LOWER EXTREMITY BIOMECHANICAL ANALYSIS OF A STOP-JUMP TASK WITH DIFFERENT STEP LENGTHS IN THE APPROACH RUN

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This study aimed to assess the kinematics and kinetics during the landing phase of 3 kinds of last step lengths in a stop-jump task to provide further perspectives on lower extremity injuries. Twelve adult males were recruited for the study. A MegaSpeed high-speed camera synchronized with an AMTI force plate was used to record the stop-jump action. Kinetic parameters were calculated using an inverse dynamic method. The results showed that the kinematical characteristics of landing were similar among the different last step lengths during the approach run. The peak vertical ground reaction force and vertical loading rate during landing significantly increased as the step length increased. The peak knee extension moment and proximal tibia anterior shear force did not differ among the 3 stop-jump tasks. These results suggest that during the stop jump task, longer last step lengths during the approach run may increase lower extremity injury.

KEYWORDS: kinematics, kinetics, inverse dynamics

INTRODUCTION: The rate of anterior cruciate ligament (ACL) injury during stop-jump tasks is high (Renstrom et al., 2008). Yu and Garrett (2007) reported that non-contact ACL injuries occur when an anterior shear force generates large forces at the proximal tibia. Previous studies have demonstrated a significant relationship between peak ground reaction forces (GRFs) and knee injury (Williams et al., 2004; Hewett et al., 2005), particularly during ACL loading (Radin et al., 1991; Shelburne et al., 2004). Yu et al. (2006) reported that increasing the peak GRF increased the peak anterior shear force on the proximal tibia during landing in a stop-jump task. The peak posterior GRF during a stop-jump landing is a very important component of the peak proximal tibia anterior shear force. Increasing the knee extension moment by increasing quadriceps muscle activity assists in counteracting the increased knee flexion moment that is created by the larger posterior GRFs experienced during landing (Yu et al., 2006; Yu and Garrett, 2007). Increasing the peak knee extension moment has been shown to increase the peak proximal tibia anterior shear force (Chappell et al., 2002; Yu et al., 2006; Chappell et al., 2007; Sell et al., 2007). Previous investigations are consistent in demonstrating the relationship between kinematics and kinetics—the motion of the hip and the knee in the sagittal plane affects lower extremity loading (Chappell et al., 2002; Yu et al., 2006; Sell et al., 2007; Yu and Garrett, 2007). Unfortunately, these previous studies only focused on the stop-jump task for the subject's preferred step length of the last step during the approach run. However, different last step lengths during the approach run are often used to arrive at a suitable start place for take-off in jumping. Whether different step lengths of the approach run used in the last step during a stop-jump task affect lower extremity loading still is not clear. Thus, the purpose of this study was to compare the kinematics and kinetics during the landing phase of 3 kinds of last step lengths in a stop-jump task.

METHODS AND PROCEDURES: For this study, 12 male, National University of Physical Education students without lower extremity injuries in the 6 months before the experiment were recruited as subjects. The mean age, standing height, and body weight of the subjects were 21.5 ± 0.8 years, 1.74 ± 0.05 m, and 67.3 ± 6.7 kg, respectively. Before the experiment, all subjects were informed of the methods and processes of the study and a signed consent form was obtained. All subjects were blinded to the purpose of this study. A MegaSpeed high-speed camera (120 Hz) was used to record the sagittal plane of the stop-jump task during the landing phase. An AMTI force plate (1200 Hz) was synchronized to calculate the GRFs and center of pressure during jumping. The maximum approach run speed permitted was with 3 steps followed by a full effort stop-jump (a symmetrical two-footed landing and a two-footed takeoff, Figure 1). Each subject performed the stop-jump task with the last step of nature (preferred stop-jump (PSJ)), shorten deliberately (short stop-jump (SSJ)), and lengthen deliberately (long stop-jump (LSJ)) length during the approach run. Three successful stop-jump performances for each step length of the last step during the approach run were collected. The subjects were instructed to land with 2 feet together on the force plate during landing. The highest jumping performance for each stop-jump task was analyzed.

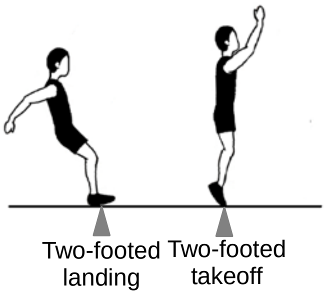

Figure 1. Stop-jump task.

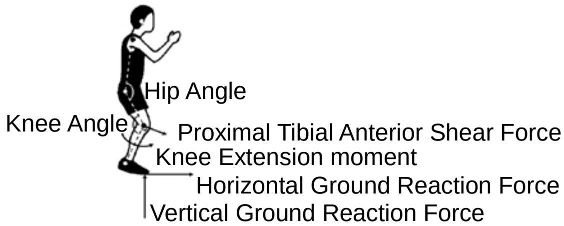

Figure 2. Kinematics and kinetics definition on the landing leg in the sagittal plane.

Sixteen markers were placed on the right and left superior aspects of the scapular acromion process, styloid process of ulna, ulnar styloid, proximal interphalangeal joint of the third finger, greater trochanter, lateral condyle of the tibia, lateral maleolus, and fifth metatarsal, according to Dempster's body segment parameters (Winter, 2005). A reflective marker placed on the edge of the force plate was used to register translational movement. The marker trajectory data were measured and calculated using a Kwon3D motion analysis system and were low-pass filtered with a 4^{th}-order Butterworth filter. All kinematic calculations were performed in the Kwon3D software package. Raw analog data from the force plate were used to calculate the GRF, moments, and center of pressure position by using a KwonGRF system. The inverse dynamic process was used to calculate the net joint reaction forces and net joint moments for the knee (Bresler & Frankel, 1950). Body segment parameters were estimated from the marker data and Dempster's coefficients. All kinetic data were normalized to body weight. The definitions of kinematic and kinetic parameters are shown in Figure 2. The landing phase was defined as the interval between the initial time of landing and the maximum knee flexion angle. The loading rate was defined as the force-to-time ratio, where force is the peak vertical GRF during the landing phase and time is the interval between the initial time of landing and the peak vertical GRF during the landing phase (Winter, 2005). The data were analyzed using the SPSS 14.0 for Windows package program. All data were analyzed using repeated measures one-way analysis of variance (ANOVA) to evaluate whether the median value of the test variable differed significantly among the 3 stop-jump tasks. The significance level was set at $\alpha = 0.05$

RESULTS: The kinematic parameters are presented in Table 1. The last step lengths were significantly differs among the PHJ, SHJ, and LHJ ($P < 0.05$). The hip and knee joint angle at initial foot contact with the ground did not significantly differ among the PHJ, SHJ, and LHJ ($P > 0.05$). The hip and knee joint angle at maximum flexion during landing did not significantly differ among the PHJ, SHJ, and LHJ ($P > 0.05$). The hip and knee joint angular displacement during landing did not significantly differ among the PHJ, SHJ, and LHJ ($P > 0.05$). The hip and knee angular velocity at initial foot contact with the ground did not significantly differ among the PHJ, SHJ, and LHJ ($P > 0.05$). The kinetic parameters are presented in Table 2. During landing, the LHJ had a significantly greater peak horizontal GRF than the PHJ and SHJ ($P < 0.05$). The peak horizontal GRF during landing did not significantly differ between the PHJ and the LHJ ($P > 0.05$). As step length increased, peak vertical GRF during the landing phase increased significantly in the PHJ, SHJ, and LHJ ($P < 0.05$). There was no significant difference in the duration from initial foot-ground contact to the peak vertical GRF among the PHJ, SHJ, and LHJ ($P > 0.05$). As step length increased, vertical loading rate during the landing phase increased significantly in the PHJ, SHJ, and LHJ ($P < 0.05$). During landing, the peak knee extension moment and proximal tibial anterior shear force did not significantly differ among the PHJ, SHJ, and LHJ (P > 0.05).

Table 1. Comparison of lower extremity kinematics (mean [standard deviation]) among 3 landing distances in a stop-jump task

	PHJ	SHJ	LHJ	Post Hoc
Last step length (m)	1.39 (0.14)	1.24 (0.18)	1.93 (0.23)	LHJ>PHJ>SHJ
Hip angle at initial foot contact with ground (deg)	113.65 (12.68)	113.08 (9.41)	111.57 (14.82)	No significant difference
Knee angle at initial foot contact with ground (deg)	141.23 (7.68)	144.19 (7.59)	139.57 (8.40)	No significant difference
Hip angle at maximum flexion during landing (deg)	103.57 (13.35)	104.27 (10.26)	102.45 (11.18)	No significant difference
Knee angle at maximum flexion during landing (deg)	93.45 (10.01)	94.81 (7.53)	94.32 (7.13)	No significant difference
Hip angular displacement during landing (deg)	10.08 (7.69)	8.81 (4.81)	9.12 (11.57)	No significant difference
Knee angular displacement during landing (deg)	47.78 (8.52)	49.37 (6.52)	45.25 (8.06)	No significant difference
Hip angular velocity at initial foot contact with ground (deg/sec)	-3.30 (2.18)	-2.12 (2.57)	-2.54 (1.34)	No significant difference
Knee angular velocity at initial foot contact with ground (deg/sec)	-8.28 (1.35)	-5.92 (4.24)	-8.22 (1.25)	No significant difference

Table 2. Comparison of lower extremity kinetics (mean [standard deviation]) among 3 landing distances in a stop-jump task

	PHJ	SHJ	LHJ	Post Hoc
Peak horizontal GRF during landing (BW)	-0.77 (0.29)	-0.64 (0.19)	-1.38 (0.50)	LHJ>PHJ; LHJ>SHJ
Peak vertical GRF during landing (BW)	1.98 (0.65)	1.50 (0.28)	3.02 (0.60)	LHJ>PHJ>SHJ
Time at which peak vertical GRF occurred following initial foot contact the with ground (sec)	1.24 (0.26)	1.16 (0.20)	1.14 (0.25)	No significant difference
Vertical loading rate (BW/sec)	1.61 (0.48)	1.29 (0.27)	2.76 (0.97)	LHJ>PHJ>SHJ
Peak knee extension moment during landing (Nm/BW)	0.35 (0.09)	0.33 (0.07)	0.39 (0.21)	No significant difference
Peak proximal tibia anterior shear force during landing (BW)	1.10 (0.20)	1.13 (0.22)	1.23 (0.28)	No significant difference

DISCUSSION: The performance of landing in a stop-jump task is important for the overall jumping performance following the landing and for the prevention of lower extremity injuries during landing (Yu et al., 2006). The purpose of this study was to compare the lower extremity loading of a stop-jump using different last step lengths during the approach run. Previous research has demonstrated that hip and knee kinematics in the sagittal plane during a stop-jump landing affect lower extremity loading. Our research shows that there were no significant differences in the hip flexion angle, knee flexion angle, hip flexion angular velocity, and knee flexion angular velocity upon initial foot-ground contact among the PHJ, SHJ, and LHJ. There were also no significant differences in the maximum hip flexion angle, knee flexion angle, and hip and knee angular flexion displacement during landing among the PHJ, SHJ, and LHJ. These results revealed that the kinematical characteristics of landing were similar among the different last step lengths during the approach run. However, the peak horizontal GRF, peak vertical GRF, and vertical loading rate during landing showed a significant increase as step length increased. These results suggest that longer last step lengths during the approach run may raise the risk of lower extremity injury in athletes performing a stop-jump task.

The impact on the lower extremity increases as the peak vertical GRF and loading rate increase (Williams et al., 2004). The results of previous studies showed that a greater vertical GRF and loading rate is associated with knee joint injury (Williams et al., 2004; Hewett et al., 2005), especially in the ACL (Radin et al., 1991; Shelburne et al., 2004). The results of the present study show that peak vertical GRF magnitudes increased significantly as step length increased. However, the time from initial foot-ground contact to the peak vertical GRF was similar among the PHJ, SHJ, and LHJ. According to these results, the loading rate increases significantly as step length increases, thereby increasing the risk of ACL injury.

The results of the present study show that peak posterior horizontal GRF magnitudes were greater in the LHJ. The peak posterior horizontal GRF during the landing of a stop jump may have the effect of muscular moment at the knee, lowering the proximal tibial anterior shear force. Yu et al. (2006) reported that the peak posterior horizontal GRF and peak knee extensor moment are significantly correlated to each other. In addition, the peak posterior horizontal GRF and peak proximal tibial anterior shear force are significantly correlated to each other (Yu et al., 2006). Previous research suggests that peak knee extensor moment and proximal tibial anterior shear force may be a potential risk factor for non-contact ACL injury (Yu et al., 2006; Chappell et al., 2007; Sell et al., 2007). However, this finding was not supported by our study. We found no significant difference in the proximal tibial anterior shear force among the PHJ, SHJ, and LHJ. This finding indicates that posterior horizontal GRF may not be responsible for the different last step lengths of the approach run in the ACL loading of subjects during a stop-jump task. However, muscle electromyographic activity should be studied further for a better understanding of the difference in quadriceps and hamstring muscle activity in the 3 stop-jump tasks.

CONCLUSION: The lower extremity kinematical characteristics of landing were similar among the different last step lengths during the approach run. However, the peak horizontal GRF, peak vertical GRF, and vertical loading rate during landing increased as step length increased, and this may raise the risk of lower extremity injury.

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