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Effects of countermovement depth on kinematic and kinetic patterns of maximum vertical jumps

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ABSTRACT

Although maximum height (H_{max}), muscle force (F), and power output (P), have been routinely obtained from maximum vertical jumps for various purposes, a possible role of the countermovement depth (H_{cmd}) on the same variables remains largely unexplored. Here we hypothesized that (1) the optimum H_{cmd} for maximizing H_{max} exists, while (2) an increase in H_{cmd} would be associated with a decrease in both F and P. Professional male basketball players ($N = 11$) preformed maximum countermovement jumps with and without arm swing while varying $H_{cmd} \pm 25$ cm from its preferred value. Although regression models revealed a presence of optimum H_{cmd} for maximizing H_{max}, H_{max} revealed only small changes within a wide range of H_{cmd}. The preferred H_{cmd} was markedly below its optimum value ($p < .05$). However, both F and P sharply decreased with H_{cmd}, while F also revealed a minimum for H_{cmd} close to its highest values. Therefore, we conclude that although the optimum H_{cmd} should exists, the magnitude of its effect on H_{max} should be only minimal within a typical H_{cmd} range. Conversely, F and P of leg muscles assessed through maximum vertical jumps should be taken with caution since both of them could be markedly confounded by H_{cmd}.

1. Introduction

It has been generally accepted that maximum vertical jumps could provide a reliable and sensitive assessment of various kinematic and kinetic variables (Markovic et al., 2004; Moir et al., 2004, 2005; Sheppard et al., 2008). Therefore, vertical jumps have been widely used not only for training purposes, but also for testing the velocity, force, and power production capacity of leg muscles both in athletes (Cormie et al., 2011; Cuk et al., 2014; Nedeljkovic et al., 2009; Sheppard et al., 2008; Vuk et al., 2012) and in various patient and elderly populations (Rittweger et al., 2004; Runge et al., 2004). A variety of vertical jumps have been employed, including those with and without a preceding countermovement, arm swing, or external loads.

The concentric phase of the natural countermovement vertical jump is inevitably performed with a preceding eccentric phase that lowers the body center of mass to a certain countermovement depth (H_{cmd}). The changes in H_{cmd} markedly affect conditions for muscle actions, and consequently the patterns of various mechanical variables that can be obtained from vertical jumps (Bobbert, 2012; Bobbert et al., 2008; Samozino et al., 2012; Vanrenterghem et al., 2004). Nevertheless, the effect of H_{cmd} on vertical jumps remains largely neglected in literature. Namely, a typical implicit presumption has been that the tested subjects are able to select the movement pattern (such as assessed by H_{cmd}) that maximizes the jump height (Moir et al., 2004) and, thereafter, to reproduce it over a series of consecutive trials. As a consequence, both the differences among various populations (Nuzzo et al., 2010; Pazin et al., 2011; Vuk et al., 2012) and the effects of the applied interventions (Cormie et al., 2011; Markovic et al., 2013) on various variables obtained from vertical jumps have been usually attributed to the differences in force and power producing ability of leg muscles, rather than to the differences between the jumping kinematic patterns.

The above discussed disregard of the possible role of H_{cmd} in vertical jumps has been partly supported by a robust and stable

Abbreviations: CMJ, countermovement jump without arm swing; CMJA, countermovement jump with arm swing; H_{cmd}, countermovement depth; H_{max}, jump height; F, force output; F_{max}, maximum force output; P, power output; P_{avg}, average power output; P_{max}, maximum power output.

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pattern of muscle activation that could be only moderately tuned to the differences in H_{cmd} (Bobbert and van Soest, 2001; Van Soest et al., 1994). This phenomenon could explain the findings of some experimental and modeling studies suggesting that H_{max} could be relatively insensitive to H_{cmd} (Bobbert et al., 2008; Domire and Challis, 2007; Selbie and Caldwell, 1996). Conversely, in addition to empirical and research evidence suggesting that subjects repeatedly select a particular H_{cmd} and adjust it to the external load (Markovic and Jaric, 2007b; Markovic et al., 2011, 2014) and effort (Vanrenterghem et al., 2004), some studies have suggested that H_{cmd} could have a marked effect on H_{max} (Kirby et al., 2011; Salles et al., 2011). This discrepancy could be explained by a larger range of H_{cmd} manipulated in the cited studies, as compared with the studies that did not reveal the effect of H_{cmd} on H_{max} (Bobbert et al., 2008; Domire and Challis, 2007; Selbie and Caldwell, 1996). Therefore, one could conclude that we still do not know whether and to what extent H_{cmd} affects H_{max} in vertical jumps. Namely, it appears that H_{cmd} has never been directly manipulated to assess its effect on H_{max} (Ziv and Lidor, 2010). As a consequence, it remains possible that a number of both the research findings and the outcomes of various testing procedures based on maximum vertical jumps have been confounded by the changes in H_{cmd}.

In addition to the jumping performance assessed through H_{max}, there is some evidence suggesting that H_{cmd} could also affect other variables frequently obtained from vertical jumps. For example, the ground reaction force (F) has often been recorded to assess the effects of various mechanical conditions, as well as to evaluate the outcomes of various strength training procedures (Domire and Challis, 2007; Hori et al., 2007; Markovic et al., 2011, 2013; Samozino et al., 2014). However, the results of some experimental and modeling studies suggest that the maximum F (F_{max}) could decrease with an increase in H_{cmd} (Kirby et al., 2011; Markovic et al., 2014; Salles et al., 2011). In addition, it is well known that the changes in muscle length associated with differences in H_{cmd} could affect the muscle stretch–shortening cycle performance [c.f., (Cormie et al., 2010)]. An important consequence could be the effect of H_{cmd} on the muscle power output (P). Namely, the maximum jumping performance (i.e., H_{max}) may not only require high P of leg muscles (Cormie et al., 2011; Samozino et al., 2012), but H_{max} could also be a measure of P normalized for body size (Harman et al., 1991; Markovic and Jaric, 2007a; Nedeljkovic et al., 2009). However, a H_{cmd} associated decrease in P has been reported in literature (Kirby et al., 2011; Salles et al., 2011). Recent studies have also shown that a jump training associated increase in H_{max} may not be associated with a comparable increase in F and P due to increased H_{cmd} (Markovic et al., 2011, 2013). Therefore, there is convincing evidence that in addition to kinematic, H_{cmd} could also affect the kinetic pattern of vertical jumps and therefore decouple F and P output of leg muscles from jumping performance (Markovic et al., 2014; Samozino et al., 2012). Nevertheless, we still do not know the magnitude of that effect within a wider range of H_{cmd}, as well as whether it could be different for F and P.

The main aim of the present study is to explore the effects of H_{cmd} on kinematic and kinetic patterns of maximum vertical jumps. Our first hypothesis was that there would be an optimum H_{cmd} for maximizing H_{max}. Our second hypothesis was that both F and P would decrease with an increase in H_{cmd}. The expected results could be of importance for interpreting the outcomes of various training and testing procedures based on vertical jumping, as well as for gaining a general understanding of the effect of H_{cmd} on the various mechanical variables typically obtained from vertical jumping.

2. Methods

2.1. Subjects

Due to the aims of the study, the subjects were required to be exceptionally familiar with vertical jumps performed under different mechanical conditions (Ziv and Lidor, 2010). Therefore, we recruited 11 elite male basketball players (I National league level; age 21.8 ± 2.9 years). We purposefully avoided recruiting the players taller than 2 m because of the prominent scaling effects that their body size could have on both the kinematic and kinetic jumping patterns (Jaric, 2003; McMahon, 1984). Their body mass (86.2 ± 7.1 kg) and body height (192.9 ± 6.0 cm) were assessed by a digital scale and standard kinanthropometer, respectively. Percent of body fat (8.5 ± 4.2%) was assessed by the bioelectric impedance method (In Body 720; South Korea). None of the subjects reported recent injuries to the musculoskeletal apparatus. The study was conducted in accordance with the Declaration of Helsinki and all subjects signed informed consent approved by the Institutional Review Board.

2.2. Experimental protocol

The study was carried out through the familiarization and experimental session separated by at least three days of rest. The anthropometric measures were taken prior to the familiarization session, but the sessions were otherwise identical. They were preceded by a standard warm-up procedure (5 min cycling, 5 min stretching, and 2 sets of 5 submaximal jumps) followed by 2 blocks of 20–23 (see further text for detailed explanations) maximum countermovement jumps performed either without (CMJ) or with an arm swing (CMJA). The countermovement depth (H_{cmd}) of both jumps was manipulated with respect to the initially self-determined *preferred* H_{cmd}. Specifically, the jumps were performed with *small*, *preferred* and *large* H_{cmd}. Both the sequence of jumps and the sequence selected H_{cmd} were randomized. The subjects were instructed to avoid any strenuous exercise one day prior to the experiment.

2.3. Testing procedures

The blocks of trials for each jump (i.e., CMJ and CMJA) were initiated by 5 maximal jumps that were used for the determination of *reference values* for all variables. Thereafter, subjects performed 3 sub-blocks of maximum jumps in a random sequence that served for data collection. Specifically, they performed 5 jumps from the *preferred* H_{cmd}, as well as 5 or more jumps from either *small* or *large* H_{cmd}. For the preferred H_{cmd}, subjects were solely instructed to jump as high as possible. The sub-block of jumps performed from the preferred served for the assessment of reliability. Regarding the sub-blocks performed from the *small* and *large* H_{cmd}, subjects were instructed to jump as high as possible either "by going less deep" or "by going deeper into the squat", respectively. In both sub-blocks, the experimenters specifically targeted H_{cmd} to be between 10 and 20 cm different from its reference value obtained from first 5 trials. Whenever the individual trials revealed a H_{cmd} out of the target interval, the subject was instructed to correct it in the subsequent trial, while the instruction regarding the maximization of jump height was always reiterated. Note that the entire procedure of H_{cmd} manipulation was based on a series of pilot experiments conducted with the aim to provide an H_{cmd} approximately equally distributed within the range up to ±25 cm with respect to the preferred H_{cmd}. The trials that did not fall within this range (about 1 per subject) were repeated.