XIXth Congress.*

Wells, R.P., and Winter, D.A. (1980). Assessment of signal and noise in the kinematics of normal, pathological and sporting gaits. *Human Locomotion*, I, 92-93.