BIOMECHANICAL STUDY OF LANDING MOTION ON A SPRING SURFACE

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The purposes of this study were to compare landing motion on a spring surface and that on the ground, and to consider about how to change the landing motion by changing the landing surface. Subjects performed drop landing motion on a force platform (DL) and drop landing motion on a spring surface (DLS) from the top of a box. The ground reaction force of DLS changed greatly up and down like a sign wave. The joint angular velocities of the lower extremity for DLS changed greatly up and down. In particular, the angular velocity of the knee joint was greater than those of other joints. The peak ground reaction forces were absorbed many times after the first peak ground reaction force. Since angular velocity after LOW was the highest in the knee joints compared with the other joints, it was suggested that ground reaction force was mainly absorbed by the knee joint.

KEY WORDS: landing motion, surface condition, adjusting, absorbing.

INTRODUCTION: In landing motion, the momentum of the whole-body center of gravity (CG) should be absorbed by ground reaction forces. At the same time, joint movement and joint torque of the lower extremities absorb the kinetic energy of the whole body. Many previous studies have analyzed changes in landing motion according to the change in initial height. Landing motion should be adjusted to the ground elasticity or hardness. Some studies have compared the movements during landing on hard ground to those on a soft mat (Mcnitt, Yokoi and Millwand, 1994). Other studies performed motion analyses and examined muscle activities during continuous hopping on a spring surface (Marquez, Morenilla, Taube and Fernandez, 2014). However, studies on landing motion on a spring surface are scarce (Daniel and Claire, 1997). The purposes of this study were to compare landing motion on a spring surface and that on the ground, and to consider about how to change the landing motion according to the surface condition.

METHODS: Four men (height, 1.73 ± 0.05 m; weight, 74.5 ± 11.4 kg; and age, 25.2 ± 2.5 years) participated in this study after providing informed consent. Figure 1 shows a schematic diagram of the experimental setup. The subjects performed drop landing (DL) motions on a force platform and drop landing motion on a spring surface (DLS) from the top of a box (height, 0.4 m). The size of spring surface was 1.2m*0.9m. The spring constant of the spring surface was about 10N/mm. The subjects were asked to land with their hands on their hips and to be static after landing. This study was approved by the ethics committee of the University of Tsukuba.
The global coordinate system was defined as shown in Figure 1. The three-dimensional coordinates of the reflective markers on the body segments and spring surface were captured using a 13-camera Vicon MX+ system (Vicon Motion Systems Ltd., UK) that operated at 250 Hz. Data on the coordinates of the body were smoothened by using a Butterworth digital filter. Optimal cutoff frequencies (15–35 Hz) were identified by using the residual method proposed by Wells and Winter (1980). Ground reaction force was collected using a force platform (Kistler 9287) that operated at 1000 Hz. Figure 2 shows a stick picture of the typical landing motion of a subject (On: foot contact with surface, LOW: instant in the lowest CG). The inertial parameters were estimated using the inertia coefficients proposed by Ae, Tang, and Yokoi (1992). The paired t-test was used to compare segment angle and joint angle at foot contact (ON) between DL and DLS.

RESULTS: Table 1 presents the segment (a) and joint angles (b) at foot contact (ON). The torso angle (θTorso) in DL was larger than that in DLS. The thigh angle (θThigh) in DL was smaller than that in DLS. The hip (θHip) and ankle angles (θAnkle) in DL were larger than those in DLS. Compared with DLS, DL tended to be performed during hip extension and ankle plantar flexion. Figure 2 showed the stick picture of a typical subject. The joint range of motion in DLS was greater than that in DL, and the change in the CG from ON to LOW in DLS was greater than that in DL. Figure 3 shows the ground reaction force of a typical landing motion. The solid line indicates the ground reaction force in DL; and the dashed line, in DLS. The left graph (a) shows the vertical component of the ground reaction force; and right graph (b), the anterior-posterior component of the ground reaction force. The both components of the ground reaction force in DLS (dashed line) changed greatly up and down like a sign wave. Figure 4 illustrated the joint angles (bottom row) and angular velocities (top row) of the lower extremities during the landing on the different surfaces. The left column shows the hip angle (θHip); the center column, the knee angle (θKnee); and the right column, the ankle angle (θAnkle). The solid line shows the joint parameter in DL; and the dashed line, in DLS. The joint angular velocities of all the joints in DLS (dashed line) changed greatly up and down. In particular, the angular velocity of the knee joint was greater than those of the other joints.

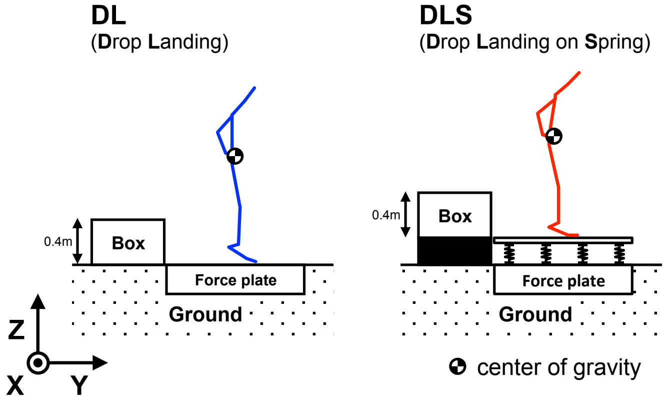

Figure 1: Schematic diagram of experimental setup from lateral view.

Table 1
The segment angles and the joint angles at foot contact (ON)

(a) Segment angles

	DL	DLS	
θTorso	87.9±3.84	81.1±7.46	*DL > DLS
θThigh	101.4±1.04	106.7±3.58	*DL < DLS
θShank	84.3±1.96	84.8±3.29	n.s.

Mean±SD n=4 * p<0.05

(b) Joint angles

	DL	DLS	
θHip	171.3±9.48	162.6±10.9	**DL > DLS
θKnee	163.2±2.75	158.2±6.31	n.s.
θAnkle	119.8±4.91	103.7±8.91	*DL > DLS.

** p<0.01 * p<0.05

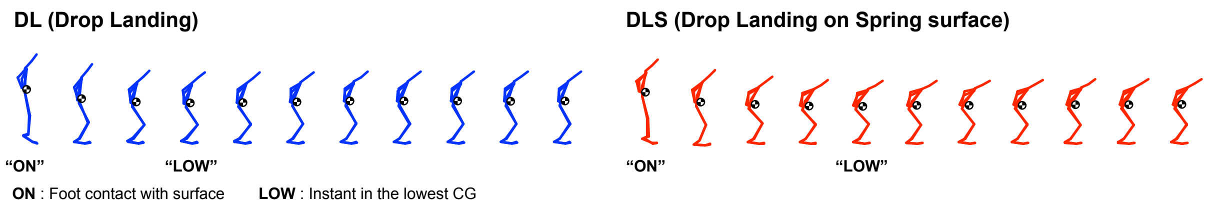

Figure 2: Stick pictures of landing motion for a typical subject.

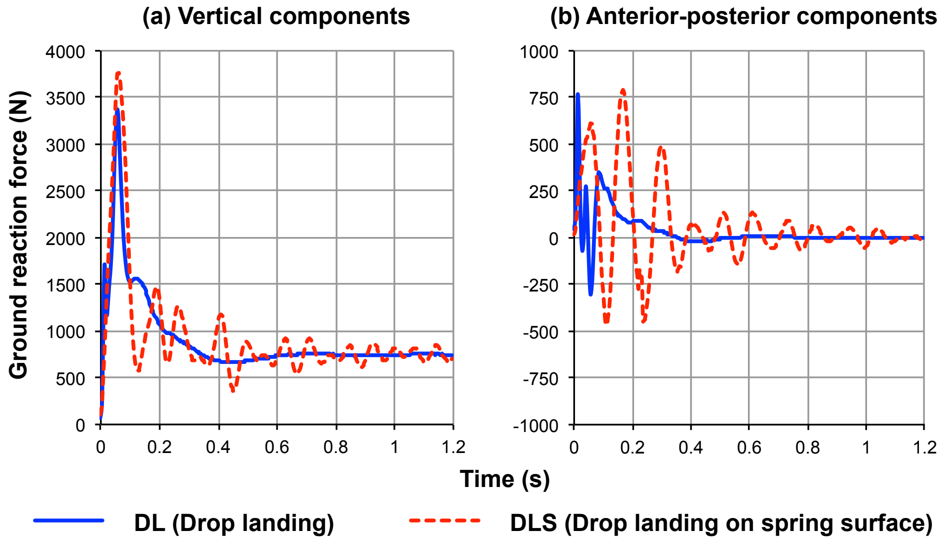

Figure 3: Stick pictures of landing motion for a typical subject.

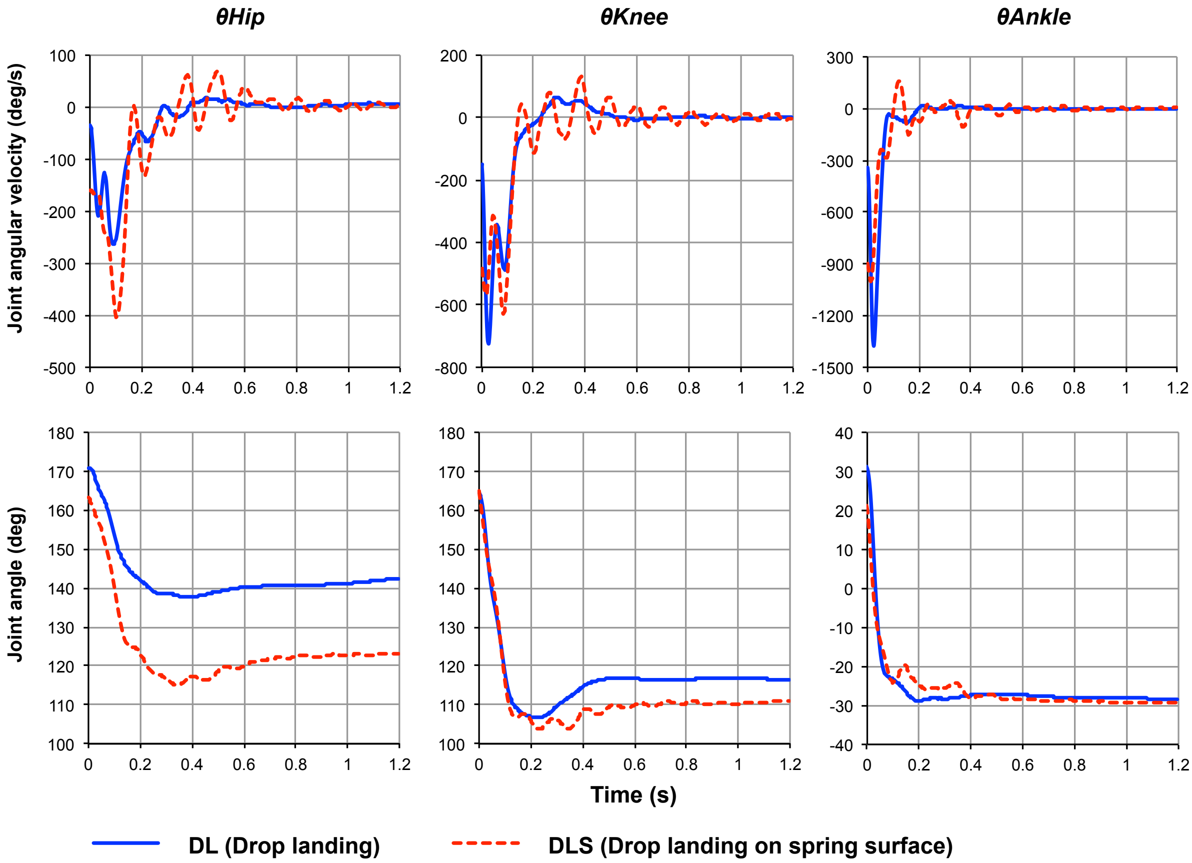

Figure 4: Lower joint angle (bottom row) and angular velocity (top row) of landing motion during difference surface condition.

DISCUSSION: The major differing factor between DL and DLS was that the spring surface has an elastic property. Because the spring is an elastic material, the response of the force depends on the displacement of the spring. The spring exerts greater force when the displacement of the spring increases, and the spring exerts lesser force when the displacement of the spring decreases. Because the displacement of the spring increased or decreased while landing, the ground reaction force in DLS increased or decreased greatly. Meanwhile, the height of the CG did not change greatly. The displacement of the CG was controlled by the joint movements of the lower extremities.

According to previous studies, leg stiffness reduced with lower limb flexion when the landing surface was stiff. This landing strategy was because the impact force applied to the body was reduced. In order to reduce leg stiffness, the peak ground reaction force should be reduced by increasing the displacement of the CG. The angular displacement of the hip and knee joints from ON to LOW in DLS was greater than that in DL. Therefore, leg stiffness in DLS was considered to be lesser than that in DL. In this study, the spring surface stiffness was lower than the ground stiffness. The strategy of reducing leg stiffness with the lower surface stiffness was the major difference of this study from the previous studies. We have clearly stated that the response of the force differed between landing on a mat (the landing surface used in the previous studies) and that on a spring surface (the landing surface used in this study). The peak ground reaction forces were absorbed many times after the first peak ground reaction force. The fact that angular velocity after LOW (about 0.24 s) was the highest in the knee joints compared with the other joints suggests that the ground reaction force was mainly absorbed by the knee joints.

CONCLUSION: Because the response of the force differed between the ground and spring surfaces, the landing motion strategy was adjusted to the landing surface condition. If the peak ground reaction forces were absorbed many times after the first peak ground reaction force, ground reaction force was mainly absorbed by the knee joint.

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