Biomechanical Analysis of Landing from Counter Movement Jump and Vertical Jump with Run -Up in the Individuals with Functional Ankle Instability

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Abstract

Ankle sprain is one of the most common sport injuries in lower extremities. It frequently occurs in landing phase when athletes perform jumping. The counter movement jump and straddle jump are common jumping strategies often used in baseball and volleyball games. Recurrent ankle sprain frequently leads to a chronic disability, the functional instability. The purpose of this study was to investigate the joint kinematics and kinetics of lower extremities in counter movement jump and straddle jump, and compare the differences between the individuals with functional ankle instability and healthy people. VICON612 motion analysis system and two AMTI force plates were used in this study. Straddle jump showed significantly shorter time to peak force, greater loading rate and greater ground reaction force than counter movement jump during landing. Differences on landing impulse between counter movement jump and straddle jump were found in the functional instability group but not in healthy control group. Based on our findings, the likelihood of injury might be greater in the straddle jump than in counter movement jump. In order to maximally reduce the risk of sports injury, counter movement jump would be recommended as a more suitable jumping strategy for the individuals with functional ankle instability due to the lower ground reaction forces and loading rates in lower extremities.

Keywords: Ankle sprain, Loading rate, Impulse, Ground reaction force

Introduction

Ankle sprain is one of the most common sport injuries in athletes. Eighty-five percent of the ankle sprains are inversion injuries. An ankle sprain occurs when the external inversion moment at the ankle is substantially greater than the internal eversion moment provided by the structures such as foot evertors and ligaments [1]. The external moment results from the acting force (ground reaction force) and the leverage between the point of application and the point of rotation at the ankle joint. Also, ankle sprain is a common sports injury that can cause major and chronic disability. Functional instability of the ankle has been defined as a tendency for the foot to give way after an ankle sprain. Such instability is a relatively widespread concern following the acute ankle sprain, persisting as a chronic condition long after the apparent signs and symptoms of the original insult have resolved [2].

An ankle sprain frequently occurs in numerous sport activities and sometimes is regarded as trivial by athletes and coaches. Several researches have documented the injury rate of ankle sprain in various sports, such as soccer (17%-36%, [3]), floorball (35%, [4]), football (11.6%, [5]) and parachuting (0.68%, [6]). In addition, basketball requiring backward, forward and vertical acceleration with quick stop and side-to-side movements, is a high risk of ankle sprain. Klein et al. [7] indicated that of the 179 basketball players, 160 (89%) had suffered severe ankle sprain. Leanderson et al. [8] carried out a retrospective study of the frequency of ankle sprains in 102 basketball players. Ninety two percent of them suffered an ankle sprain while playing basketball, and 83% of these injured players reported repeated sprains of one ankle. Volleyball is a sport in which the participant must combine vertical and horizontal motions. The athlete must utilize lateral, backward, forward and rotational motion complemented with

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jumps. Based on Bahr's epidemiologic investigation [9], the injury rate of ankle sprain could be 54% in volleyball players, indicating that more than half of the volleyball players have been suffering an ankle sprain. The rate of recurrent ankle sprain could be as high as 79% in the volleyball players with ankle sprain.

Functional ankle instability is often related with strength reduction, muscle imbalance, ligament laxity and balance impairment [10]. It has been postulated that functional instability could arise from delayed reflex responses to stress on ankle ligaments due to the damage to ankle joint receptors at the time of initial injury [11]. Some evidences suggested that dynamic control of ankle stability is achieved by feed-forward mechanisms of the central nervous system rather than by feedback via peripheral reflexes [12]. Movement patterns that optimize bone on bone contact at impact during sport activities could serve to decrease resultant forces acting on joint structures [13]. Subjects with functional instability would exhibit altered patterns of movement during landing compared to healthy subjects [14]. The discrepancy might be caused by learned changes to patterns of movement control in consequence of previous injury [15].

A superior landing skill is the prerequisite in numerous sports. Landing on forefoot is regular, with the foot eventually being levered into dorsiflexion and pronation. Loose lateral ligament, muscle imbalance, impairment in proprioception receptors, or landing on the foot of another player would lead to increase of supination and injury risk [16]. Biomechanical analysis of the loading and the function in the ankle joint during landing is important to understand the pathology and the compensative mechanism following the recurrent ankle sprains. Therefore, the purpose of this study was to investigate the joint kinematics and kinetics of lower extremities in counter movement jump and vertical jump with run-up and double leg take-off, the jumping movements frequently used in basketball and volleyball. The biomechanical differences between the individuals with functional ankle instability and healthy people were evaluated.

Methods

Nine male subjects (body height: 168.6±8.0 cm; body weight: 60.0±11.1 kg; age: 20.6±0.5 yrs) with functional ankle instability (instability group) and nine male subjects (body height: 168.57±8.90 cm; body weight: 63.4±8.2 kg; age: 21.4±1.7 yrs) without any musculoskeletal problem in the lower limbs (control group) were recruited in this study. The criteria for the instability group included: at least two sprain experiences in the same ankle, feeling of giving way in the ankle during exercise, no ankle sprain within recent six months and no structural/mechanical instability. Anterior drawer test and talar tilt test were conducted by an experienced physical therapist to exclude any subject with ankle mechanical instability. Each subject was asked to perform counter movement jump and vertical jump with run-up and double leg take-off (Figure 1). A Helen Hayes Marker Set with nineteen reflective markers was placed on the selected anatomic landmarks bilaterally for each subject. The selected anatomic landmarks included bilateral anterior superior iliac spine, lateral thigh, medial and lateral epicondyles of femur, lateral shank, medial and lateral malleolus, calcaneus, base of second metatarsal bone, and sacrum. The VICON612 motion analysis system (Oxford Metrics Limited., UK) with ten cameras was used to collect the marker's trajectories at 250 Hz. Each subject was asked to perform counter movement jump and vertical jump with run-up and double leg take-off and landing on two AMTI force plates (Advanced Mechanical Technology, Inc., Watertown, MA) in order to measure the ground reaction forces and moments at a sampling rate of 1000 Hz. Each leg was landed on one force plate. Five useful repetitions were collected for each testing condition. The trajectories of the markers were smoothed using a generalized cross-validation spline smoothing routine at a cut-off frequency of 6 Hz ([17]. Personal designed MATLAB programs were used to calculate the biomechanical parameters during landing. Euler angles were used to describe the orientation of a distal segment reference frame relative to a proximal segment reference frame [18]. The first rotation about the y axis represented the flexion/extension angle. The second rotation about the x' axis represented the adduction/abduction or side bending angle. The third rotation about the z" axis represented the axial rotation.
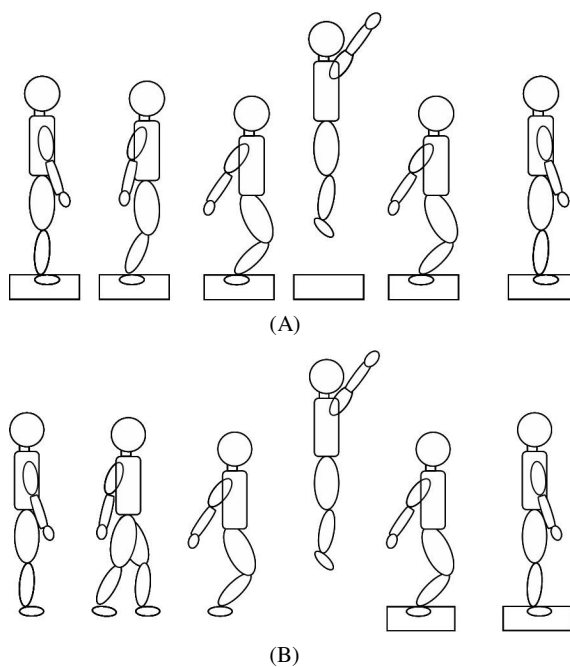

(A)

(B)

Figure 1: Counter movement jump (A) and vertical jump with run-up (B).

The biomechanical parameters including joint kinematics and kinetics during landing were computed and demonstrated as follows. Typical ground reaction force of landing was shown in Figure 2. The first and the second peak forces and their corresponding time to peak force were calculated. Loading rate was definited as the increasing rate of ground reaction force divided by the time. The jumping height was

definited as the maximum distance between jubject's toe and the ground during jumping movements. The impulse was defined as the ground reaction force integrated with time. Independent t test was used to compare the differences between instability group and control group. Paired-t test was used to compare the differences between the counter movement jump and the vertical jump with run-up.
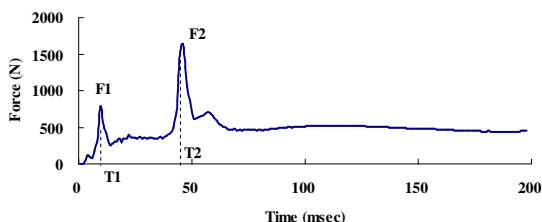

Figure 2: The vertical ground reaction force during landing (F1: the first peak force; F2: the second peak force; T1: time to the first peak force; T2: time to the second peak force).

Results

The loading rates and the jumping height were shown in Figure 3. No significant differences on jumping height were found between the instability group and the control group, and between counter movement jump and vertical jump with run-up. There was a significant difference on the loading rate between two jumps and two groups. The instability group had significnatly greater loading rate I than the control group (p<0.05). The vertical jump with run-up showed significnatly greater loading rate I and II than the counter movement jump (p<0.05).
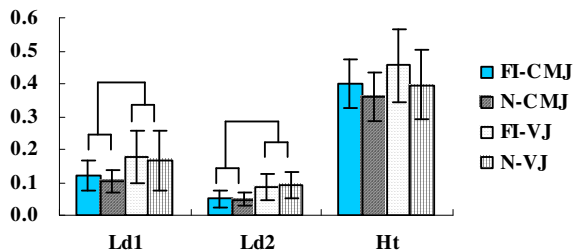

Figure 3: The loading rates (N/(kg-ms)) of the first peak (Ld1) and the second peak (Ld2) vertical ground reaction forces and the jumping height (m) during landing in counter movement jump (CMJ) and vertical jump with run-up (VJ) (FI: functional instability group; N: control group).

The range of motion (ROM) of the hip, knee, and ankle joints in counter movements jump and vertical jump with run-up for the instability group and control group were shown in Figure 4. No significant differences on ROM were found between the instability group and the control group, and between the counter movement jump and the vertical jump with run-up.

The time to the first (T1) and the second (T2) peak vertical ground reaction force during landing were shown in Figure 5. No significant differences on T1 were found between the

instability group and the control group, and between counter movement jump and vertical jump with run-up. The counter movement jump showed significantly greater T2 than the vertical jump with run-up both in the instability and normal groups.
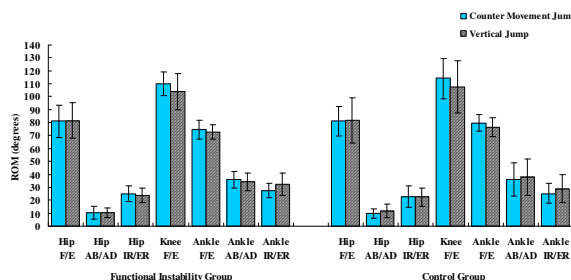

Figure 4: The range of motion (ROM) of the hip, knee, and ankle joints in counter movements jump and vertical jump with run-up (F/E: flexion/extension; AB/AD: abduction/adduction; IR/ER: internal rotation/external rotation).
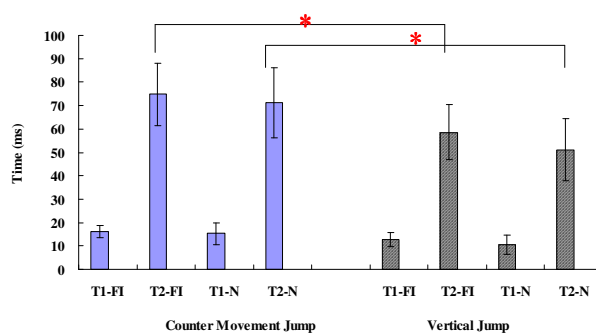

Figure 5: The time to peak ground reaction force in counter movement jump and vertical jump with run-up (FI: functional instability group; N: control group).
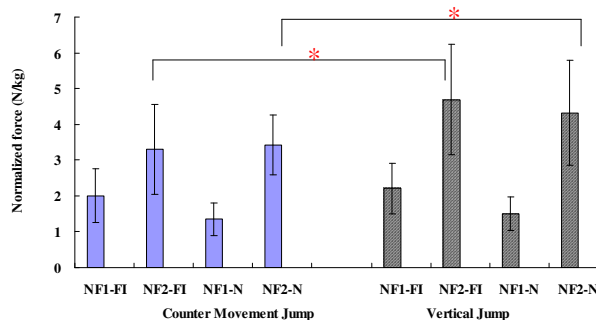

Figure 6: The peak ground reaction forces in the counter movement jump and vertical jump with run-up (FI: functional instability group; N: control group).
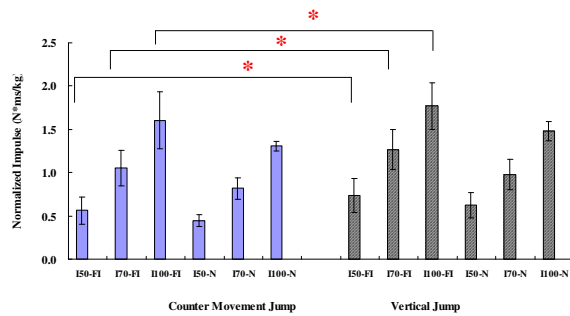
Figure 7: The impulses (I50: 50 msec; I70: 70 msec; I100: 100 msec) during landing in counter movement jump and vertical jump with run-up (FI: functional instability group; N: control group).

The peak normalized vertical ground reaction forces during landing were shown in Figure 6. The first (NF1) and the second (NF2) ground reaction forces were normalized by each subject's body weight. No significant differences on NF1 were found between the instability group and the control group, and between the counter movement jump and vertical jump with run-up. The vertical jump with run-up showed significantly greater NF2 than the counter movement jump both in the instability and control groups.

The integrated impulses in 50ms (I50), 70ms (I70) and 100ms (I100) during landing were shown in Figure 7. There were significant differences on I50, I70 and I100 between the counter movement jump and the vertical jump with run-up in the instability group, but not in the control group. The vertical jump with run-up showed significantly greater impulses than the counter movement jump in the instability group ($p<0.05$).

Discussion

Functional instability of the ankle joint has been associated with disordered strength, defeat of balance and ligamentous laxity [10]. Based on our finding, several biomechanical parameters investigated in this study showed no significance between the functional instability group and the healthy control group. These parameters included the jumping height and the ROM in the lower extremities. Jumping height is an indicator of one's jumping ability. Chronic ankle instability did not have any negative influence on the jumping performances, implying that the most powerful ankle muscle responsible for jumping performance, the plantar flexors, was not affected by the functional instability. The individuals with functional instability had similar jumping performances both in the counter movement jump and the vertical jump with run-up.

There was no obvious difference on the ROM required in landing between the counter movement jump and the vertical jump with run-up, and between the instability and control groups. In this study, the ROM in the hip, knee and ankle joints in the counter movement jump and the vertical jump with run-up were basically within the anatomical range. Kinematics in the lower extremity was influenced neither by the jumping type nor by chronic functional instability.

McNitt-Gray's study [19] reported that the T2s were about 61 ms and 41 ms during drop landing from 0.32 m and 0.72 m, respectively. Decker et al. [20] reported that T1 and T2 were 10.35~11.34 ms and 40.0~44.4 ms, respectively, when the subjects performed drop landing from 0.6 m. The time to peak ground reaction forces decreased with the increase of the height of drop landing. In our study, the average jumping height was about 0.40 m. The T1 and T2 in the vertical jump with run-up were 11.66 ms and 54.75 ms, respectively. The T1 and T2 in the counter movement jump were 15.6 ms and 72.9 ms, respectively. There was a good agreement between McNitt-Gray's and Decker's studies and our study. Besides, McNitt-Gray conveyed that the NF2 was 4.16 N/kg with a jumping height of 0.32 m. The average NF2 was 3.65 N/kg with an average jumping height of 0.40 m in our study. Our results generally coincided with those in McNitt-Gray's study.

In comparing the counter movement jump with the vertical jump with run-up, there were several significant parameters in our findings, including the time to the second peak force (T2), the second peak forces (NF2) and the loading rate (Ld1 and Ld2). T2 in the vertical jump with run-up was shorter than in the counter movement jump. Vertical jump with run-up showed substantially greater NF2, Ld1and Ld2 than the counter movement jump. The shorter the time to reach the peak force in landing, the more chance to get injury. Hence, performing the vertical jump with run-up with higher impact might have higher risk in lower extremity injuries.

Impulse is the integration of a force and the time interval over which the force acts [21]. Significantly higher impulses (I50, I70 and I100) were found in the vertical jump with run-up than in the counter movement jump in the instability group. However, no significant impulse difference was found in the control group. Caulfield and Garrett [14] indicated that people with functional instability may alter their movement pattern prior to ground impact during landing as a result of previous injury. The duration of muscle contraction after ground impact for energy absorption was about 50-70 ms [22]. The injury risk would be possibly increased if more ground reaction force was generated in this duration. Based on our findings, there might be a higher injury risk in the vertical jump with run-up in which the considerable ground reaction force and load rate were found in the landing phase.

In summary, we found that the likelihood of injury might be greater in the vertical jump with run-up than in the counter movement jump. In order to maximally reduce the risk of sports injury, counter movement jumps would be recommended as a more suitable jumping strategy for the individuals with functional ankle instability, because of lower ground reaction forces and load rates in the lower extremities.

Acknowledgment

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