BIOMECHNICAL STRATEGY DURING PLYOMETRIC BARRIER JUMP-INFLUENCE OF DROP-JUMP HEIGHTS ON JOINT STIFFNESS

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The purpose of this study was to explore the joint stiffness of lower-extremity during plyometric barrier jump. Fourteen power-oriented track and field men of collegiate and national level volunteered to participate in the study. All performed 3 maximal effort drop jumps where they landed and immediately jumped over a 60 cm barrier after dropping from 30, 60 and 90 cm. The results showed both knee and ankle joint stiffness became progressively and significantly lower with the increment of drop heights. Modulating knee and ankle joint stiffness, mainly by the joint angles during touchdown, is the biomechanical strategy to accommodate for changes in different drop heights. Our findings suggest the increment of drop heights during plyometric barrier jump diminished the benefit from stretch-shortening cycle.

KEYWORDS: plyometric, stiffness, drop jump.

INTRODUCTION: Plyometric exercises are frequently used neuromuscular training in athletics (Meyer et al., 2005). Drop jump involved the stretch-shortening cycle (SSC) in the ankle, knee and hip muscles. Such rapid stretch supplied the elastic energy stored in muscle-tendon unit complexes during the braking phase of a SSC and elicited the stretch reflex for the greater power output during the push-off phase. Greater leg stiffness allows greater storage and release of elastic energy to increase the force of motion (Gollhofer et al., 1992; Komi, 1992; Wang, 2008). Commonly, athletes perform the drop jump at increased heights for a greater training stimulus. The purpose of this study was to determine the changes in the joint stiffness of lower-extremity associated with drop height increments when jumping over a barrier.

METHOD: Fourteen power-oriented track and field men of collegiate and national level (age: 22.5±3.5 years; body height: 177.1±5.6 cm; body weight: 87.2±16.5 kg) volunteered to participate in the study. All volunteers were enrolled after providing written informed consent. Prior to experiment, subjects changed specific footwear (New Balance Running Shoe, Model 629; New Balance Athletic Shoe, Inc., Boston, MA, USA) to control for different shoe-sole absorption properties. Lower-body lunging and squatting movements were performed as the warm-up exercise. Then they were asked to perform 3 maximal effort drop jumps where they landed and immediately jumped over a 60 cm barrier after dropping from 30, 60 and 90 cm (DJ30, DJ60, DJ90) (Figure 1). Kinematic data were collected at 240 Hz using 6 Eagle cameras which were positioned around the performance area and synchronized to force platforms (Bertec 4060 NC; Bertec Corp., Columbus, OH, USA) collected at 1200Hz. One platform recorded right extremity data, and one recorded left extremity data. The cameras and subsequent performance area were calibrated, yielding mean residual errors of 1.1-1.53 mm over a volume of 2.5 x 2.1 x 2.5 m. The marker coordinate data were processed using Orthotrak (Motion Analysis Corporation, Santa Rosa, CA, USA) and custom Matlab programs (Mathworks Inc., Natick, MA, USA). Based on a frequency content analysis of the digitized coordinate data, marker trajectories were filtered at 10.5 Hz using a fourth order Butterworth filter. Raw ground reaction force data were exported, and data were normalized to body weight. The onset of the ground contact phase was determined when the vertical ground reaction force (VGRF) exceeded 30N threshold. Net muscle joint moments (M) were calculated by combining the kinematic and force plate data with anthropometric data using the inverse dynamics solution. Positive net muscle joint moment was defined as extensor activity, while negative net muscle joint moment indicated the activity of the flexors. The joint stiffness (k_{joint}) was calculated by the formula: $(M_{joint})/(\Delta\theta_{joint})$, where the M_{joint} was the net muscle joint moment while the joint was maximally flexed during the ground contact phase, and the $\Delta\theta_{joint}$ was the angle change of the joint in the sagittal plane between the start of the ground contact phase and the instant when the joint was maximal flexed. The normalized joint stiffness was defined as the normalized net muscle joint moment divided by the joint angle change, and the unit was $Nm \cdot kg^{-1}/deg$. A repeated measures analysis of variance (3 drop height and 2 legs) was performed on normalized knee and ankle stiffness, normalized knee and ankle moment, knee and ankle joint angle changes, knee and ankle joint angles at touchdown, and maximal knee and ankle joint angles during ground contact phase using SPSS for Windows (Version 11.0, Chicago, IL) with alpha level of 0.05.

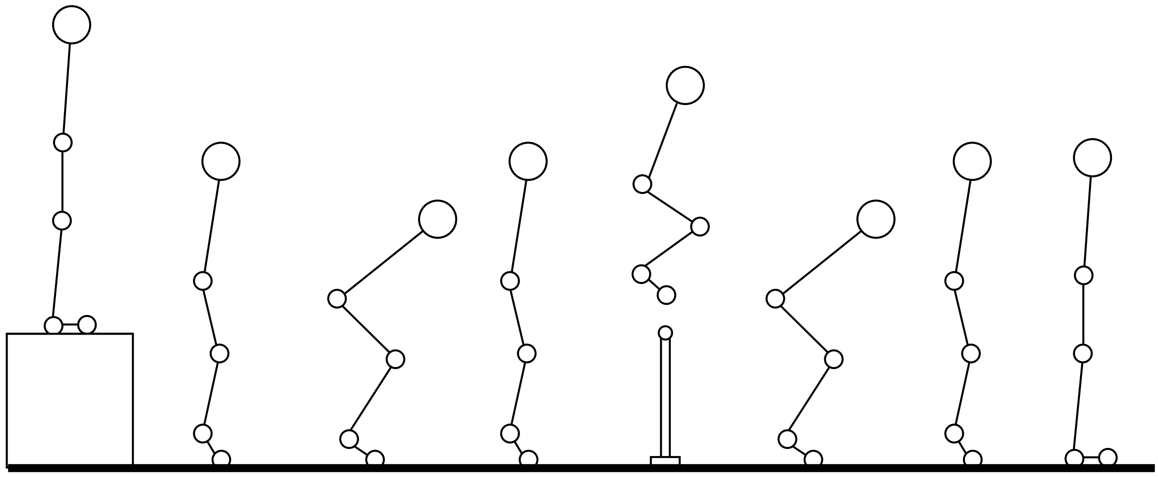

Figure 1. Modelled Representation of the Human Body during Plyometric Barrier Jump

RESULTS: There was no interaction between drop heights and legs for all outcome variables tested except for the knee flexion angle at touchdown. The normalized joint stiffness related parameters were summarized in Table 1. Both knee and ankle joint stiffness became progressively and significantly lower with the increment of drop heights (all p=0.001 and p<0.005 for pairwise comparison between each drop height for knee and ankle joint, respectively). The normalized muscle joint moment of knee joint was significantly higher in 60DJ and 90DJ than that in 30DJ (p=0.009 and p<0.005, respectively). Similarly, the ankle muscle joint moment was significantly higher in 60DJ and 90DJ than that in 30DJ (p=0.008 and p=0.022, respectively). There were no significant differences between 60DJ and 90 DJ for knee and ankle muscle joint moments (p=0.055 and p=0.451, respectively). With the increment of drop heights, both knee and ankle joint showed progressively and significantly larger angle changes during ground contact phase (all p<0.005 for pairwise comparison).

Table 1. Comparison between Drop Height Changes of Normalized Joint Stiffness Related Parameters during Plyometric Barrier Jump[a]

	30DJ		**60DJ**		**90DJ**	
	R't Leg	**L't Leg**	**R't Leg**	**L't Leg**	**R't Leg**	**L't Leg**
Knee						
Normalized M_{knee} ($Nm \cdot kg^{-1}$)	3.38(0.73)	3.49(1.23)	3.66(0.71)	3.65(1.30)	3.79(0.76)	3.76(1.34)
$\Delta\theta_{knee}$ (degree)	31.61(8.87)	31.50(9.01)	38.29(8.35)	40.57(11.21)	46.53(7.86)	47.49(9.53)
Normalized k_{knee} ($Nm \cdot kg^{-1}$/degree)	0.12(0.06)	0.13(0.06)	0.11(0.04)	0.10(0.04)	0.09(0.03)	0.08(0.03)

Ankle						
Normalized M_{ankle} (Nm·kg^{-1})	2.52(0.51)	2.66(0.71)	2.73(0.50)	2.91(0.82)	2.73(0.32)	2.81(0.82)
$\Delta\theta_{ankle}$ (degree)	30.77(10.18)	29.42(8.25)	43.34(7.27)	42.52(6.14)	51.50(6.81)	50.06(5.82)
Normalized k_{ankle} (Nm·kg^{-1}/degree)	0.09(0.02)	0.10(0.02)	0.06(0.01)	0.07(0.02)	0.05(0.01)	0.06(0.02)

[a] Data are presented as mean (SD)

Plyometric barrier jump with different drop heights demonstrated different landing patterns (strategies) (Table 2.). The knee and ankle joint became more straight and plantarflexed, respectively with the increment of drop heights (all p<0.005 for pairwise comparison between each drop height for both knee and ankle joint). However, they soon reached comparable degrees of maximal knee flexion and ankle dorsiflexion angles before taking-off (all p>0.05, except for maximal ankle dorsiflexion between 60DJ and 90DJ).

Table 2. Changes of Knee and Ankle Joint Angles during Ground Contact Phase of Plyometric Barrier Jump[a]

	30DJ		60DJ		90DJ	
	R't Leg	L't Leg	R't Leg	L't Leg	R't Leg	L't Leg
Knee						
Angle at touchdown (degree)	39.65(9.44)	40.21(9.25)	30.76(7.85)	28.15(6.14)	24.34(6.72)	23.05(5.69)
Maximal flexion angle (degree)	71.27(5.44)	71.70(6.92)	69.05(5.99)	68.72(8.32)	70.87(4.51)	70.54(6.83)
Ankle						
Angle at touchdown (degree)	0.50(9.60)	1.09(9.25)	-12.69(7.52)	-13.40(8.73)	-18.91(6.42)	-19.43(6.82)
Maximal flexion angle (degree)	31.27(4.82)	30.52(5.00)	30.65(5.25)	29.13(5.29)	32.59(4.59)	30.63(6.03)

[a] Data are presented as mean (SD)

DISCUSSION: Plyometric jumping exercises have became more and more popular in athletic training field, however, little is known about lower-extremity joint stiffness characteristics during plyometric barrier jump. Drop jumps involve a spring-like manner, where the leg spring compress and then lengthens during the ground contact phase (Farley and Morgenroth, 1999). The current study showed high-level athletes demonstrated significant decreases of knee and ankle joint stiffness while the drop heights increased from 30 to 90 cm. Comparing 60DJ with 30 DJ, both muscle joint moments and joint angle changes increased at knee and ankle joint. As the drop height increased to 90 cm, only knee flexed and ankle dorsiflexed angles increased around 8-degree without changes of lower-extremity muscle joint moment were evident. Interestingly, adjustment of knee and ankle joint stiffness, which was mainly modulating the knee and ankle angles during touchdown, was the biomechanical strategy to accommodate for changes in different drop heights. There were no differences between maximal flexion angles during ground contact phase regardless the joint. It may probably because these 3 drop jumps have the fixed barrier height in common that affect the activation of the neuromuscular system to the degree leading to achieve the success of the following barrier jump.

Joint stiffness depends on many factors, including the stiffness of each muscle-tendon unit that cross the joint (Farley and Morgenroth, 1999). Tendon and muscle stiffness increased with the force and activation level of the muscle. In the present study, the net muscle moment at knee and ankle joints increased from 30 to 60, and to 90 cm, however, these increases did not result in simultaneously increases in the knee and ankle joint stiffness. According to our previous report (Kernozek et al., 2007), the power absorption was increased with the increments of the drop height during plyometric barrier jump. The increase of knee extensor and ankle plantarflexor moments were used in the power absorption, therefore, decreased the joint stiffness. Although drop jump at increased heights could obtain a greater training stimulus, the diminishing leg stiffness during landing motion might decrease the benefit from the SSC, since greater leg stiffness allows greater storage and release of elastic energy to increase the force of motion (Gollhofer et al., 1992; Komi, 1992; Wang, 2008). Additionally, since enhanced joint angular stiffness could resist sudden angular displacement, which is beneficial to the joint stability. Previous study suggested that reduced joint angular stiffness may increase the damage to cartilage and ligaments (Butler et al., 2003).
There were some limitations of this study. The results of the current experiment were not comprehensive for every lower-extremity joint performance. Only men of advance athletic ability were used, hence the results might not relate directly to all athletic populations.

CONCLUSION: Decreased knee and ankle joint stiffness associated with the increment of drop heights during plyometric barrier jump diminished the benefit from stretch-shortening cycle. The result may serve as training basis for plyometric exercise practitioners.

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