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Muscle activation history at different vertical jumps and its influence on vertical velocity

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ABSTRACT

In the present study we investigated displacement, time, velocity and acceleration history of center of mass (COM) and electrical activity of knee extensors to estimate the dominance of the factors influencing the vertical velocity in squat jumps (SJs), countermovement jumps (CMJs) and drop jumps (DJs) performed with small (40°) and large (80°) range of joint motion (SROM and LROM). The maximum vertical velocity ($v4$) was 23.4% (CMJ) and 7.8% (DJ) greater when the jumps were performed with LROM compared with SROM ($p < 0.05$). These differences are considerably less than it could be expected from the greater COM and knee angular displacement and duration of active state. This small difference can be attributed to the greater deceleration during eccentric phase (CMJ:32.1%, DJ:91.5%) in SROM than that in LROM. $v4$ was greater for SJ in LROM than for SJ in SROM indicating the significance of the longer active state and greater activation level ($p < 0.001$). The difference in $v4$ was greater between SJ and CMJ in SROM (38.6%) than in LROM (9.0%), suggesting that elastic energy storage and re-use can be a dominant factor in the enhancement of vertical velocity of CMJ and DJ compared with SJ performed with SROM.

1. Introduction

Vertical jump with or without countermovement (CMJ or SJ) is a widely used model to study the mechanical behavior of muscles in vivo (Asmussen and Bonde-Petersen, 1974; Komi and Bosco, 1978; Golhoffer et al., 1992; Fukashiro and Komi, 1987; Moran and Wallace, 2007) and in computer simulations (Pandy and Zajac, 1991; Bobbert et al., 1996; Bobbert and van Soest, 2001). By now it is accepted that positive work done during vertical jumping depends upon several factors, such as displacement of center of mass (COM) depending upon initial joint flexion and angular displacement (Bobbert et al., 2008; Vanrenterghem et al., 2008; Selbie and Caldwell, 1996; Moran and Wallace, 2007), the activation (pretension) level of the muscles (Zajac, 1993; Bobbert et al., 1996; Bobbert and Casius, 2005; McBride et al., 2008), the elastic energy stored and re-used during joint flexion and extension (Asmussen and Bonde-Petersen, 1974; Komi and Bosco, 1978; Vanrenterghem et al., 2008), and muscle activation pattern (Hudson, 1986; Bobbert and van Ingen Schenau, 1998; Pandy and Zajac, 1991; Vanrenterghem et al., 2008). These factors acting together are believed to cause 3–6 cm greater jump height when jumps are performed with countermovement vs. squat jumps. This phenomenon was reported in most of the studies when the positive work started from semi-squat position (knee angle was approximately 80–100°).

The question arises as to whether the same difference will appear between the two types of jumps if the joint extension starts at a smaller joint angle. So far few studies have addressed this problem. Recently, Bobbert et al. (2008) and Vanrenterghem et al. (2008) studied the effect of different ROM, called submaximal jump, on jumping height and joint activation patterns in SJ and CMJ and reported that jumping height decreased in the function of the decreasing angular displacement. They found an altered joint activation pattern that explained the differences in jumping height. As SJ and CMJ were investigated separately in these studies no comparative data were available concerning identical joint movement amplitude. There is only one study (Moran and Wallace, 2007), at least to our knowledge, in which SJ, CMJ and drop jump (DJ) were compared by applying two different controlled angular displacements (90° or 70° of knee joint angle). They found significant differences in jumping height and joint moment between

Abbreviations: a, vertical acceleration of COM; CMJ, countermovement jump; CMJL, countermovement jump – large range of motion; CMJS, countermovement jump – small range of motion; DJ, drop jump; DJL, drop jump – large range of motion; DJS, drop jump – small range of motion; h, height of COM from ground; LROM, large range of joint motion; P, position of COM; ROM, range of motion; SJ, squat jump; SJL, squat jump – large range of motion; SJS, squat jump – small range of motion; SROM, small range of joint motion; t, elapsed time between different jump phases; v, vertical velocity of COM; VL, vastus lateralis.

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different types of jumps and the differences were greater at 70°. However, we thought that this shorter angular displacement is still not short enough to provide a solid basis to estimate the dominant role of the influencing factors, such as muscle pretension, duration of active state, activation level of muscles or storage and reuse of elastic energy (Bobbert et al., 1996). On the other hand, from a practical point of view, the applied range of motion of COM and the angular displacement of the knee joint was considerably larger than that observed in athletes during running and jumping or in explosive strength exercises or for example in hopping exercises. Previous studies did not pay sufficient attention to the kinematic profile of COM, which may also explain the differences in jumping heights and consequently in muscle energy consumption while executing vertical jumps with or without countermovement and with extra preload. It can be assumed that kinematic profile prior to joint extension substantially affects jumping height and may allow us information to determine the role of each factor in vertical jump height. Therefore, we examined the displacement, time, velocity and acceleration history of COM and the electrical activity of knee extensors, and their influence on final vertical velocity during large range of motion (knee angle 80°, LROM) and also in small range of motion (knee angle 40°, SROM) applying SJ, CMJ and DJ.

Our hypotheses were: (1) using SROM, muscle activation and pretension are greater for DJ than for CMJ because the deceleration of COM is greater and the acceleration of COM is also greater during joint extension and therefore the difference in final velocity is greater between SJ, CMJ and DJ compared to LROM; (2) in LROM, the deceleration of COM during joint flexion may be greater in DJ than in CMJ but acceleration during joint extension will be the same, because by flexing the joint with large angular displacement the original extra potential energy dissipates and therefore acceleration and final velocity will be identical; (3) because the difference in jumping performance between SJ and CMJ, SJ and DJ is greater in SROM, elastic energy storage and re-use can be a dominant factor in the enhanced vertical velocity of CMJ and DJ.

2. Methods

2.1. Subjects

Five male physically active students (age: 20–21 years, body mass: 76.4 ± 5.17 kg, height: 180.6 ± 3.5 cm) were recruited in the present study. Before the experiment they were familiarized with the experiment and the possible risk in executing vertical jumps. The study protocol was approved by the Research and Ethics Committee of the University and all subjects gave their informed written consent according to the Declaration of Helsinki.

2.2. Study design

Subjects familiarized with the experimental protocol after warm-up. Subjects carried out three different types of vertical jumps, i.e. DJ from a 20 cm high plateau, CMJ and SJ. The jumps were executed in two different ranges of joint motion. The target knee joint flexion was 40° and 80° in SROM and in LROM, respectively (Fig. 1). To eliminate arm movement, subjects firmly held a light rigid wooden bar (0.4 kg) on their shoulders. Angular displacement of the knee joint was controlled by an electric goniometer (Musclelab 4010, Ergotest Technology a.s., Langesund, Norway) and was displayed on a large screen in front of the subjects, so that they and the chief supervisor of the experiment could receive immediate feedback about the angular position. If the joint angle deviated from the target by more than 5°, the jump was discarded and another execution was requested. At least three successful executions were recorded. Jumps with the highest vertical displacement of COM were chosen for further analysis.

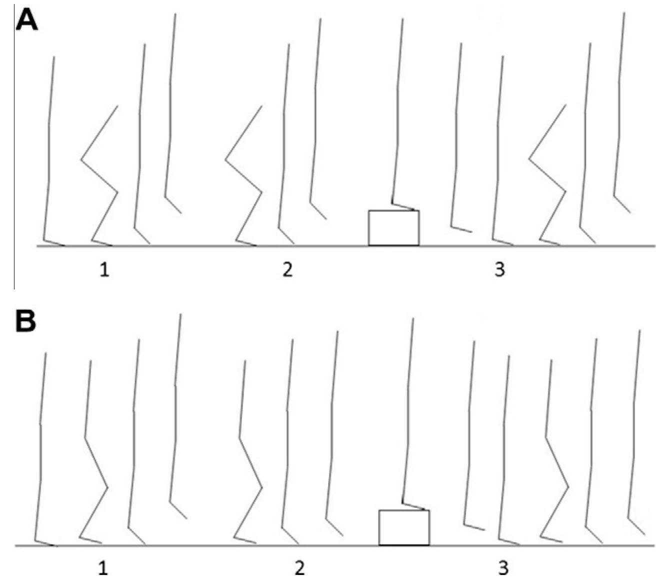

Fig. 1. Free body diagrams indicate the vertical jumps applied in this study. Panels A and B represent CMJ (1) SJ (2) and DJ (3) in LROM (A) and small SROM (B).

3. Data collection and analyses

3.1. Motion capture

Jumps were recorded by a JVC digital video camera (JVC DVL 9800V NTSC) with a sampling rate of 120 Hz. The camera was secured on a 1.5 high tripod six meters away from the subjects, perpendicularly to the sagittal plane of the jumpers. Reflective markers 1.5 cm 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. 2003) was used to digitally process the raw data obtained by the displacement of the markers. The temporary location of COM was calculated for the segments (trunk including head, neck and upper extremities, thighs, shanks and feet) and for the whole body in the function of time (Fig. 2) using the Dempster body model (1955).

Five distinctive points were defined on the vertical displacement and time curves in CMJ and DJ: $P1$ 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; and $P5$ when toe-off occurred (Fig. 4). $P3$ was also determined in SJ in relation to either CMJ or DJ. Time was measured between $P1$ and $P2$, $P2$ and $P3$, and $P3$ and $P4$ ($T1$, $T2$ and $T3$). Height of COM was measured from the ground at $P1$, $P2$, $P3$ and $P4$ ($h1$, $h2$, $h3$ and $h4$) (note that $h3$ is equal to $h1$). Vertical velocity was calculated at $P1$, $P3$ and $P4$ ($v1$, $v3$ and $v4$). Average acceleration and instantaneous acceleration were calculated between $P1$ and $P2$ ($a1_{P1-P2}$), $P2$ and $P3$ ($a3_{P2-P3}$), and at $P2$ ($a2$), respectively (Fig. 4). Knee joint angle was also measured at $P1$, $P2$, $P3$, $P4$ and $P5$ to estimate similarities at $P2$ and to reveal differences among jumps executed by LROM and small SROM.