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Stretch-shortening cycle characteristics during vertical jumps carried out with small and large range of motion

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ABSTRACT

In the present study we investigated kinematical characteristics of the knee and ankle extensors to estimate the length change properties of the contractile and the passive elements in countermovement jumps (CMJ) and drop jumps (DJ) performed with small (40°) and large (80°) range of joint motion (SRM and LRM). At SRM the accelerations at maximal muscle lengths compared with the last phase of joint flexion were greater for the gastrocnemius and the soleus (124.9% and 79.4%) and also were greater than at the beginning of joint extension, while no difference was measured at LRM. The differences suggest that at LRM the length change of the serial passive elements from the end of joint flexion to the beginning of joint extension is minimal and simultaneously the length change of the contractile elements is significant, but at SRM – especially in the plantar flexors – the length change of the contractile elements is minimal while in the passive elements significant. It can be presumed that for SRM at the end of joint flexion significant elastic energy is stored and at the beginning of joint extension reused, while for LRM elastic energy storage is not dominant.

1. Introduction

It is a well known phenomenon that the muscle can develop greater force and perform greater work in the concentric phase if, prior to the shortening, stretch occur compared to shortening without prior stretch (Cavagna et al., 1968; Edman et al., 1978). Scientists suggest that this greater work can partly be explained by the use of elastic energy stored in the muscle's elastic components during lengthening (Cavagna et al., 1968; Edman et al., 1978; Bosco and Komi, 1979; Bosco et al., 1981; Anderson and Pandy, 1993).

A widely accepted method to investigate the effect of different magnitude of lengthening and preload on muscle performance in the concentric contraction phase is the comparison of altered executions of vertical jumps. The execution is called countermovement jump (CMJ) if the erect position is the starting posture, and joint flexion is followed by rapid joint extension (Fig. 1). (Komi and Bosco, 1978; Golhoffer et al., 1992; Fukashiro et al., 1995; Bobbert et al., 1996; Gehri et al., 1998; Bobbert and van Soest, 2001; Moran and Wallace, 2007; Caserotti et al., 2008). In this type of jump during the first phase of the joint flexion the center of mass (COM) is accelerating, and muscle activation is minimal, while in the second phase of the joint flexion the muscle activation increases to stop the vertical momentum of the COM. (Komi and Bosco, 1978; Finni et al. (2000)). In the 1990s this explanation was questioned (Schenau Ingen van et al., 1997). Zajac (1993) and Bobbert et al. (1996) concluded that the greater muscle work is the result of increased activity of the motor elements and the role of the elastic components is to help the contractile elements to work more efficiently in the joint extension phase, but the elastic energy use is minimal. Another way to execute vertical jump is when the jump is preceded by falling from an elevated plateau (Fig. 1). After the subject jumps down from the plateau the feet contact the ground. As a result of the freefall from the plateau at this point the vertical momentum of the COM is not zero. Consequently as the joints are flexing the COM is decelerating. After the COM reaches its deepest position and joint flexion is maximal, joint extension and the vertical acceleration of the COM occur. This jump is called drop jump (DJ). In this execution the muscles are already active when the foot reaches the ground and as a result, compared with CMJ, the muscles can achieve greater tension in the phase of joint flexion (Komi and Gollhofer, 1997; McBride et al., 2008). The comparison of CMJ and DJ showed that, if the amplitude of joint angle movement is greater in the joint flexion phase, the difference in jump height will be smaller between the two jumps (McBride et al., 2008; Kopper et al., 2013).

Previous studies concluded that the length change in the muscle prior to concentric contraction affects the rate of elastic energy utilization. If the muscle lengthening is rapid, and the amplitude of the movement is small, the lengths of the contractile elements re-

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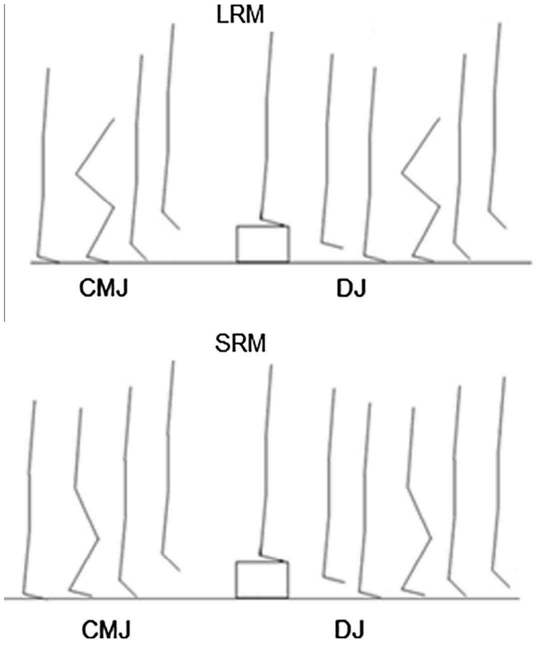

Fig. 1. Schematic drawing of the execution of different vertical jumps for LRM (top) and SRM (bottom).

main constant, while the serial elastic elements elongate, and subsequently during the concentric contraction considerable amount of elastic energy can be reused (Fukunaga et al., 1996; Finni et al., 2003; Ishikawa et al., 2005; Sousa et al., 2007). But if the amplitude of the movement is greater, and muscle lengthening is slower, significantly smaller amount of elastic energy can be reused. (Griffiths, 1991; Kawakami et al., 2002).

Based on the results of our previous study (Kopper et al., 2013), we concluded that in the case of vertical jumps the amplitude of joint flexion prior to extension affects the elastic energy use similarly. If the joint movement amplitude is greater, the level of muscle activation is the dominant factor that affects jump height, and elastic energy reuse is not a significant factor. But if joint movement amplitude is small during DJ and CMJ the role of elastic energy use is significant.

Based on these results the question may arise, at which point of the joint extension does elastic energy reuse dominantly occur?

Previous studies concluded with the investigation of jumps executed with large joint angular displacement (80–90° maximal knee angle) that elastic energy utilization can only amplify the energy used by the contractile elements to accelerate the COM at the end of joint extension, and therefore elastic energy reuse can only take place at the end of the execution (Finni et al., 2000; Bobbert, 2011). Bobbert (2011) also concluded that elastic energy storage occurs predominantly in the plantar flexors, where the ratio of elastic elements are the greatest to the contractile elements compared to other muscle groups taking part in vertical jumps.

In our opinion as an extension of our previous results, where we investigated the kinematics of the COM during vertical jumps (Kopper et al., 2013) the detailed investigation of muscle contraction at the beginning of joint extension can bring us closer to the understanding of muscle behavior in stretch-shortening cycle (SSC). We hypothesize that if joint movement amplitude is smaller than those applied in the studies of either Bobbert (2011) or Finni et al. (2000), muscle lengthening is predominantly the result of lengthening in the passive elements, while the length change in the active elements is minimal. Consequently significant elastic energy storage and, at the beginning of joint extension, elastic energy reuse may occur in the passive elements.

2. Methods

2.1. Subjects of the experiment

Five healthy, trained men (age: 20–21; weight: 7.4 ± 5.17; height: 180.6 ± 4.79) familiar with the execution of vertical jumps participated in this study. Before the experiment they were introduced to the experiment and the possible risks of executing vertical jumps. The Research and Ethics Committee of Semmelweis University, Budapest approved the study methods, and all subjects gave their written informed consent according to the Declaration of Helsinki.

2.2. Study design

The subjects carried out two different types of vertical jumps: CMJ and DJ from a 20 cm high plateau. The jumps were executed with two different range of joint motion. The maximal knee joint flexion was 40.2 ± 2.2 and 82.1 ± 2.3° in small range of motion (SRM) and in large range of motion (LRM), respectively. Before executing the jumps the subjects warmed up and thereafter they carried out three jumps using each type. To eliminate arm movement the subjects firmly held a light rigid pole on their shoulders. The experiment started with the execution of DJ. First the subjects were asked to execute DJ jumps with the highest effort and with 40° of maximal knee flexion. Thereafter the subjects were instructed to carry out CMJ with similar 40° of maximal knee flexion. In the next task the subjects carried out DJ followed by CMJ with 80° of maximal knee flexion. In all jumps if the knee angle difference was greater than five degrees compared with the target knee angle, the jump was discarded and another execution was requested. For every different jump at least three successful executions were recorded. To eliminate the effect of fatigue, 5 min of rest was applied between jumps (Fig. 1).

2.3. Instrumentation and motion analysis

We measured the knee joint angle with a goniometer (Musclelab 4010, Ergotest Technology a.s., Langesund, Norway) secured on the thigh and the shank. To have visual control over the execution the real-time measured knee joint angles were displayed using a projector, therefore the subject and chief supervisor of the experiment were able to have visual control over the jumps. We recorded the jumps with a JVC digital video camera (JVC DVL 9800 V NTSC) with the sampling rate of 120 Hz. The camera was secured on a 1.5 m high tripod six meters from the execution perpendicular to the sagittal plane of the subjects. We secured reflective markers 1.5 cm in diameter on the neck (on the vertical line of the auris externa at the height of the prominentia laryngea), hip joint at the greater trochanter, ankle joint (malleolus lateralis), the heel of the shoe and the palpable joint of the first proximal phalange of the big toe. To digitally process the raw data and obtain the horizontal (x) and vertical (y) position of the markers we used the APAS movement analyzing software (Ariel Performance Analysis System, Ariel Dynamics Inc. CA 92679 USA).

2.4. Calculations

For later analysis we used four body segments. In the model the trunk, the head and the upper limbs are represented as one segment. The segments were determined between the Neck and the Hip containing the head-trunk-upper limbs (TRUNK) between the Hip and the Knee (THIGH), between the Knee and the Ankle (SHANK) and between the Ankle and Toe/Foreleg (FOREFOOT). The APAS software after digitalization and filtering (least square