LOWER EXTREMITY JOINT KINETICS DURING LANDING OF A DROP JUMP FROM DIFFERENT HEIGHTS AND LANDING SURFACES.

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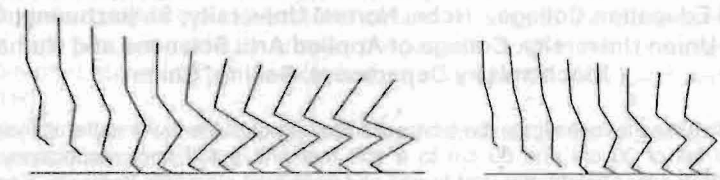
This study aimed to investigate the biomechanical effect of the lower extremity joints from a vertical fall of 30 cm and 60 cm to a soft mat and a stiff floor respectively. Result shows, from either height, the joint forces and peak joint moments decrease significantly, while the joint angles changes to a greater degree when landing on a soft mat and it needs more time from initial contact till the action stops. Each joint moment is effect of external moment and internal muscle moment together. The correct landing technique is that moments of all joints reduce simultaneously, i.e. the contraction and passive extension of muscles should be controlled in sequence and magnitude. The highest muscle moment on contact landing is observed at hip joint on both landing conditions and the muscles of the knee and ankle joints guided by the hip muscles assist each other.

KEY WORDS: landing height, landing stiffness, knee, hip, ankle, angle

INTRODUCTION: This study concerns the moment changes of lower extremity joints of the human body when landing on different kinds of surfaces: the stiff gymnasium floor and 10 cm thick soft gym mat, investigating the dynamical contributions to lower extremity joints damnification during the free fall from different heights on different landing conditions.

METHODS: Ten female university students with an average age of 20 $\pm$ 0.63 yrs and an average mass of 51.1 $\pm$ 3.1 kg were asked to jump with the hand keeping on the anterior superior lilac spine all the time from heights of 30 cm and 60 cm with no initial vertical velocity, and land on a force platform on one foot wearing gym shoes. There were two types of surfaces of the force platform -- a hard floor or a 10 cm thick soft mat.
The ground reaction force and moment were recorded by a force platform made by the Tsinghua University. Landing time refers to the duration from the moment the foot contacts the landing to the moment the knee flexes to the greatest degree. The jump landing motion was recorded by a Panasonic AG-DP200 video camera (25 Hz). The video images were analyzed with an AG image analysis system (Beijing Aijie Human Body Investigation Institute, No.11 Gymnasium Road, Beijing, China).
The hip and knee joint angles were defined as 180° when the body stands upright, and the ankle joint angle was greater than 90° during plantar flexion. Provided the three joints of the lower extremity are made up of three rigid bodies, The moment of joints are calculated from Newton's law $\sum M = J\beta = J\frac{d\omega}{dt}$ ($\sum M$ is the joint moment, J is the moment of inertia, β is the angular acceleration, ω is the angular velocity, $\frac{d\omega}{dt}$ is the derivative of angular velocity). The direction of the extensor is defined as the positive direction. Still in order to avoid the variation brought about by weight difference, it is proposed that the moment of joint per kilo weight is M/m, the moment of the ankle, knee and hip per kilo weight are M1/m, M2/m and M3/m, respectively. The parameters were calculated and analyzed using SPSS for windows version 10.0. The significant level for difference was set at α= 0.05.

RESULTS AND DISCUSSION: This study aimed at the definition and comparison of ground reaction force, the angle of joints and the moment of joints during the free fall from different heights on different conditions. The result shows, in the experiment, the joints of hip, knee and ankle flexes to different degrees. From the height of 30 cm to the soft mat and the stiff floor, the landing time is 140 ms and 300 ms respectively. It is 160 ms and 320 ms respectively from the height of 60 cm on the two different landing conditions. From either height, the average landing time on the two landing conditions are significantly different. The force at the joints of lower extremity reduces with the increase of landing time and it is good for the prevention of joint injuries.



(a) soft landing (b) stiff landing

Figure 1 Stick figure representations of typical soft and stiff landing.

Figure 1 is a sketch of the movement of lower extremity falling from the height of 60 cm to soft and stiff landing. Compared to the soft landing, the range of movement of each joint falling on stiff floor is comparatively smaller. With the increase of stiffness of the landing, the flexural angle of joints of lower extremity reduces. The reduction of angle of hip can reach about 45°, knee about 29° and ankle at least 9° Falling to two different landings from the height of 30 cm, the flexion degree of the joints of lower extremity is smaller than from the height of 60 cm, but the change of joints tend the same way. Table 1 shows the average angle of joints falling from two different heights to different landing surfaces. The result of joint angle shows that when foot contacts the landing, the kinetic property of the lower extremity relates to the stiff landing, legs flex to a greater degree when subjects land on the softer surface.

It should be noticed that the change of the angle of joints is dependent on whether the subject has sports experience. Subjects without any sports experience are not steady in landing skills, so the angles of joints change considerably at each trial. While subjects habit of sports and with sports experience have steady landing skills, so the angle of joints is almost the same at each trial, and with the increase of landing stiffness, the angles of joints do not change as much as those of the subjects without any sports experience. It shows when the stiffness of landing changes, the subjects with sports experience has a stronger sense of self-protection by changing the joint angles of lower extremity during landing.

Regardless of landing conditions, all subjects jumped off without an initial vertical velocity from the height of 30 cm and 60 cm, the vertical ground reaction forces all appeared as curves with two peak values. To avoid the influence of weight difference, is ground reaction force was divided by the mass of the subject (F/m). Combined with the synchronously taken the video images, it shows the first peak (F1/m) appears at the moment toe contacts landing and the second peak (F2/m) appears at the same time when heel contacts landing.

The first and second peaks in the vertical GRF curves have no obvious change in time when subjects fell from either height or on either landing surface. The time on contact landing is about 10 ms and 49 ms from the height of 30 cm and it is about 11 ms and 50 ms from the height of 60 cm. Although it is mentioned that the average landing time on stiff floor is 140 ms and 160 ms, while it is about 300 ms and 320 ms on soft mat, but the great force produces within a very short time, which is called the impact phase. This phase begins at the moment foot contacts landing and ends at GRF comes up to a relatively unchanging value after the second peak vertical to GRF. The impact phase ends after about 80 ms from the height of 30 cm and 85 ms from 60 cm. Meanwhile, the two vertical forces appear with two peaks and with the increase of the flexion of knee joint, the vertical GRF reduces. For all subjects, the peak value of normalized force has no significant different in the same experimental condition, but has relationship with the height and the landing condition (see table 1). With the same landing from different heights, there is significant different between F1 (30 cm)/m and F1 (60 cm)/m, and between F2 (30 cm)/m and F2 (60 cm)/m. With the different landing condition from the same height, there is also significantly different between F1 (soft)/m and F1 (stiff)/m and F2 (soft)/m and F2 (stiff)/m.

Table1 Ground reaction forces and mean of joints angle.

Drop height	Landing condition	F1/m (N/kg)	F2/m (N/kg)	θ_1 (°)	θ_2 (°)	θ_3 (°)
30 cm	Soft	11.7 (± 1.17)	21.5 (± 1.23)	44 (± 1.66)	83 (± 2.03)	105 (± 1.74)
	Stiff	17.6 (± 1.79)	26.4 (± 2.15)	64 (± 2.02)	122 (± 2.89)	150 (± 2.48)
60 cm	Soft	14.8 (± 0.95)	25.0 (± 1.73)	61 (± 2.26)	52 (± 3.43)	72 (± 2.81)
	Stiff	23.1 (± 2.05)	34.1 (± 2.51)	70 (± 2.46)	80 (± 2.92)	118 (± 2.25)

* The values in parenthesis are standard deviation.

From the height of 30 cm or 60 cm, on soft landing or stiff floor, the moment of all joints tends to change the same way, only different in range. With the same landing condition, the highest normalized moment of all joints from 30 cm high is significant smaller than that from 60 cm high ($p < 0.001$). From the same height, the normalized moment of all joints on the soft landing is significantly smaller than that on the stiff landing ($p < 0.001$) (Figure 2). Regardless of the drop height, 30 cm or 60 cm, the highest value of the moment appears in the hip joint, 5.4 Nm/kg from 30 cm high and 6 N m/kg from 60 cm on average.

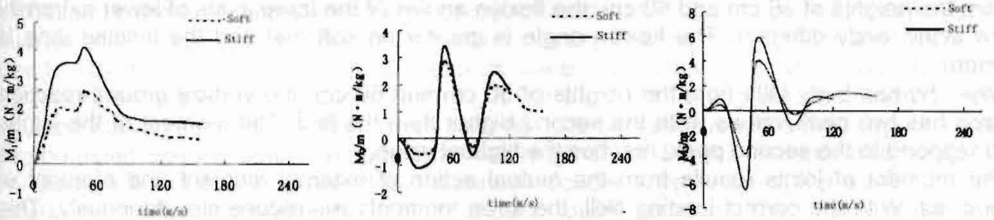


Figure 2 Curves of Joint moment when falling from the height of 60 cm to different surfaces.

As soon as the foot contacts landing, subjects first control knee flexion and ankle plantarflexion, then actively flexing the hip and rotating the trunk forward and downward. Finally, hip stops flexion and ankle plantarflexies less and less till stops. Mizrahi et al. (1982) have discovered that the peak value of forces in all segments speeds up it's reducing simultaneously, while this study discovers that for subjects with sports experience, the forces of the joints of hip, knee and ankle almost reduces simultaneously, but for subjects without any sports experiences, the reducing of forces of knee and ankle lags a bit behind that of hip. In this case, the joints of knee and ankle are likely to receive more force than that of hip, and therefore likely to get injured. What leads to this situation is the subjects' incorrect skill in landing, i.e. the incorrect order of contraction and extension of muscles around the three joints of lower extremity, and the lack of coordination of muscle contractions. Therefore, to grasp the correct landing skill, that is to understand the correct flexion order and the correct angle of the flexion of the three joints of the lower extremity is the key to prevent joints from being injured.

The moment of the joints of lower extremity results from the common function of muscles around joints. When the human body falls to landing from a certain height, the movement pattern of the joints of lower extremity is defined in anatomy as flexion and extension action, so the moment of joints is the sum of flexor moment and extensor moment of the joints. To compare the moments of joints of each subject on soft and stiff landing, it was discovered that the function of the moment of hip is to make the trunk and upper limb rotate forward with hip as the axis after floor contact phase, and continue until the landing completes. To reduce the impact force to the spine, the extensor moment of hip begins eccentric contraction so as to reduce the angular velocity of hip flexion. It is just because of the greater extensor moment that the angular velocity of hip flexion reduces greatly when falling on stiff landing. At the same time, the flexor moment of hip makes the trunk and upper extremity rotate forward so that the mass of the human body approaches the knee joint, and the arm of force from body's center of gravity to knee shortens. Therefore, it reduces the external moment and load at the knee, and that is to say, reduces the moment of knee. The result shows when falling from a certain height, the posture of body has to be changed according to the landing condition, which results in the adjustment of the extensor moment of hip joint to reduce of the impact force on body.

By studying the flexor moment at the knee, it is discovered that the extensor moment at the hip and flexor moment at the knee are mainly provided by hamstrings muscle group, which is also supported by EMG activity in the middle of hamstrings during the descent phase in landing by Miyatsu et al. (1982). The knee flexor moment is necessary. The highest muscle moment occurs at the hip in both landing condition. It is probably because the hip muscles must control the movement of the entire upper body (head, upper limbs, trunk), which consists of 68% of the body, mass, while knee and ankle joint muscles just assist each other and are assisted by the hip muscles in controlling segmental rotations and the greatest moment of all joints appear at about the same time as the second peak of the vertical ground reaction force.

CONCLUSION: When human body falls without initial velocity on the stiff floor and soft mat, from the heights of 30 cm and 60 cm, the flexion angles of the three joints of lower extremity are significantly different. The flexion angle is greater on soft mat and the landing time is longer.

When human body falls from the heights of 30 cm and 60 cm, the vertical ground reaction force has two peak values, with the second higher than the first. The moment of the joints, correspond to the second peak, reaches the highest value.

The moment of joints results from the mutual action of external moment and moment of muscles. With the correct landing skill, the three moments will reduce simultaneously. This result suggested that the contraction and passive extension of muscles must be controlled in order and magnitude.

Among the moments of the three joints, the moment of hip is the greatest and the muscles of knee and ankle joint assist each other and are assisted by the hip muscles.

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