EFFECTS OF DIFFERENT JUMP-LANDING DIRECTIONS ON SAGITTAL PLANE KINEMATICS, KINETICS AND ENERGY DISSIPATION AT LOWER EXTREMITY JOINTS

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The purpose of this study was to investigate the effects of different jump-landing directions on sagittal plane kinematics, kinetics, and energy dissipation. Subjects were required to perform a double-leg jump at three directions to a height equivalent to 50% of their maximum vertical jump height and land with single-leg and maintain balance for three seconds. Our findings indicated that landing strategy changed across different jump-landing directions in a way that maintained the same level of shock attenuation via altering body position and using the knee and ankle joints as primary dissipaters. We suggested that the knee joint showed major contributions to energy dissipation at forward and diagonal directions, and increased the use of ankle joint to dissipate energy while landing at lateral direction.

KEY WORDS: shock attenuation, injury, single-leg landing.

INTRODUCTION: Jump-landing is a common movement repeatedly used in sports activities, such as basketball and volleyball. These types of sports activities carry higher risk associated with lower extremity injuries when landing from a jump, particularly for a single-leg landing. During the landing period, mechanical impact must be attenuated by the musculoskeletal system. Therefore, lack of adequate shock attenuation capability of lower extremity joints during landing may lead to injuries (Coventry, O'Connor, Hart, Earl, & Ebersole, 2006). As a result, it is important to note that the lower extremity joints contribute to shock absorption via energy dissipation by the joint muscles. Previous studies reported that these lower extremity contributions to energy dissipation can be influenced by various factors, like gender, landing height and muscle fatigue (Devita & Skelly, 1992; Decker, Torry, Wyland, Sterett, & Richard Steadman, 2003; Coventry et al., 2006). However, few studies have discussed energy dissipation while performing different jump-landing directions. Researches have suggested that only investigating sagittal jump-landing protocol might neglect some important information about neuromuscular control.

The landing movements usually involve lower extremity joints movements and are often characterized as soft or stiff. The use of different landing strategies might be a way to cope with the landing impact during different landing tasks. In general, work done on the extensor muscles through eccentric muscle action during landing can be described as energy absorption or energy dissipation. In the past, several studies have looked into the contributions of different muscle groups to total energy dissipation in the sagittal plane during landing which usually involves dissipations of kinetic energy (Devita & Skelly, 1992). Devita and Skelly (1992) also suggested that ankle joint plantarflexors absorbed more energy in a stiff landing, whereas hip and knee extensors absorbed more energy in the soft landing. In this current study, we combined both joint kinematics and kinetics to discuss the effects of lower extremity joints contributing to energy dissipation during different jump-landing directions.

METHODS: Eleven healthy males (24±1.0years old; 71.3±8.3 kg; 172.8±3.7 cm) were recruited for this study. All subjects were free from previous lower extremity and head injuries, and none had experienced any acute disorders for the past three months.

One force plate (Kistler 9821, Germany) embedded within the floor, was used to collect ground reaction force data (GRF) at a sampling rate of 1000 Hz. Kinematics data were collected using a ten-camera, three-dimensional (3D) motion analysis system (VICON, MX13+Oxford Metrics, UK) at a sampling rate of 200 Hz. Totally 15 reflective markers were placed on bony landmarks of each subject, specifically on the sacrum and bilaterally on the second metatarsal head, medial and lateral malleolus, calcaneus, medial and lateral femoral epicondyle, anterior superior iliac spine. In addition, triads of rigid reflective tracking markers were securely placed bilaterally on the lateral surfaces of the subject's thigh, shank and dorsum of the foot.

Subjects started in a standing position 70 cm away from the center of the force plate for each direction (forward, diagonal and lateral). All subjects were required to perform a double-leg jump in three different directions and reach an overhead target equivalent to 50% of the subject's maximum vertical jump height and land with single-leg (supporting leg only) on the force plate. When landing with testing leg, subjects were asked to use toe-heel strategy and maintain their balance for 3 seconds with their hands on the waist, look straight ahead as quickly as possible. If the subjects lost balance and stepped off on the force plate, or if their non-testing leg, or upper extremity swayed excessively, all of these trials were defined as failed trials. Each jump-landing direction would include three successful trials. To avoid learning effect, subjects were asked to practice before the experiment.

The Visual3D™ software (C-Motion, Rockville, MD, USA) was used for data analysis to calculate joint kinematics and kinetics. Kinematics and kinetics data were filtered using a fourth-order Butterworth filter with the cutoff frequency set at 6 Hz. Joint kinematics were calculated using a joint coordinate system approach. Positive values represented flexion angles for the hip, knee and ankle (dorsiflexion). Internal joint moment was calculated for lower extremities using inverse dynamics equations. Negative values represented extension moments for the hip, knee and ankle (plantarflexion) joints. Joint power was computed as product of the internal joint moment and joint angular velocity (determined from kinematics data). Mechanical work was calculated as joint power integrated over time; negative work values represent energy absorption via eccentric muscular contractions (Devita & Skelly, 1992; Decker et al., 2003). GRF was normalized to body weight. Sagittal plane joint moments, powers and eccentric work were normalized to body mass and body height. All data were analyzed from landing phase of the supporting leg, which was defined as the time between initial foot contact and maximum knee flexion. One-way ANOVA with repeated measures was used to compare the effects of different jump-landings on the sagittal plane kinematics and kinetics.

RESULTS: Table 1 lists the kinematics and kinetics variables at three jump-landing directions. The results indicated significant differences among three directions on joint kinematics ($p<.05$). When performing forward jump-landing protocol, the hip flexion angle was significantly greater when compared to other directions, and the ankle tended to be less plantarflexed at the time of initial foot contact. After landing, the hip was flexed 3.2° and 9.8° more when compared to diagonal and lateral directions, the knee was flexed 5.3° more when compared to lateral direction. During the forward jump, range of motion of the knee joint was greater and range of motion of the ankle joint was smaller when compared to other directions. Only the peak knee extensor moment was significantly different among directions ($p=.004$). Peak negative power at each joint was significant differences among directions ($p<.05$). Greater hip and knee power occurred at forward and diagonal directions when compared to lateral direction, but the ankle power tended to increase at lateral direction. Net joint work was found significant different at knee and ankle joint when compared at three different jump landing directions. However, no significant difference was found at the hip joint.

Table 1: Group mean (SD) data for kinematics and kinetics variables at three directions.

	Forward	Diagonal	Lateral	*P*-Values
Ground reaction force (BW)				
	2.59 (0.18)	2.57 (0.21)	2.53 (0.23)	.407
Initial contact (degree)				
Hip	28.2 (5.6) [ab]	25.7 (6.4) [c]	19.9 (5.6)	.000*
Knee	7.0 (3.7)	7.2 (3.3)	8.0 (3.9)	.113
Ankle	-31.6 (6.4) [ab]	-33.5 (6.4)	-34.1 (6.2)	.024*
Peak flexion angle (degree)				
Hip	57.2 (13.7) [ab]	54.0 (12.1) [c]	47.0 (14.8)	.003*
Knee	64.8 (9.9) [b]	62.9 (7.3)	59.5 (8.8)	.012*
Ankle	25.9 (4.1)	27.2 (3.7)	27.9 (2.6)	.090
Range of motion (degree)				
Hip	28.5 (10.4)	27.8 (8.6)	26.7 (11.8)	.578
Knee	57.1 (8.3) [b]	55.1 (6.5) [c]	50.8 (7.1)	.003*
Ankle	57.5 (7.1) [ab]	60.7 (7.8)	62.0 (7.0)	.012*
Peak angular velocity (degree/s)				
Hip	207.8 (41.4)	202.7 (38.1)	195.2 (36.7)	.192
Knee	464.5 (48.5) [ab]	448.4 (44.4) [c]	407.3 (37.9)	.000*
Ankle	712.2 (86.3) [ab]	754.3 (75.8)	765.1 (77.1)	.012*
Peak extension moment (Nm/Kg*BH)				
Hip	-0.80 (0.28)	-0.74 (0.20)	-0.63 (0.34)	.060
Knee	-1.73 (0.26) [b]	-1.70 (0.25) [c]	-1.55 (0.17)	.004*
Ankle	-1.22 (0.16)	-1.24 (0.22)	-1.30 (0.26)	.182
Peak negative power (W/Kg*BH)				
Hip	-1.39 (0.58) [b]	-1.40 (0.59) [c]	-1.01 (0.63)	.010*
Knee	-10.47 (2.15) [ab]	-9.75 (1.84) [c]	-8.30 (1.61)	.000*
Ankle	-8.27 (1.74) [b]	-8.86 (2.26) [c]	-9.96 (2.22)	.000*
Net work (J/Kg*BH)				
Hip	-0.66 (0.34)	-0.68 (0.33)	-0.57 (0.43)	.266
Knee	-3.74 (1.20) [b]	-3.64 (0.85) [c]	-3.13 (0.58)	.016*
Ankle	-2.42 (0.68) [b]	-2.68 (0.76) [c]	-3.27 (1.15)	.001*
Contribution to total work (%)				
Hip	10.3 (5.6)	10.2 (5.4)	8.7 (7.1)	.360
Knee	54.0 (6.8) [b]	51.7 (7.1) [c]	45.4 (6.7)	.000*
Ankle	35.7 (9.0) [b]	38.1 (9.0) [c]	45.9 (10.8)	.000*

*represented significant differences among three jump-landing directions ($p<.05$).
a represents a significant difference between forward and diagonal.
b represents a significant difference between forward and lateral.
c represents a significant difference between diagonal and lateral.

DISCUSSION: The purpose of this study was to investigate the effects of different jump-landing directions on sagittal plane kinematics, kinetics, energy dissipation and access how joint mechanics relate to energy dissipation during a single-leg landing. Our results indicated three major findings: (1) the knee and the ankle joints were the major contributors to energy dissipation for a single-leg jump-landing, (2) the knee joint was the dominant contributor to energy dissipation for forward and diagonal jump-landing directions, (3) the knee and ankle joints were the main contributors to energy dissipation for lateral jump-landing direction.
No matter in which direction, we observed greater range of motions, peak angular velocities, peak extension moments, peak negative powers and net works occurred at the knee and ankle joints as compared to hip joint. Moreover, in terms of percentage contribution to total energy dissipation, we observed 10.3% for the hip, 54.0% for the knee and 35.7% for the ankle while landing at the forward direction (Table 1). However, we noted that the contributions decreased to 10.2% and 8.7% for the hip, decreased to 51.7% and 45.4% for the knee and increased to 38.1% and 45.9% for the ankle while landing at the diagonal and lateral directions, respectively. These findings emphasized the roles of the knee extensors and ankle plantarflexors as the major energy dissipaters for single-leg jump-landings.

When landing at forward and diagonal directions, we found that the knee extensors working harder to provide adequate energy dissipation in response to the landing impact, and accompanied with greater knee flexion angular velocities. Previous research demonstrated that the knee flexion angular velocity revealed a negative correlation with peak GRF during landing, which implied that active knee flexion was an important factor in impact attenuation (Yu, Lin, & Garrett, 2006). Furthermore, we demonstrated that the knee joint power increased in forward and diagonal directions, which suggested that the knee extensors are major contributors to impact energy dissipation during landing.
When landing in a lateral direction, the smaller range of motion at the knee was likely to indicate a stiffer landing strategy, although the greater range of motion at the ankle was not consistent with a stiff overall landing strategy. In general, a stiffer landing might result in greater GRF (Devita & Skelly, 1992); but interestingly, the GRF in our study did not significantly increase. The occurrence of less knee flexion during landing might lead to a smaller knee joint power (Devita & Skelly, 1992), which might diminish shock absorption capacity (Coventry et al., 2006). This indicated that the body needed to use other compensatory strategies to maintain the same impact while the knee absorption capacity decreased (less knee joint power and work). Therefore, we further found that the greatest ankle range of motion occurred at lateral direction. However, the single-leg landing strategy might impose greater balance demands on the ankle joints (greater angular velocities) in order to adequately absorb landing impact especially pairing with reducing hip and knee motions (Coventry et al., 2006). In addition, previous studies have also proposed that impact shock was affected by the body position at initial contact (Coventry et al., 2006). Self & Paine (2001) have suggested greater ankle plantarflexion at initial contact demonstrated more shock absorption and a reduction of the GRF. In our results, body position at initial foot contact changed across different jump-landing directions. A more erect landing position might change the absorption capacity during landing. Furthermore, results of the current study demonstrated that ankle joint power increased while knee joint power decreased. These findings suggested that knee extensors (45.4%) and ankle plantarflexors (45.9%) were the major energy dissipaters, but the importance of ankle plantarflexors was significant during lateral direction when compared to other directions.

CONCLUSION: Our findings indicated that landing strategy changed across different jump-landing directions in a way that maintained the same level of shock attenuation via altering body position and using the knee and ankle joints as primary dissipaters. We proposed that the knee joint showed major contributions to energy dissipation for forward and diagonal directions, and increased the use of ankle joint to energy dissipation for lateral direction.

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