THE INTERRELATIONSHIP OF JOINT STIFFNESS IN DROP JUMP UNDER DIFFERENT CONDITIONS: A SINGLE-SUBJECT DESIGN

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The purpose of this study was to examine the relationship between leg stiffness and joint stiffness in the various conditions of drop jump. A women's athlete was recruited as the subject and asked to perform drop jump from different height of box to another box in different horizontal distance between them. The leg stiffness is influenced on the contact time and relates to knee and ankle joint stiffness. The change in leg length is greater at great horizontal distance and peak ground reaction force is greater at higher box of jump off and up. The contact time was also related to the horizontal distance and to the knee and ankle joint stiffness, peak ankle joint torque and minimum knee joint angle. These might suggest that leg stiffness influenced by ankle and knee joint stiffness due to peak ankle joint torque and knee joint angular displacement to adjust the conditions of drop jump.

KEY WORDS: leg stiffness, joint stiffness, drop jump, contact time

INTRODUCTION: Drop jump is well known to enhance the power and widely use training for athlete to jump off a certain height as a typical stretch-shortening activity of lower limb muscles (Thys et al., 1972 ; Komi and Bosco, 1978). It has been studied the effect of the height of jump off on muscular power and contribution of lower limb joints (Bobbert et al., 1987 ; Vitasalo et al., 1998 ; Walshe and Wilson, 1997). However, the muscular activity in drop jump should be not only enhanced muscular power but also coordinated the output in the lower limb joints effectively. Although there were a lot of studies in drop jump for the characteristics of the power output, there was few study for coordination of lower limb joints in drop jump. Therefor this study is a pilot case to examine the effect of the height and forward distance in drop jump on coordination of lower limb joints by inter-individual comparison of the variation. Individual (singlesubject) analysis has revealed varied responses to interventions (Stergiou and Scott, 2005), with increased sensitivity to change compared to group analysis.

Joint stiffness which is calculated by joint torque divided by joint angular displacement is a useful index of power output in stretch-shortening muscular activity. There were several studies focused on the joint stiffness in jump movement. Recently it would be hypothesized that the joint stiffness is not merely a parameter to evaluate power output biomechanically, but might be an index to examine a regulation of power output. Farley and Morgenroth (1999) showed that leg stiffness was depended on the ankle stiffness in hopping. On the other hand, Hobara et al. (2009) showed that leg stiffness was depended on the knee stiffness in maximal hopping. Athletes have frequently used not only different height of a box but also various distance between boxes in drop jump for their training. There is no study to examine the influence of horizontal distance or forward movement on joint stiffness in drop jump. We are interested in how athlete adjust the joint stiffness of the lower limb to various condition in drop jump. The findings of this study may be useful to arrange the drop jump condition for individual training.

The purpose of this study is to examine the relationship between leg stiffness and joint stiffness in the various conditions of drop jump and to get an insight into a regulation of power output in lower limb joints.

METHODS: A women's athlete who is a midle distance runner was participated in this study as the subject. The subject was asked to perform the drop jump which is eleven different conditions in the height of boxes (30 and 60 cm) to jump off and jump up and the horizontal

distance between them (60, 120 and 180 cm). We collected both kinetic and kinematic data during each drop jumping trial. The subject performed the trials on a force platform (Kistler, Kistler Japan Co., Ltd., Japan).
During the trials, we collected (sampling frequency"1000 Hz) the vertical and horizontal components of the ground reaction force. The subject was videotaped in the sagittal plane at 120 fields per second using a high speed video camera (EX-100, CASIO Inc., Japan). The 7 body landmarks (toe, ball, heel, ankle, knee, greater trochanter, and shoulder), and the 4 reference marks were digitized for every frame during support phase. Two dimensional positional data of the reflective makers was digitized by motion analysis software (FrameDias V, DKH Inc., Japan).
Leg stiffness was calculated with the spring-mass model (Blickhan, 1989), which can be calculated as the ratio of peak vertical GRF to change in leg length in the shortening phase (Farley and Morgenroth, 1999). The change in leg length shortening is defined as the displacement of the line between hip and toe from touchdown (Ltd) to the minimum value (Lmin). Joint stiffness was calculated with the torsional spring model (Farley et al., 1998; Farley and Morgenroth, 1999). We calculated joint stiffness by dividing peak joint torque by minimum joint angle at mid support. Joint stiffnesses were normalized by the subject's body mass.
Pearson's product-moment correlation coefficient was determined for each parameter.

RESULTS: Table 1 shows mean and standard deviation of kinetic and kinematic parameters in the drop jumps for the subject. The contact time is 0.227±0.024 s and the peak ground reaction force, leg shortening length, and leg stiffness are 3.45±0.64 kN, 0.19±0.03 m, and 18.5±4.0 kN/m. However, these standard deviations are slightly large, which are 20 % variation in the stiffnesses although the contact time is 10.4%. Asterisks in the table indicate significant relationships between the parameters and the contact time. There are significant relationships between contact time and Leg stiffness, ankle and knee joint stiffness.
Figure 1 shows leg stiffness, peak ground reaction force and the change in leg length shortening in the different conditions of drop jump for the subject. The horizontal lateral and anteroposterior axes indicate the horizontal distance and the height of jump up respiratory. And the dark and white bars show 30 and 60 cm height of jump off respiratory. The leg stiffness of 30 cm jump off and 60 cm jump up in the distance of 120 cm is highest in these conditions (e). However, it varies with the jump off and up and the horizontal distance, which means leg stiffness would be increased by not only the height of jump off but also jump up and would be decreased by the horizontal distance.
Figure 2 shows relationships between leg stiffness and hip, knee and ankle joint stiffness in various drop jump for the subject. There is the significant relationship between leg stiffness and knee joint stiffness. Ankle joint stiffness is shown a tendency of relationship with leg stiffness although hip joint has no relationship to leg stiffness.

Table 1: Kinetic and kinematic parameters in drop jumpFigure 1 (Left): Leg stiffness, peak ground reaction force and the change in leg length shortening in the different conditions. Figure 2 (Right): Relationships between leg stiffness and hip, knee and ankle joint stiffness.

	Mean	SD	
Ground contact time (s)	0.227 ±	0.024	
Peak GRF(kN)	3.45 ±	0.635	
Leg compression (m)	0.19 ±	0.03	
Leg stiffness (kN/m)	18.5 ±	4.0	*
Hip peak moment (Nm/kg)	2.10 ±	0.41	
Knee peak moment (Nm/kg)	2.61 ±	0.39	
Ankle peak moment (Nm/kg)	2.97 ±	0.41	*
Hip minimum anguler (deg)	121.0 ±	5.5	
Knee minimum anguler (deg)	107.1 ±	5.4	*
Ankle minimum anguler (deg)	92.9 ±	3.7	
Hip joint stiffness (Nm/deg/kg)	35.2 ±	7.0	
Knee joint stiffness (Nm/deg/kg)	35.4 ±	7.2	*
Ankle joint stiffness (Nm/deg/kg)	33.6 ±	4.5	*

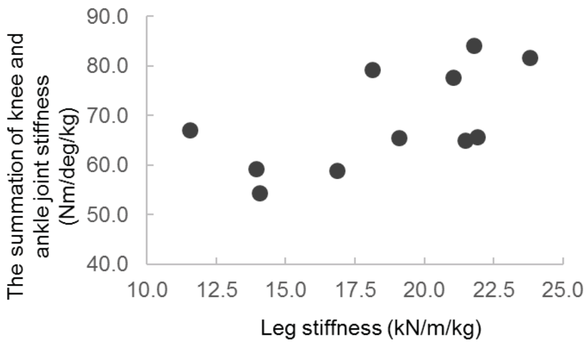

Figure 3: Relationships between leg stiffness and the summation of knee and ankle joint stiffness.

DISCUSSION: The significant relationship between the contact time and the leg stiffness was found in the various condition of drop jump, but the change in leg length shortening and peak ground reaction force are not shown significant relationship to the contact time (Table 1). It would be frequently discussed that leg spring relates to contact time (Kuitunen et al., 2011). The horizontal distance between the boxes could change the forward movement which influence on the contact time of the jump. It was shown that the leg stiffness was low in the condition of large horizontal distance of drop jump (Figure 1). Furthermore, leg stiffness was significantly correlated to peak ground reaction force ($r=0.744$, $p<0.05$) and not significant but moderate correlation coefficient was shown to the change in leg length shortening ($r=-0.610$, n.s.). These results imply that the leg stiffness is influenced by both the peak ground reaction force and the change in leg length shortening in various conditions of drop jump and the subject might adjust her leg stiffness as to complete jump up from various height of jump off and to horizontal distance. It would be speculated that the increase in height of jump off or up may induce enhance of peak ground reaction force and the increase in horizontal distance between boxes lead to increase in the change in leg length shortening, which would change the leg stiffness.

This study is aimed to examine the relationships between leg stiffness and hip, knee and ankle joint stiffness. The significant relationship between leg stiffness and knee joint stiffness was found and Leg stiffness was shown a trend of relationship to ankle joint stiffness but not to hip joint stiffness (Figure 2). Furthermore, the summation of knee and ankle joint stiffness was shown a trend of relation to leg stiffness (Figure 3). It was indicated that leg stiffness is influenced by both knee and ankle joint stiffness in the various conditions of drop jump.

It was examined that leg stiffness may control the contact time and is influenced by knee and ankle joint stiffness in the various height and horizontal distance of drop jump in this study. Moreover, it was shown that the parameters in relationship to the contact time are the knee and ankle joint stiffness and the peak ankle joint torque and the minimum knee joint angle (Table 1). These results indicate that peak ankle torque and knee joint angular displacement might be influenced on each joint stiffness and then on the contact time. From the results and discussion of this study, it would be concluded that the subject could adjust leg stiffness by the flexion of knee joint in the condition of large horizontal distance and by enhancing ankle torque in the condition of great height of the box in drop jump.

CONCLUSION: The leg stiffness was related to knee and ankle joint stiffness in various height and horizontal distance of drop jump. The leg stiffness might be adjusted to the horizontal distance by knee joint stiffness and to the height of jump off or up by ankle joint stiffness. These findings could give a useful information for the athletes to enhance the leg stiffness and might play a role to evaluate the characteristic of the leg stiffness for athletes. However, this was only the case study for one subject, so we need to confirm it for various subjects. But it was useful to get an insight to control the leg stiffness as to examine for one subject.

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