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Investigation of joint reaction forces and moments during the countermovement and squat jump

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Abstract

The purpose of the study is to determine the force and the moments (torques) using the inverse dynamic modelling acting on the joints during countermovement (CMJ) and squat jump (SJ) by using link segment modelling. An elite male volleyball player participated in this study (Height = 1.85 m, Weight = 80 kg). One high-speed cameras operating at 500 frames per second were used to record the player's countermovement and squat jumping (Basler A 602f high speed camera). Captured views were digitized in the SIMI Motion 7.3 (SIMI Reality Motion Systems GmbH-Germany) by tracking 9 anthropometrical markers. Displacement data were filtered with 4th order 8Hz low pass Butterworth filter. Segment's centre of gravity was computed linear velocity and accelerations. Angles were calculated and it used to compute angular velocity and accelerations. Joint reaction forces and moments were computed by applying the inverse dynamic analysis into the calculated kinematic values. As result; the height of jump was higher in CMJ than SJ whereas resultant ground reaction force (GRF) was slightly higher in SJ compared to CMJ (SJ: 1749.8 N, CMJ: 1710.3 N). Furthermore, there were two different GRF peaks during CMJ and SJ. These peaks were occurred due to the backward movement of trunk, upper arm, lower arm and head during from descent to ascent. Meanwhile shank and thigh were moving the downward. In other words, it was observed a preparation phase between the descent phase (or stage or state) and ascent phase both jumps (at CMJ and SJ). Calculated moments in the CMJ jumping were higher than the SJ.

Keywords: Countermovement, squat jump, joint reaction force, moment (torque), inverse dynamic analysis

INTRODUCTION

Vertical movement is a test widely used while defining performance quality in addition to its being an important combination of skill (Feltner et al., 1999) when the concern is recreational activities and many different branches of sport (Vanezis and Less, 2005).

When maximum vertical jump is realized, many athletes use countermovement as a result of the fast extension of same joints following coordinately flexion of hip, knee, and ankle. In many jumps, a fast arm release occurs simultaneously with the movement of leg. Various studies inform that countermovement increased vertical jump highness by making use of stress-contraction circle during contraction and from preloading in lower extremity muscular system (Enoka, 1988; Harman et al., 1990). Studies also inform that countermovement increases the time of body`s having upright positive acceleration (Feltner et al., 1999).

Inner mechanisms that construct required power during vertical jump are muscles. As there is no opportunity to measure the force which muscles apply on tendons with direct methods, while the forces which muscles apply during movement are calculated indirectly (Spagele et al., 1999b) by using static and dynamic optimization, force and moments occurred on joints are calculated by using kinematic and anthropometric data (Winter, 2005).

Squat jump can be divided into three different phases. The first phase of squat jump is the phase starting from passive position of body until its being accelerated toward upright direction. The second one is the flight phase and it starts with takeoff of foot from ground and goes on with upright position of body that reaches to the peak point. And then, it ends with foot`s contact with ground. The third and the last one is the phase of slowdown after landing and provide body balance.

Countermovement, though, can be divided into four different phases on its own. The first step of countermovement is until bringing body to a passive position by fast acceleration of it toward downward while it is standing on foot with upright position. In countermovement, another three steps following the first one may be regarded as these of squat jump (Figure 1) (Spagele et al., 1999a).

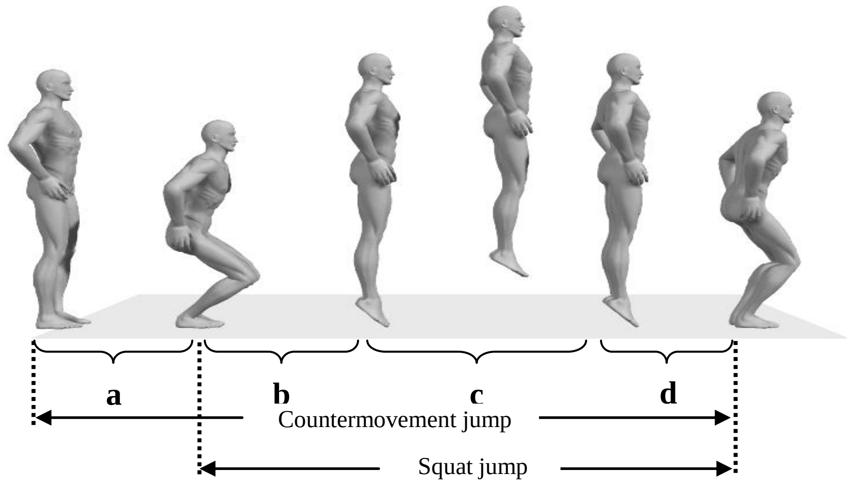


Figure 1. The position of body during countermovement (a, b, c, d) and squat jump (b, c, d) of test subject.

Defining model of vertical movement has been displayed in Figure 2. Height of jump, in other words maximum height of center of body mass (CM), has been explained as the function of center of body mass highness during takeoff and flight.

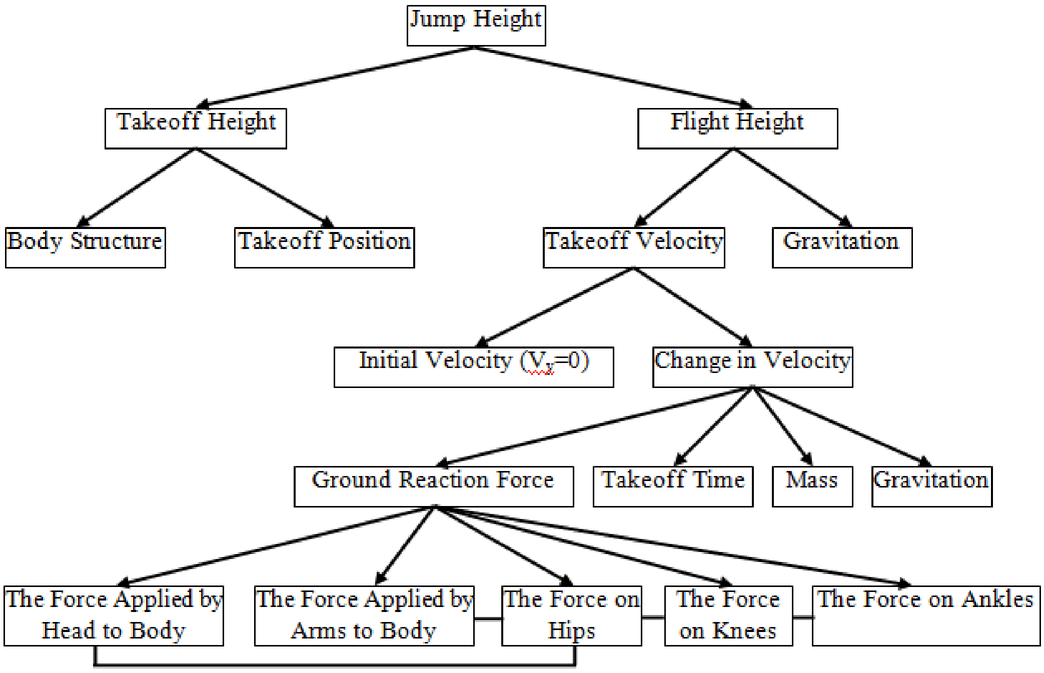


Figure 2. Defining model of vertical jump. It was taken from Feltner et al., 1999.

During the countermovement and squat jump, movement mainly happens on sagittal plane and it is assumed that the left and right body segments behave symmetric (Vanrenterghem et al., 2004).

The changes in the movement control from a small jump to a maximum one and moreover, the changes observed in the movement coordination are stated below:

1) Movement with opposite direction and compulsory that occurred on joints before extension.

2) Higher inertia proximal segments than that of distal segments. Rotation of proximal segments increases together with the increasing jump height.

3) It is the stable remaining of foot`s position on horizontal plane before jump and anatomic position. The fact that ankle is partly tightened during the position of standing at the beginning is an advantageous situation. Hence, flexion, the realization of which is necessary before extension, is less on knee and hip points. According to anatomic position, hip is able to realize hyperextension. However, at this point, it will not help CM to get high. This extension occurred on knee joint is assumed to have important contribution to jump height (Vanrenterghem et al., 2004).

Angular velocity of segments is defining and indispensable for CM`S velocity. In addition, rotation of proximal segments requires higher mechanic energy than that of distal segments. Just because of this, by decreasing rotation of proximal segments while jumping to less high points, ineffective loss of energy is decreased. As a result, it is assumed that rotation of proximal segments is reduced to minimum level during jumps that are done for low heights (Vanrenterghem et al., 2004).

When lower extremity muscular system is in advantageous position in order to use vertical ground reaction force, upright acceleration of arms (when combined with arm`s release), slowing down the rate of quadriceps and gluteal muscles' contraction (negative acceleration), leads to such force on shoulders and body downwards. According to force-velocity relationship of muscle contraction, slower concentric actions of leg muscles will lead to increase in muscle contraction and will probably be resulted with bigger vertical ground reaction forces (Harman et al., 1990).

In countermovement, changes in the joint rotation resultant force of hip, knee, and ankle; arm movements in the last 2/3 part of accelerating phase have increased the rotation force of hip' extensors by slowing down the extension rate of trunk and has increased resultant force of joint rotation by applying bigger force and by holding hip extensor muscles in slower concentric position (Feltner et al., 1999).

In this study, by using the link segment model and the inverse dynamic method, it has been aimed to determine the two dimensions (2D) of force and moments which occur in joints during countermovement and squat jump.

METHODS

Research Group
An elite male volleyball player participated in this study (Height = 1.85 m, Weight = 80 kg). The study has been planned with two dimensions as it is supposed that left and right body segments act symmetrically in countermovement and squat jump. After warm-up exercises for 20 minutes, the subject had 5 different countermovement and squat jump with rests done. In order for proceeding analysis and calculations, the two best jump performances are evaluated from both of jumps.

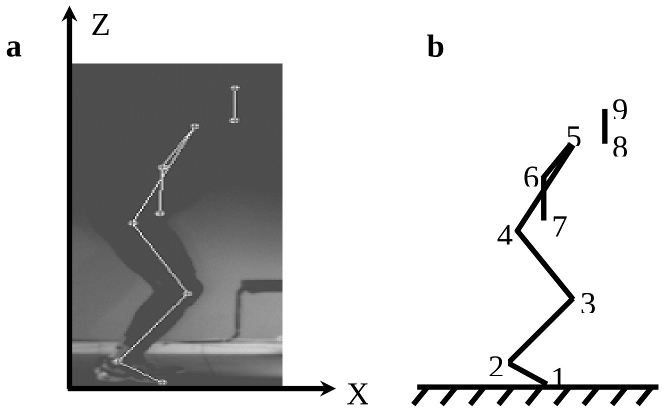
Data Collection Instruments
Movement Analysis: In order to the analysis of the subject`s countermovement and squat jump movements, SIMI Motion 7.3 motion analysis system (SIMI Reality Motion Systems GmbH-Germany), high-speed camera integrated with system (Basler A 602f), image capture card (Board Firewire PCI) and reflective markers which were put in joints have been used. Calibration cage which consist of 4 points has been used in order to be define in 2D plane of movement area (0.16 x 1.31m)

Anthropometric Measurements: Body mass has been measured with bascule (Sega, France) with ±0.1 kg sensitiveness. Measurement of height has been measured with stadiotmeter (Holtain Ltd. UK) with ±0.1 kg sensitiveness. Measurement of circumference has been done by using anthropometric measuring tape with sensitiveness of ±0.1 mm (Gullick`s meter). Length and width measurement have been done with anthropometric set (Holtain Ltd. UK).

Data Collection
Movement Analysis: In this study, reflective markers have been placed on 9 anthropometric points to the right part of the subject`s body (metatarsal, knee, ankle, shoulder, elbow, wrist, chin and forehead) (Figure 3). CMJ and SJ images of the subject has been recorded with high-speed camera (500 fps) which is integrated with movement analysis system. The camera was placed in to the right side of

body in the manner it will have 90 degree of angle. The images of CMJ and SJ were captured via firewire connection.

Anthropometric measurements: Anthropometric measurements were taken from foot, lower and upper leg, fore arm, upper arm, trunk and head. One length measurement for each segment, one circumference measurement for the head and one for each circumference measurement from three different section for the other segments, and additional one width measurement three different section for the trunk were taken.



1. 5th metatarsal
2. Lateral malleolus
3. Lateral femoral epicondyle
4. Trochanter major
5. Acromion
6. Lateral epicondyle of humerus
7. Lateral styloid of radius
8. Chin
9. Forehead

Figure 3. The frame of test subject`s jump (a) and the presentation of stick man (b).

Data Analysis
a) Digitizing and Data Process
Before the start of digitizing, in order to defined the long jump movement on 2 dimensions' plane, known spatial position of calibration cage whose measurements were taken before has been introduced to movement analysis system software. After this operation is completed, reflective markers in each frame have been digitalized with automatic digitizing of movement analysis software. The model used in digitizing is showed in Figure 3. Spatial positions of digitalized points, by using the results of calibration cage, have been calculated by Direct Linear Transformation (DLT) algorisms with 11 parameters. Raw position data was smoothed by using a fourth-order Butterworth low-pass digital filter with cutoff frequency is 8 Hz. All computing was performed Matlab 5.3 software.
b) Determination of segments' inertia parameters

Body segments were accepted as rigid body. Rigid body is defined as substance, the distance between two points of which is accepted as the constant, and whose smallest part reflects the qualifications of the whole substance, is constructed from endless number of substantial point and which does not show any deformation as a result of the externally acting forces (Rızaoğlu and Sünel, 2002). Segments mass, center of body mass positions and inertia parameters have been calculated by using Yeadon and Morlock`s (1989) regression equations which is based on model with 14 segments which Chandler et al. (1975) used in anthropometric measurements. Inertia parameters of trunk have been calculated with the use of Eq.1, Eq.2 and Eq.3 equations.

$$I_x = dwh\left[c_2 w^2 + c_3 h^2\right] \quad \text{Eq.1}$$

$$I_y = dwh\left[c_1 d^2 + c_3 h^2\right] \qquad \text{Eq.2}$$

$$I_z = dwh\left[c_1 d^2 + c_2 w^2\right] \qquad \text{Eq.3}$$

Where I_x, I_y, I_z are the values of moment of inertia (X, Y, Z); d, w, h are the values of depth, width and length; c_1, c_2, c_3 are the positive constant of trunk density. And it has been calculated with the use of Eq.4, Eq.5 and Eq.6 equations mentioned below.

$$w = \frac{(w_1 + 2w_2 + w_3)}{4} \qquad \text{Eq.4}$$

Where w is measurement of width of trunk.

$$p = \frac{(p_1 + 2p_2 + p_3)}{4} \qquad \text{Eq.5}$$

Where p is measurement of trunk.

$$d = \frac{(p - 2w)}{\pi - 2} \qquad \text{Eq.6}$$

Where d is measurement of depth of trunk. The inertia parameters of head, upper arm, forearm, upper leg, lower leg and foot were calculated by means of Eq.7, Eq.8, Eq.9 and Eq.10.

Eq.7

Where p is circumference measurement of head.

$$\begin{aligned} p &= p_1 \\ p_i &= \frac{(p_{1i} + 2p_{2i} + p_{3i})}{4} \\ i &= 1,2,....,5 \end{aligned} \qquad \text{Eq.8}$$

Where p explains circumference measurement values of upper arm, fore arm, upper leg, lower leg and foot.

$$I_{ti} = \frac{1}{2} I_{zi} + k_{2i} p_i^{\,2} h_i^{\,3} \qquad \text{Eq.9}$$

$$\begin{aligned} I_{zi} &= k_{1i} p_i^{\,4} h_i \\ i &= 1,2,....,6 \end{aligned} \qquad \text{Eq.10}$$

Where I_t, I_z express moment of inertia values of segments in three axes (X, Y, Z). It is assumed that I_t=I_x=I_y. While p and h express circumference and length values of segments respectively, k_1 and k_2 are positive constant.

c) Calculation of Center of Body Mass

The position of body mass center was calculated from the center of segment mass which was acquired from Eq.11 and Eq.12 (Winter, 2005).

$$X_{cg} = \frac{\sum_{i}^{n} m_i x_i}{\sum_{i}^{n} m_i} \qquad \text{Eq.11}$$

$$Y_{cg} = \frac{\sum_{i}^{n} m_i y_i}{\sum_{i}^{n} m_i} \qquad \text{Eq.12}$$

$$i = 1,2,....,7$$

Where X_{cg} and Y_{cg} are the position of CM in horizontal and vertical axis; x and y are the position of the center of segment mass in horizontal and vertical axis; m is the mass of body segments and i is segment numbers.

d) Invers Dynamic Calculations

From the derivations of dependent on time of the raw position data, linear velocity and acceleration of center of segments mass have been calculated. After that, angles which segments made on plane have been computed. From derivations of dependent on time of angles, angular velocity and acceleration of them have been calculated. By using segment mass and linear acceleration values of CM, forces occurring in joints to which each segment is connected have been calculated with the inverse dynamic analysis method (Eq.13 and Eq.14).

$$\sum F_{yi} = ma_{yi} \Rightarrow F_{ypi} - F_{ydi} - m_i g = m_i a_{yi} \qquad \text{Eq.13}$$

$$\sum F_{xi} = ma_{xi} \Rightarrow F_{xpi} - F_{xdi} = m_i a_{xi} \qquad \text{Eq.14}$$

Where F_{xi} and F_{yi} are vertical and horizontal joint forces; F_{xpi} and F_{xdi} are horizontal force on segments proximal and distal points; F_{ypi} and F_{ydi} are vertical force on segment's proximal and distal ends; m is segment mass; a_{xi} and a_{yi} are vertical and horizontal acceleration of center of segments mass; g is acceleration of gravity and lastly i is number of segments.

Moments occurred in the joints have been calculated with the method of inverse dynamic analysis by using segment`s inertia value, segment`s angular acceleration value and by using moment value according to CM of forces acting on the joints to which segment is linked (Eq.15) (Winter, 2005).

$$\sum M_i = -(I_i \alpha_i) - M_{i-1} - (F_{ypi} l_{pxi} - F_{xpi} l_{pyi}) + (F_{ydi} l_{dxi} - F_{xdi} l_{dyi}) \qquad \text{Eq.15}$$

$$i = 1,2,....,7$$

Where M_i is joint moment; I_x is inertia of segment, α is angular acceleration of the segment; F_{ypi}, F_{xpi}, F_{ydi} and F_{xdi} are vertical and horizontal joint forces on proximal and distal ends; l_{pxi}, l_{pyi}, l_{dxi} ve l_{dyi} are vertical and horizontal length from CM of segment to proximal and distal ends and i is the segment`s number.

The calculated moment values were normalized according to body weight of the subject and maximum values were found from Eq.17.

$$M_{norm} = \frac{M}{VA} \qquad \text{Eq.17}$$

The calculations mentioned above were realized by using student version MATLAB 5.3 (The Math Works Inc., MA, and USA).

RESULTS

As a result of anthropometric measurements, length, circumference and width values of head, trunk, upper arm, fore arm, upper leg, lower leg and foot were given in Table 1.

Table 1. Anthropometric data of subject (length, circumference and width values).

Segments	Length (m)	Circumference (m)			Width (m)		
		1. section	2. section	3. section	1. section	2. section	3. section
Head	0.19	0.57					
Trunk	0.55	0.94	0.79	0.94	0.27	0.25	0.30
Upper arm	0.33	0.33	0.35	0.27			
Fore arm	0.27	0.27	0.27	0.17			
Upper leg	0.40	0.56	0.53	0.40			
Lower leg	0.42	0.40	0.39	0.24			
Foot	0.28	0.24	0.27	0.24			

As a result of kinematic analysis, the trajectory of body`s CM during countermovement and squat jump was displayed in Figure 4. Maximum vertical jump distance of the hip is presented in Table 2.

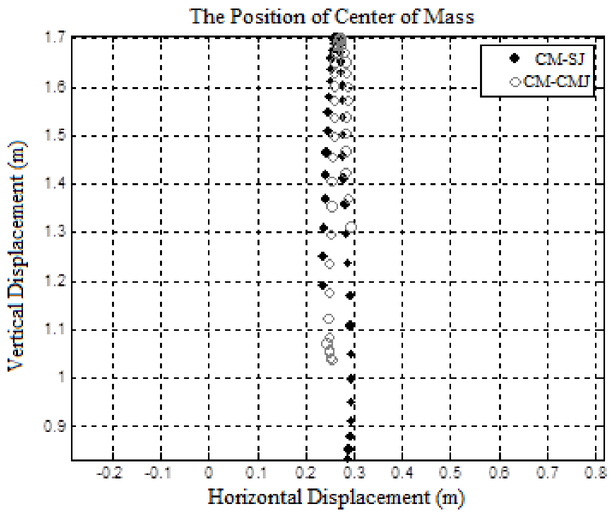


Figure 4. The position of mass of center during squat (CM-SJ) and countermovement jump (CM-CMJ).

Table 2. Starting, minimum and maximum vertical jump distance values of center of mass during the countermovement and squat jump.

	Countermovement Jump			Squat Jump		
	Start	**Min.**	**Max.**	**Start**	**Min.**	**Max**
Vertical Distance (m)	0.98	0.6	1.5	0.71	0.66	1.48

The horizontal and vertical forces on the hip, the knee and the ankle joints during the countermovement and squat jump when the resultant force applied to ground is maximum were given in Table 3 and the point of movement when the maximum resultant ground reaction force occurred was shown in Figure 5.

Table 3. The horizontal and vertical forces on the hip, the knee and the ankle joints when the resultant force applied to ground is maximum.

	Countermovement Jump			Squat Jump		
Maximum Force (N)	**Horizontal**	**Vertical**	**Resultant**	**Horizontal**	**Vertical**	**Resultant**
Hip	52.54	-1506.4	1507.3	148.16	-1485.8	1493.1
Knee	31.44	-1662.4	1662.7	148.16	-1681.6	1688.1
Ankle	30.14	-1699.7	1700	155.61	-1732.5	1739.5
Ground Reaction Force	29.72	1710.1	1710.3	156.02	1742.8	1749.8

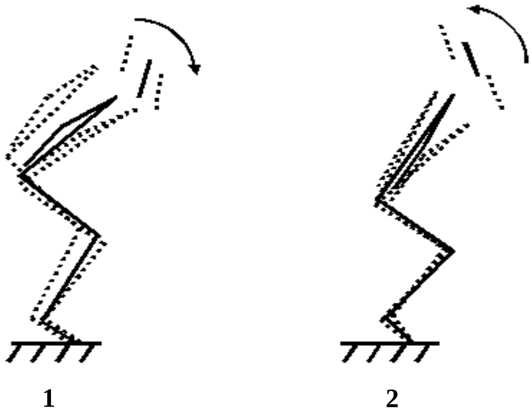


Figure 5. The moment of movement when the maximum resultant ground reaction force occurred during countermovement (1) and squat jump (2).

The computed ground reaction forces were given in Figure 6.

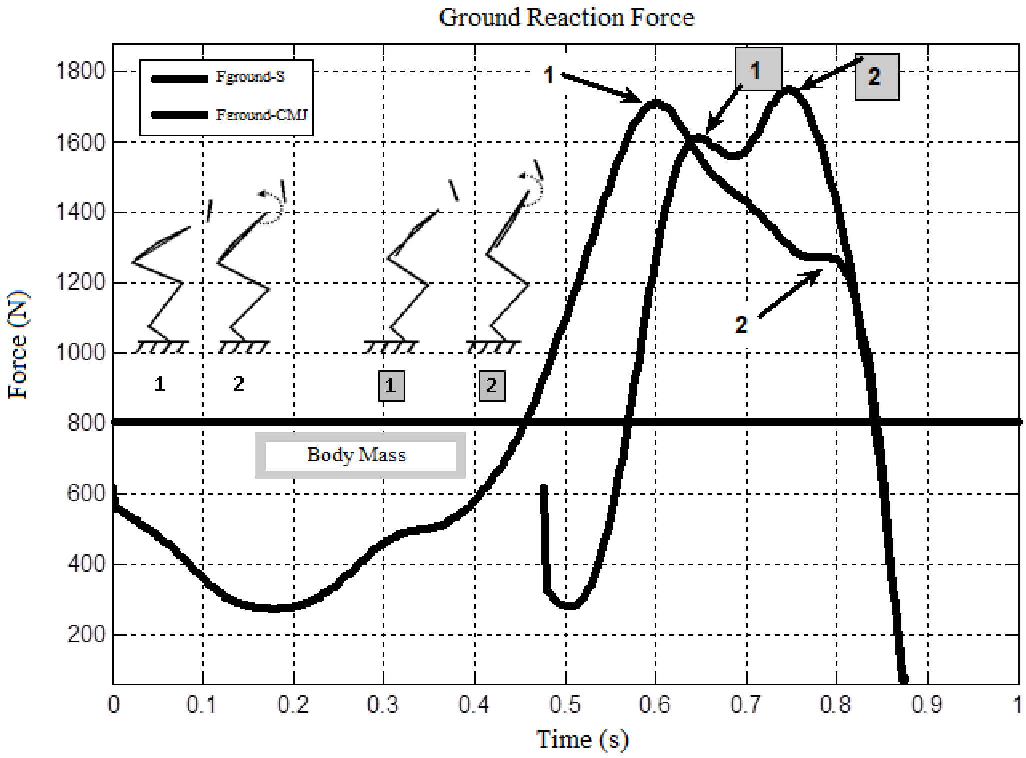


Figure 6. Ground reaction force (N) calculated during squat jump (F_{ground}-SJ) and countermovement (F_{ground}-CMJ).

Maximum relative moments (according to the body weight) that occurred on the hip, knee and ankle joints in countermovement and passive jump are given in Table 4. Moment (torque) from the 5th metatarsal was shown in Figure 7 when the foot is in contact with the ground.

Table 4. Maximum moment values occurred on hip, knee and ankle during countermovement and squat jump.

Maximum Moment (Nm/kg)	Countermovement Jump	Squat Jump
Hip	0.466	0.659
Knee	3.305	3.525
Ankle	0.364	0.306

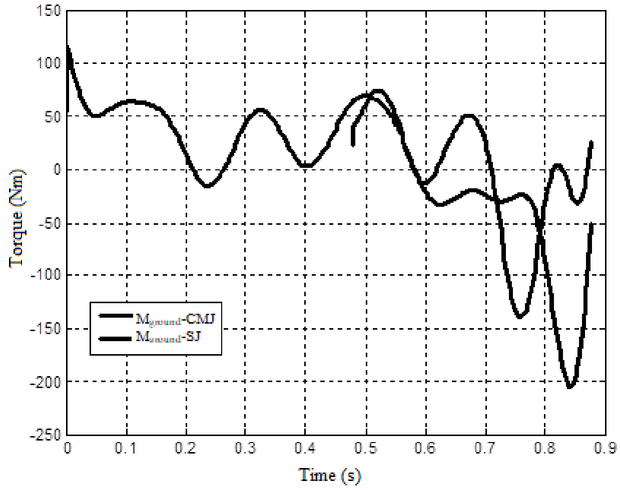


Figure 7. Moment (torque) from the 5th metatarsal when the foot is in contact with the ground in countermovement (M_{ground}-CMJ) and Squat jump (M_{ground}-SJ).

DISCUSSION

In countermovement and squat jump, the study of reliability of ground reaction forces calculated with inverse dynamic method has been made convenient to similar studies (Harbili and Arıtan, 2006). In countermovement and squat jump, maximum jump height values were found similar. In nature of the movement of countermovement jump, while initial position of hip on vertical axis are more than from squat jump; minimum value that hip reached on vertical axis during the countermovement jump is lower than from the squat jump (Table 2). As countermovement jump starts in a standing position, with the transfer of gained velocity to other phases, takeoff and drop velocity accordingly linear and angular acceleration of segments increase. This fact leads to increase of velocity while rising from ground and so causes to the increase of jump height.

Bobbert et al. (1996) notified that while the position of body is same at the start of pushing in countermovement and squat jump, jump height is approximately 3.4 cm more during countermovement jump. There is an emphasis on the probability of the fact that this difference originates from coordination defect during squat jump. However, there is no evidence in order to support this probability. Moreover, during squat jump, like that of countermovement, takeoff has been executed on fingertip. It may be said that because the subject reaches to greatest joint moments in the takeoff position of countermovement jump, he has got greater jumping height. In order to joint moments during countermovement jump to produce more works than that of squat jump, they become bigger during the first part of joint extension wideness.

Maximum highness of CM during vertical jump is increased with the lower extremities and strong arm swinging before takeoff. Arm swinging increases the highness of CM of body and vertical velocity of it (Feltner et al. 1999; Feltner et al., 2004, Harman et al., 1990). Vertical jumping realized with arm swinging generates a greater impulse in the pushing phase of jump. When arm swinging jump is compared with jump without swinging, CM of body has got bigger velocity during takeoff. Its reason may probably be the tendency of pushing phase time to increase as a result of wideness of a vertical movement of CM, not because of greater ground reaction force (Feltner et al., 2004). In Figure 3, trajectory of CM is observed to move forward during both countermovement and squat jump according to start position (respectively 0.088 m and 0.041 m). The fact that forward body CM movement is more during countermovement, jump may be because of the fact that wideness of CM movement is more than that of squat jump.

The horizontal and vertical forces on the hip, the knee and the ankle joints during the countermovement and squat jump when the resultant force applied to ground is maximum were showed in Table 3. In each three joints estimations of horizontal, vertical, resultant and ground reaction force were found to be close to each other. Vertical and resultant values of ground reaction force during countermovement and squat jump similar to both each other and in themselves. The fact that the force values similar to each other except minor differences may be said that the knee, ankle and hip joints are equally sharing the applied force in spite of small differences.

During squat jump, while the subject is expected to act opposite direction towards acceleration of gravity from the starting of his movement, descend downward is observed. In squat jump, the resultant force applied to ground is a bit more than that of countermovement jump (Squat: 1749.8 N, Countermovement: 1710.3 N). In squat jump, it is aimed both to have higher acceleration than that of gravitational acceleration and have maximum height of body mass. Because of this, it is thought that force values of movement in squat jump may be higher. On the other hand, in countermovement, while descending is happening from standing position, the direction of movement is the same with acceleration of gravity (Figure 6). Countermovement, when compared to squat jump, has got an extra phase (Figure 1). It means that, the duration of movement until the moment of takeoff is longer in countermovement jump from squat jump. As observed in Figure 6, although there is a phase difference between each jump, it shows similar behaviors. In both jumps, there are two different peaks. However, it is observed that, in countermovement, there is longer duration between two peaks (0.198 s) and 1st peak has got higher force value than the 2nd one (1710.3 N; 1273 N). In squat jump, though, in contrast to countermovement, it is observed that there is a shorter duration between two peaks (0.100 s) and the 1st peak has got lower force values than the 2nd one (1612 N; 1750 N).

The reason why there are two peaks in both jumps stems from the fact that lower and upper part of leg move to downward vertical axis while it is passing from drop to takeoff during jump, and that trunk, upper arm, fore arm and head start to act back. It means that it is possible to mention about preparation process between drop phase and takeoff phase in both jumps. The 1st peak value is higher than that of 2nd one in countermovement jump may stem from the deceleration of vertical acceleration since the starting of movement towards down and its being turned upward. In squat jump, like countermovement, while passing from dropping to takeoff during jump, downward movement of upper and lower leg in vertical axis contributes to trunk, upper arm, fore arm and head to act upward. Hence (that preparation phase happens in a shorter time) it is thought that the 2nd peak values is higher than that of first peak values.

The horizontal and vertical forces on the hip, the knee and the ankle joints during the countermovement and squat jump when the resultant force applied to ground is maximum were given in Table 3 and the point of movement when the maximum resultant ground reaction force occurred was shown in Figure 5. Calculated resultant force values in all of hip, knee, and ankle joints and ground reaction force are at their maximum point like 0.600 s in countermovement jump and 0.270 s in squat jump. At that time, all body and body segments, during countermovement, act towards direction of gravitational acceleration and its linear acceleration has reached to its maximum point. Trunk which has the biggest part as a mass in body with its maximum linear speed 0.600 s may be thought to cause occurrence of maximum jointing force values in joints and ground reaction force. But in squat jump, body acts opposite of gravitational acceleration in 0.270 s and as mentioned above, soon after preparation phase, lower segments start to contribute upper segments movement upwards. In this way, in joints and ground reaction force, maximum jointing force values were observed. During countermovement jump, moment values that segments have created on joints to which they are linked were found to be high when compared with squat jump. The fact that moment values are high in countermovement jump may be because of high segment angular acceleration values (Figure 7).

Athletes whose better vertical jump ability have got greater joint moments in their hip, knee and ankle, furthermore have got greater power and work values. In addition to this jumping performance was better in arm swinging and without arm swinging jumps. Rather than technique, this is about bigger muscle capacities related with lower extremities` force and force developing rates. While muscle force qualities of lower extremity segments are the major determiner of vertical jump, technique plays small amount of role (Vaneziz and Less, 2005).

Fukashiro and Komi (1987) have applied three different vertical tests (squat jump, countermovement jump and repetitive submaximal jump) in order to determine joint moments and mechanic force happened in lower extremity joints during vertical jump. They have found that the maximum moment values of countermovement jump are greater than squat jump. However, in both jumps, hip moment value was greater than knee, and knee moment values was greater than ankle.

Relative moment values of countermovement and squat jump resemble to moment values of knee joints informed by studies of Vaneziz and Less (2005) (Table 4). Vaneziz and Less (2005) have done biomechanical analysis of good and bad vertical jump, and they have notified that relative moment values for hip is 3.50 ± 0.75 Nm/kg, for knee 3.40 ± 0.81 Nm/kg and 3.08 ± 0.44 Nm/kg for ankle. Differences between moment values calculated as a result of studies with literature are thought to stem from the three dimensional analysis results or from differences of anthropometric measurements and the subjects` body weight.

Consequently, height of CM of body during countermovement has been found more than that of squat jump. The resultant force applied to ground during squat jump is a little more when compared with countermovement (Squat: 1749.8 N, Countermovement: 1710.3 N). Two different peaks have been found in force values applied to ground during countermovement and squat jump. The reason why there are two peaks in both jumps stems from the fact that lower and upper part of leg move to downward vertical axis while it is passing from drop to takeoff during jump, and that trunk, upper arm, fore arm and head start to act back. It means that it is possible to mention about preparation process between drop phase and takeoff phase in both jumps. In countermovement jump, the moment values of the joints in which the segments are linked were found to be higher when compared with the squat jump.

References

Bobbert, M.F., Gerritsen, K.G.M., Litjens, M.C.A., Van Soest, A.J. (1996). Why is countermovement jump height greater than squat jump height? *Medicine and Science in Sports and Exercise*, 28(11), 1402-1412.

Chandler, R. F., Clauser, C. E., McConville, J. T., Reynolds, H. M., Young, J. W. (1975). Investigation of inertial properties of the human body. *AMRL Technical Report*. Dayton, OH: Wright-Patterson Air Force Base.74-137.

Enoka, R.M. (1988). *Neuromechanical basis of kinesiology*. Champaign, IL: Human Kinetics.

Feltner, M.E., Elijah, J.B., Cassandra, M.P. (2004). Segmental and kinetic contributions in vertical jumps performed with and without an arm swing. *Research Quarterly for Exercise and Sport*, 75(3), 216-230.

Feltner, M.E., Fraschetti, D.J., Crisp R.J. (1999). Upper extremity augmentation of lower extremity kinetics during countermovement vertical jumps. *Journal of Sports Science*, 17, 449-466.

Fukashiro, S., Komi, P.V. (1987). Joint moment and mechanical power flow of the lower limb during vertical jump. *International Journal of Sports Medicine*, 8(Suppl.1), 15-21.

Harbili, E., Arıtan S. (2006). Koparma tekniğinin biyomekaniği. *Spor Bilimleri Dergisi*, 17(3), 124-142.

Harman, E.A., Rosenstein, M.T., Frykman, P.N., Rosenstein, R.M. (1990). The effects of arms and countermovement on vertical jumping. *Medicine and Science in Sports and Exercise*, 22, 825-833.

Rızaoğlu, E., Sünel, N. (2002). *Klasik mekanik*. Ankara: Ankara Ofset.

Spagele, T., Kistner, A., Gollhofer, A. (1999a). A multi-phase optimal control technique for the simulation of a human vertical jump. *Journal of Biomechanics*. 32, 87-91.

Spagele, T., Kistner, A., Gollhofer, A. (1999b). Modelling, simulation and optimization of a human vertical jump. *Journal of Biomechanics*, 32, 521-530.

Vanezis, V., Lees, A. (2005). A biomechanical analysis of good and poor performers of the vertical jump. *Ergonomics*, 48(11), 1594-1603.

Vanrenterghem, J., Lees, A., Lenoir, M., Aerts, P., De Clercq, D. (2004). Performing the vertical jump: Movement adaptations for submaximal jumping. *Human Movement Science*, 22, 713-727.

Winter, D. (2005). *Biomechanics and motor control of human movement*. New Jersey: John Wiley & Sons.

Yeadon, M. R., Morlock, M. (1989). The appropriate use of regression equations for the estimation of segmental inertia parameters. *Journal of Biomechanics*, 22(6/7), 683-689.