THE EFFECT OF MUSCLE ACTIVATION, ELASTIC ENERGY AND JOINT ACTIVATION PATTERN ON VERTICAL JUMP RESULT

PhD thesis

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INTRODUCTION

One of the most important questions of biomechanical research, is how greater stress, greater power can be achieved during an execution of a movement. In case of sports movements, when maximal result can decide winning, it's especially important to find the optimal movement pattern with the best result. Concerning injury and rehabilitation it's important to know how the healthy muscle groups can work with higher efficiency, and consequently the injured joints and muscle groups can be relieved. In our study we examined vertical jumps executed in different ways. We aimed to find out which factors and at which magnitude affect the result of the jump.

Previous studies compared vertical jumps executed in different ways with great detail, and these studies through vertical jumps examined the differences in muscle behavior. In most of the studies when different jumps were compared little attention was payed for identical movement amplitude. But if movement amplitudes are not identical, and muscle contractions are executed at different lengths, the results from comparisons can be questioned. Therefore in our study we compared the kinematical variables of vertical jumps executed differently, but with identical range of joint movement amplitude regarding the effect of elastic energy storage, muscle activation level and joint activation pattern.

OBJECTIVES

To eliminate the problems concerning previous studies and to examine the effect of different parameters we set the following general objectives:

Determining the magnitude of elastic energy reuse through the investigation of mechanical parameters of various vertical jumps executed with different range of motion.

Determining the factors affecting muscle activation level in various vertical jumps executed with different range of motion, and the effect of muscle activation level on vertical jump height.

Determining joint activation pattern in various vertical jumps executed with different range of motion and the investigation of differences in movement pattern and their effect on jump height.

To reach our general objectives we set the following hypothesizes:

1. In jumps executed with small range of motion and countermovement the elastic energy reuse plays a significant role in jump height.
2. In jumps executed with large range of motion and countermovement the effect of elastic energy reuse on jump height is negligible.
3. In jumps executed with small range of motion and countermovement the short time of eccentric contraction does not result in the elevated activation level of the contractile elements at maximal joint flexion.
4. In jumps executed with large range of motion and countermovement the longer time of eccentric contraction results in the elevated activation level of the contractile elements at maximal joint flexion.
5. In jumps executed with small range of motion and countermovement elastic energy reuse occurs predominantly at the beginning of joint extension.
6. In jumps executed with small range of motion significant deviation occur in joint activation pattern for different jumps.
7. In jumps executed with large range of motion the joint activation patterns are similar for different jumps.

METHODS

Subjects. Nine male subjects participated in the investigation (age: 20-21 years; body mass: 77.4±5.2kg; height: 184±4.8cm), students of the Semmelweis University, Faculty of Sport Sciences, four volleyball and five basketball players. The subjects were chosen because they were familiar with the execution of vertical jumps, physically they were fit therefore the risk of fatigue between jumps could be minimized.

Execution Prior to the experiment the subjects warmed up in 15 minutes and afterwards practiced the vertical jumps. We started the experiment only when the execution of the jumps met the criteria of the experiment. The subject executed three different vertical jumps:

1. joint extension from squat position (squat jump: SJ),

2. joint flexion started from erect body position followed by immediate joint extension (countermovement jump: CMJ),

3. drop jump executed from a 20cm high plateau (drop jump: DJ).

The jumps were executed in two different range of joint motions. The target knee joint flexion was 40 degrees in short range of motion (SRM) and 80 degrees in large range of motion (LRM), respectively. The subjects held a light bar on their shoulders to eliminate arm movement.

Using the knee angle data collected with a goniometer the supervisor controlled the execution of the jumps. If the jump did not meet the criteria, it was repeated. For each type of jump at least three executions were recorded which met the criteria. Between jumps the subjects rest 3-5 minutes therefore muscle fatigue did not alter the results.

Data collection. Jumps were executed on a three dimensional force platform with 0.5x0.7 m surface (Kistler Force Platform System 92-81 B, Switzerland, 600Hz). To record knee angles we secured a digital goniometer on the thigh and the shank (Musclelab 4010, Ergotest Technology a.s., Langesund, Norway). The jumps were recorded with a digital video camera (JVC DVL 9800V NTSC, 120Hz). The camera was secured on a 1.5m high tripod six meters away from the subjects, perpendicularly to the sagittal plane of the jumpers. Reflective markers 1.5cm in diameter were secured on the neck (on the vertical line of the auris externa at the height of the prominentia laryngea), the hip joint at the greater trochanter, the ankle joint (malleolus lateralis), the heel of the shoe and the palpable joint of the first proximal phalange of the big toe. The APAS movement analyzing system (Ariel Performance Analysis System, Ariel Dynamics Inc. California. CA 92679 USA) was used to digitally process the raw data obtained from the displacement of the markers. EMG data was recorded on the vastus lateralis and the soleus muscles. After the preparation of the skin we secured bipolar, circular 10 mm diameter silver-silver chloride surface electrodes using the SENIAM protocol [www.seniam.org]. EMG signals were recorded and amplified by the TeleMyo telemetric hardware system (Noraxon U.S. Inc., Scottsdale, Az, USA) synchronized with the force platform and the motion capture system. Signals were digitalized at 1000Hz with the Myosoft software (Noraxon Myoclinical 2.10). EMG data reduction consisted of high pass filtering (20 Hz), full-wave rectification and smoothening. To determine muscle activation levels rmsEMG was calculated at 100ms windows.

Calculations. We used four body segments and calculated the proportional mass and the position of the COM for the segments. In the model the trunk, the head and the upper limbs are represented as one segment. The following four segments were determined:

(a) between the neck and the hip containing the head-trunk-upper limbs (trunk);

(b) between the hip and the knee (thigh);

(c) between the knee and the ankle (shank);

(d) between the ankle and toe (forefoot).

With the horizontal and vertical displacement of the markers we calculated the displacement, velocity and acceleration for the segment center of mass (COM) and the total body COM as the function of time using the APAS software and the Dempster body model (1955). We also calculated the joint angles as the function of time.

Five distinctive points were defined on the vertical displacement and time curves in the jumps:

P1 when the vertical velocity of COM was the highest during joint flexion;

P2 when COM was in the lowest vertical position;

P3 when COM was in the same vertical position during joint extension as in P1;

P4 when the maximum upward vertical velocity was attained;

P5 when toe-off occurred.

The mechanical energy of the subject was determined as the sum of the potential and kinetic energy. We used the vertical displacement of the body COM for the potential energy and the sum of the segment translational and rotational energies. We calculated the power values as the first differential of the energy.

To determine muscle activation levels rmsEMG was calculated at 100ms windows around P1, P2, P3 points.

With joint angle values and the Hawkins and Hull (1990) model we calculated muscle lengths in the vastus lateralis, rectus femoris, biceps femoris (short and long head), soleus and gastrocnemius. From muscle lengths we calculated numerically the muscle contraction velocities and accelerations as the first and second differentials. Before and after (t=1/24sec) the minimal length of the muscle, at the transition time, we determined the accelerations of the eccentric and concentric muscle contraction.

From the joint kinematical data to obtain information about joint activation sequence we determined the time of the beginning of joint extension (V_0) and maximal angular velocity of joint extension (V_{MAX}) for hip, knee and ankle joints.

Statistical calculations: our results were represented by means and standard deviations. To identify significant differences after normality test we used for parametric distribution t-test for independent samples and Anova or the suitable corresponsive nonparametric method. The statistical significance level was set to $p<0.05$.

RESULTS

Jump height. In LRM jump height for DJ was 0.25% (45.9±2.9 cm) smaller, than for CMJ (46.2±3.7 cm), and SJ was 15.7% (39.0±5.2 cm) smaller, than CMJ. For SRM jump height for DJ was 21% (40.4±3.3 cm) greater than for CMJ (33.8±4.7 cm), and 102% greater than for SJ (20.0±2.9 cm).

Maximal velocity of muscle contractions in joint extension phase. In SRM we recorded the smallest velocity in DJ for the vastus lateralis, 68% less than for CMJ and 43% less than for SJ.

Average acceleration of muscle contractions in joint extension phase. In SRM for DJ we calculated 68% and 120.3% less for vastus lateralis and 65% and 101.8% less for rectus femoris than for CMJ and SJ. In LRM no significant difference was observed. For DJ and CMJ the accelerations of gastrocnemius and soleus were greater for SRM than for LRM.

Accelerations in the transition time. In SRM for CMJ we calculated 106.4% more for the gastrocnemius and 160% more for soleus in the concentric than in the eccentric contraction. The differences in accelerations between DJ and SJ and CMJ and SJ in SRM were greater than for LRM.

Energy. In SRM 24% of the extra energy that was available in DJ from the plateau could be reused compared with CMJ at toe-off. In LRM no differences could be observed between DJ and CMJ energies at toe-off**.**

Power. In SRM for DJ we calculated 23.1% more maximal power than in LRM. In SRM at the beginning of contraction power was greater for DJ than for CMJ, but in the later phase of contraction there were no differences between DJ and CMJ.

Joint angles. In SRM at toeoff the hip and knee joint angles were greater for DJ than for CMJ and SJ. In LRM there was no difference at toe-off between DJ, CMJ and SJ joint angles at toe-off.

Vertical acceleration of the center of mass. For DJ and CMJ in the eccentric phase (P1), at the deepest point of the COM (P2) and in the concentric phase (P3) the accelerations were greater in SRM than in LRM. At P2 the acceleration in SRM for DJ (36.1±2.0m/s^2) was 50% greater, than for CMJ (23.9±3.4m/s^2), while in LRM between DJ (18.8±4.2m/s^2) and CMJ (18.2±1.5m/s^2) there was no difference.

Muscle activation level. In LRM for vastus lateralis and soleus at P2 the EMG values for DJ and CMJ were higher than for SJ, while in SRM at P2 no difference could be observed between DJ, CMJ and SJ values.

Activation time. The activation time in the eccentric phase in LRM for DJ and CMJ were 243.3±37ms and 218.3±30ms, while for SRM the activation times were shorter, for DJ and for CMJ 133.3±11.8 and 108.3±25.7ms.

Joint activation sequence. In LRM for DJ, CMJ and SJ proximal-distal joint activation sequence occurred, no difference could be observed in movement pattern. In SRM for DJ compared with CMJ and SJ the hip extension started earlier and the hip and knee angles were greater at toe-off. In SRM for SJ the joint extension sequence was not proximal-distal, first the ankle started extension, than the knee and the hip was the last to start the extension.

DISCUSSION

Elastic energy reuse. In SRM in the eccentric phase the tension increased in the contractile elements, while their lengths remained the same, and consequently the serial elastic elements elongated and stored elastic energy. The great acceleration measured in the deepest point of the COM (P2) is the result of great tension generated by the increased elongation of the elastic elements The intensive acceleration measured at the beginning of the concentric phase is the result of the shortening in the passive and also in the active elements. Because of the greater stretch at maximal joint flexion the elastic energy reuse was greater in DJ than in CMJ especially at the beginning of joint extension predominantly in the plantar flexors.

In LRM for DJ and CMJ the accelerations at P2 and also the velocities at toe-off were identical, consequently the extra energy available for DJ compared with CMJ was not used in the concentric phase. Therefore in this case the elastic energy utilization was minimal, and the work produced by the contractile elements plays the dominant role in the vertical movement.

Muscle activation. In LRM the elapsed time in the eccentric phase is sufficient for the muscles to reach elevated activation level at maximal joint flexion for DJ and CMJ. Presumably the work of the contractile elements decelerated the mass of the body at the end of joint flexion. In SRM the short time of eccentric contraction doesn't result in the elevated activation level of the contractile elements at maximal joint flexion for DJ and CMJ compared with SJ. Therefore at the end of joint flexion the elongation of the elastic elements decelerate the mass of the body.

Joint activation sequence: In LRM the differences in joint activation sequence has no effect on vertical jump results for DJ, CMJ and SJ, as the joint activation patterns are similar for the different jumps. In SRM for DJ the early extension of the hip resulted in greater stress in the quadriceps and the plantar flexors, which is indicated by the acceleration at P2, but also resulted in early toe-off. In SJ the explanation for inverse joint activation sequence is that the angle of the trunk measured from the vertical line at the beginning of the joint extension is the smallest compared with all of the jumps, therefore the muscles responsible for the rotation of the trunk have minimal role in the acceleration of the body, and the trunk is mainly responsible for stabilization, while the jump is executed.

On the basis of our results we can reach decisions about the hypothesizes we set, as our objectives:

1. In jumps executed with small range of motion and countermovement the elastic energy reuse plays a significant role in jump height.

We accept the hypothesis. In SRM for DJ and CMJ the differences in jump height; the differences in the accelerations at P2; the energy and velocities at toe-off; for the gastrocnemius and soleus the differences in the eccentric and concentric phase accelerations at transition time support our decision.

2. In jumps executed with large range of motion and countermovement the effect of elastic energy reuse on jump height is negligible.

We accept the hypothesis. In LRM for DJ and CMJ the jump heights, the accelerations at P2, the energy and the velocities at toe-off are similar; the similar accelerations in the eccentric and concentric phase at transition time for all muscles support our decision.

3. In jumps executed with small range of motion and countermovement the short time of the eccentric contraction does not result in the elevated activation level of the contractile elements at maximal joint flexion.

We accept the hypothesis. The activation times in the eccentric phase for DJ and CMJ are longer in LRM than in SRM; the EMG values at maximal joint flexion in SRM are similar for DJ, CMJ and SJ support our decision.

4. In jumps executed with large range of motion and countermovement the longer time of eccentric contraction results in the elevated activation level of the contractile elements at the maximal joint flexion.

We accept the hypothesis. The activation times in the eccentric phase for DJ and CMJ are longer in LRM than in SRM; the EMG values at maximal joint flexion in LRM are greater for DJ and CMJ than for SJ support our decision.

5. In jumps executed with small range of motion and countermovement elastic energy reuse occurs dominantly at the beginning of joint extension.

We accept the hypothesis. In SRM for gastrocnemius and soleus the differences in the eccentric and concentric phase accelerations at transition time and the greater power values for DJ than for CMJ support our decision.

6. In jumps executed with small range of motion the significant deviation occurs in joint activation pattern for the different jumps.

We accept the hypothesis. The differences in joint activation sequence for SJ and the early trunk extension and early toe-off for DJ support our decision.

7. In jumps executed with large range of motion the joint activation patterns are similar for the different jumps.

We accept the hypothesis. For DJ CMJ and SJ the joint activation sequences were similar support our decision.

CONCLUSION

Although the investigation of muscle behavior in vivo circumstances is difficult, on the basis of our results we can conclude, that if the movement amplitude is restricted in the case of vertical jumps executed with countermovement, elastic energy storage occurs in the serial elastic elements, which can be reused in the beginning of the joint extension phase. On the other hand if the movement amplitude is not restricted, the activation level of the contractile elements determine muscle power, and elastic energy reuse is minimal. From our results we can also conclude, that if the movement amplitude is restricted, the joint activation sequence affects jump height.

List of publications

Papers on the topic of the thesis:

Kopper B, Ureczky D, Tihanyi J. (2012) Trunk position influences joint activation pattern and physical performance during vertical jumping. Acta Physiologica Hungarica, 99:194-205.

Kopper B, Csende Z, Sáfár S, Hortobágyi T, Tihanyi J. (2012) Muscle activation history at different vertical jumps and its influence on vertical velocity. Journal of Elecromyography and Kinesiology, In Press, DOI: 10.1016/j.jelekin.2012.09.005.

Kopper B, Rácz L, Szilágyi T, Sáfár S, Gyulai G, Tihanyi J. (2009) Elasztikus energiafelhasználás függôleges felugrás során: Elastic energy utilization during vertical jumps. Magyar Sporttudományi Szemle 10:10-16.

Papers independent from the topic of the thesis:

Nagy Z, Horváth O, Kádas J, Valtinyi D, László L, Kopper B, Blaskó G. (2012) D-dimer as a potential prognostic marker. Pathology & Oncology Research 18:669-674.