CONTRIBUTION OF THE JOINT TORQUE OF THE TAKEOFF LEG IN THE LONG JUMP

Yutaka Shimizu[1], Michiyoshi Ae[2] and Sekiya Koike[2]

Doctoral Program in Physical Education, Health and Sport Sciences, University of Tsukuba, Tsukuba, Japan[1]
Faculty of Health and Sport Sciences, University of Tsukuba, Tsukuba, Japan[2]

The purposes of this study were to investigate effects of the joint torques of the takeoff leg on the GRFs in the long jump and to obtain suggestions to long jumpers' training. The subjects were ten male university long jumpers. Three-dimensional coordinates and ground reaction forces (GRF) were collected by Vicon cameras and a force platform. The force components of the joint torque of the takeoff leg were calculated by a multi-body dynamic method. The results in this study revealed that functions of the hip extensors and abductors seemed to obtain the vertical GRF and to maintain the position of the upper body throughout the takeoff phase. The knee extensors prevented the knee joint from collapsing and bear the body, and the ankle planter flexors played a major important role to generate the vertical GRF.

KEY WORDS: running jump, three-dimensional analysis, multi-body dynamics.

INTRODUCTION: A long jumper transfers the horizontal velocity obtained in the approach into the vertical velocity during the takeoff phase (Hay, 1986). The takeoff leg of the long jumper plays an important role in converting the horizontal velocity into vertical the velocity. A few investigations have focused on effects of the takeoff leg joint torques during the takeoff phase (Ae et al., 1989; Muraki et al., 2008). They found that the knee and ankle joints exerted large extension torque and plantar flexion torque throughout the takeoff phase. Shimizu and Ae (2013) revealed that the hip joint of the takeoff leg exerted large abduction torque as well as extension torque. They suggested that the hip abduction torque played important roles to obtain the vertical velocity and to bear the body immediately after the foot strike. However, they did not show how the joint torques of the takeoff leg contributed to obtain the ground reaction force (GRF). Koike et al. (2007) developed a method to quantify effects of the joint torques on the GRF. The purposes of this study were to investigate effects of the joint torques of the takeoff leg on the GRFs in the long jump and to obtain suggestions to long jumpers' training.

METHODS: The subjects were ten male university long jumpers (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 toward the landing area. One trial in which 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. The GRFs were obtained with the force platform at 1000Hz, which were 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 center of gravity (CG) positions of the body segments were estimated from the body segment parameters of the Japanese athletes (Ae, 1996) and then differentiated for the velocity and acceleration. The force components of the takeoff leg joint torques were calculated by a method of Koike et al. (2007), as mentioned in the Introduction. The equations of motion for the body segment can be summed up in a matrix from as follows:

$$\boldsymbol{M\dot{V}} = \boldsymbol{PF} + \boldsymbol{QN} + \boldsymbol{H} + \boldsymbol{G} \tag{1}$$

where ***M*** is the inertia matrix and ***V*** is the vector containing the translational and rotational velocity vectors of the segment's CG, ***P*** are the coefficient matrix of joint force vectors ***F***, ***Q*** is

the coefficient matrix of moment vectors at all joints ***N***, ***H*** is gyro-moment vectors of all segments, and ***G*** is gravitational vector.
The equation of constraint condition for adjacent segments connected by a joint is expressed as follows:

$$x_i + P_{\overline{cgA,i}} - x_{i+1} - P_{\overline{cgB,i+1}} = O_{3\times1} \quad (2)$$

Differentiating equation (2) yields accelaerational constraint equations for all joints:

$$C\dot{V} + \dot{C}V = \ddot{\eta} \quad (3)$$

where η is the position vector of center of pressure x_{cp}. Substituting equation (3) into equation (1), the equation of motion for the system can be obtained as follows:

$$\dot{V} = A_T T + A_V + A_G G \quad (4)$$

where A_T and A_G are the coefficient matrices of the joint torque vector ***T*** and gravitational acceleration vector ***G***, and A_V is the motion dependent term. These terms can be converted into GRF via the transformation matrix ***S***:

$$GRF = S\dot{V} = SA_T T + SA_V + SA_G G \quad (5)$$

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.

RESULTS: The horizontal and vertical CG velocities at the TO were 6.09±0.52 m/s and 2.44±0.25 m/s, respectively. The decrease in the horizontal CG velocity during the takeoff phase was -0.98±0.28 m/s.
Figure 1 shows averaged patterns of the joint torques of the hip extension / flexion (hFE), hip abduction / adduction (hAA), knee extension / flexion (kFE), and ankle plantar flexion / dorsal flexion (aPDF) of the takeoff leg during the takeoff phase. The hip joint exerted the large extension and abduction torques during the initial period, i.e. 0-30% time. The knee and ankle joint exerted the large extension and plantar flexion torques throughout the takeoff phase.

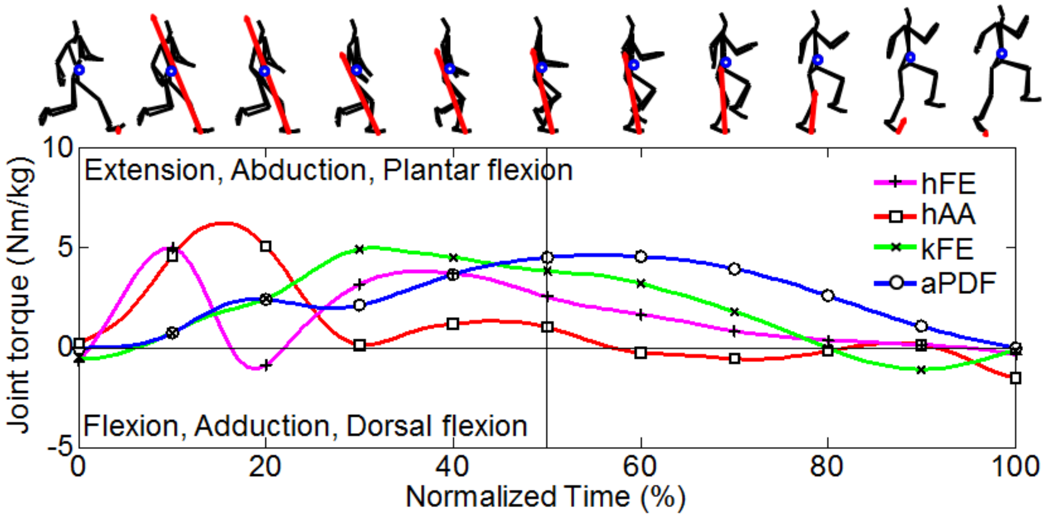

Figure 1: Averaged patterns of the joint torques of the takeoff leg during the takeoff phase.

The contribution of the motion dependent term and gravitational acceleration term to the horizontal and vertical GRFs were much smaller than that of the joint torque term.
Figure 2 shows averaged patterns of the GRF components by the joint torques of takeoff leg during the takeoff phase. Most of the horizontal GRF was exerted by the kFE torque. The hFE and hAA torques showed slightly the negative GRF immediately after the foot strike and the aPDF torque showed slightly the positive horizontal GRF during the second phase. Most of the vertical GRF was contributed by the aPDF torque. The hFE and hAA torques showed

slightly the positive GRF immediately after the foot strike and the kFE torque showed the positive vertical GRF during the 10-80% time.

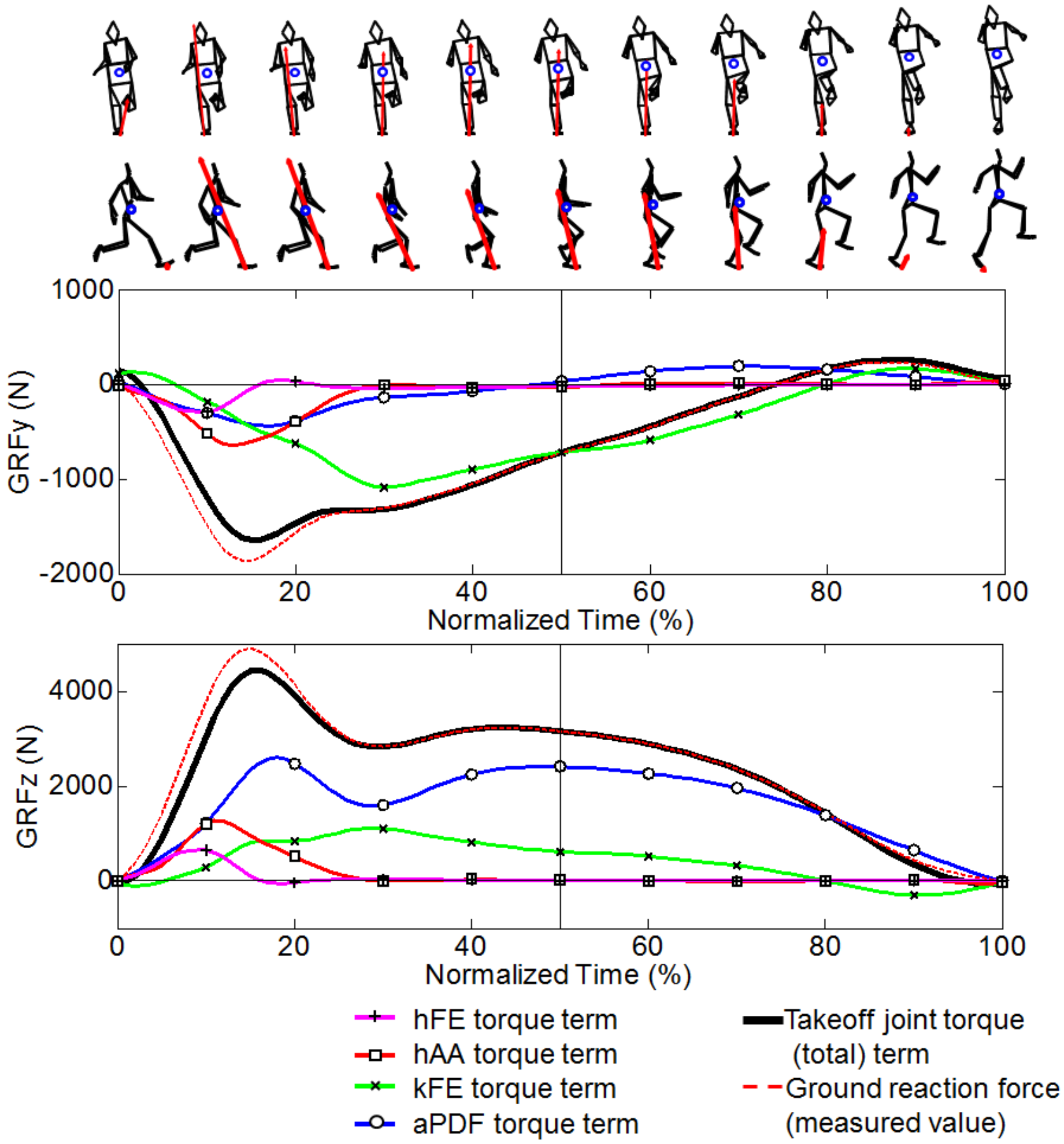

Figure 2: Averaged patterns of the contribution of each takeoff joint torques to the horizontal (top) and vertical (bottom) GRFs during the takeoff phase.

DISCUSSION: Graham-Smith and Lees (2005) and Koyama et al. (2009) pointed out that elite male long jumper tended to laterally lean in the frontal plane at the instant of the touchdown of the takeoff foot. Similar result was observed in the present study of the middle run-up jump of the university male long jumpers. The hip joint exerted the large extension and abduction torques immediately after the foot strike during the takeoff phase. The GRF by the takeoff leg joint torques revealed that the hip extension and abduction torques generated the positive vertical GRF and the negative horizontal GRF during the 0-30% time. Shimizu and Ae (2013) have investigated the hip abduction torque plays an important role to obtain the vertical CG velocity and to bear the body immediately after the foot strike.

Although the hip joint exerted larger extension and abduction torques than the ankle and knee joints, the contribution of the hip joint torque to the vertical GRF was smaller during the 10-30% time than those of the ankle and knee joint torque. The hip torque did not contribute to GRFs after 30% time. The hip extension and abduction torques contributed to maintain the upper body position in straight and vertical throughout the takeoff phase. If a long jumper had

not exerted large hip extension and abduction torques around the touchdown of the takeoff foot, the upper body would have leaned forward and right direction or collapsed due to the large forward and lateral moments. If so, the jumper could not generate the large vertical GRF during the second takeoff phase. Okuyama (2003) pointed out that leaning the body laterally at the touchdown rendered the hip to exert abduction torque during the takeoff phase in the Fosbury-flop. Thus, functions of the hip extensors and abductors seemed to obtain the vertical CG velocity and to maintain the position of the upper body throughout the takeoff phase. This suggests that long jumpers need to pay attention to strength training of hip extensors and abductors.
The knee and ankle joints exerted the large extension torque and plantar flexion torque throughout the takeoff phase. Long jumpers transfer the horizontal CG velocity into the vertical CG velocity effectively during the takeoff phase (Hay, 1986). The knee extension torque showed the large negative horizontal GRF and the aPDF torque showed the large positive vertical GRF. These results indicated that the function of the knee extensors was to prevent the knee joint from collapsing and bear the body at the foot impact, and the ankle planter flexors played a major important role to generate the vertical GRF in active manner.

CONCLUSIONS: The hip joint exerted the large extension and abduction torques immediately after the foot strike during the takeoff phase. The functions of the hip extensors and abductors were to transfer the horizontal CG velocity into the vertical CG velocity immediately after the foot strike and to control the body position during the takeoff phase. In addition to training of the knee extensors and ankle plantar flexors, jumpers should consider the strength training of the hip extensors and abductors.

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., Muraki, Y., Ishikawa, N., Kintaka, H., and Ito, N. (1989). Functions of muscles of the takeoff leg in the long jump in terms of torque and torque power (in Japanese). *Resurch Bulletin of the Japan Association of Athletics Federations,* 2, 2-9.
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.
Koike, S., Mori, H., and Ae, M (2007). Thee-dimensional analysis of jump motion based on multi-body dynamics –The contribution of joint torques of the lower limbs to the velocity of the whole-body center of gravity–. *The Impact of Technology of Sport II , Taylor & Francis*, 649-654.
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.*
Muraki, Y., Ae, M., Koyama, H., and Yokozawa, T. (2008). Joint torque and power of the takeoff leg in the long jump. *International Journal of Sport and Health Science, Vol.6,* 21-32.
Shimizu, Y., and Ae, M. (2013). Theree dimensional analysis of the takeoff motion in the long jump. *The 31th Conference of the International Society of Biomechanics in Sports proceeding*, 16-19.
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.