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A comparison of the mechanical effect of arm swing and countermovement on the lower extremities in vertical jumping

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The purposes of this study were to quantify and compare how arm swing and countermovement affect lower extremity torque and work during vertical jumping and to gain insight into the mechanisms that enable the arm swing and countermovement to increase jump height. Five participants maximally performed two types of vertical squat jumps with (SJA) and without (SJ) an arm swing and two types of countermovement vertical jumps with (CJA) and without (CJ) an arm swing. The participants jumped from a force platform and all performances were videotaped with a high-speed video camera (200 Hz). Jump heights, joint torques and work were calculated by combining kinematic and kinetic data. It was found that of the four jumping conditions, the participants jumped highest when they used an arm swing with countermovement (i.e., CJA). The increase of the countermovement jump height with an arm swing is the result of the increase of the lower extremity work. In the hip joint, the increase in torque caused by the countermovement predominantly occurred at the beginning of the propulsion phase, while the increase in torque caused by the arm swing occurred in the rest of the propulsion phase. A

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key finding of our study is that arm swing and countermovement have independent effects on lower extremity work, and their effects are additive in CJA to produce greater jump height.

1. Introduction

Voluntary arm movements and countermovement in the lower extremities are strategies frequently used in jumping to improve performance. The effects of countermovement in jump performance have been investigated for at least the last three decades (Asmussen & Bonde-Petersen, 1974; Bobbert & Casius, 2005; Bobbert, Gerritsen, Litjens, & van Soest, 1996; Bosco & Komi, 1979; Bosco, Viitasalo, Komi, & Ito, 1981; Bosco, Viitasalo, Komi, & Luhtanen, 1982; Fukashiro & Komi, 1987; Komi, 1984; Sagawa, Kamuro, & Matsumoto, 1989). From the viewpoint of the work output during countermovement jump, it has been reported that the greater jump height in countermovement jump (CJ) compared to squat jump (SJ) was due to a greater work output of the hip extensor muscles (Bobbert & Casius, 2005; Bobbert et al., 1996; Fukashiro & Komi, 1987; Sagawa et al., 1989). For example, Bobbert and Casius (2005) used a two-dimensional neuromusculoskeletal model to show that the hip extensor muscles could produce more force and work over the first 30% of their shortening range. This was explained by the fact that, in this period, the extensor muscles had a higher active state in CJ than in SJ.

Countermovement is not the only strategy employed to improve jump height performance. Several researchers (Harman, Rosenstein, Frykman, & Rosenstein, 1990; Payne, Slater, & Telford, 1968) found that the ground reaction force ($\mathbf{F}_{GR}$) in the latter half of the push-off phase was increased by the use of the arms. The higher $\mathbf{F}_{GR}$ resulted in an increased net ground reaction impulse which was the direct reason for the augmented jump height.

Luhtanen and Komi (1978) studied the separate segmental movements at maximum intensity to quantify the contribution of the different body segments including the arms. Ae and Shibukawa (1980) and Lees and Barton (1996) divided segment momentum into two components: transfer momentum and relative momentum. In order to express the contribution of arms to vertical momentum, the relative momentum was used. Although, in these studies, the arm swing effect was addressed as the relative momentum of the arm to the shoulder, the effect of the arm swing on lower extremities was not considered. By employing an inverse dynamics method, Feltner, Fraschetti, and Crisp (1999) discussed the changes of the resultant torques on countermovement vertical jump with and without an arm swing (CJA, CJ), but they did not calculate the work output of each joint.

The work–energy theorem shows that work done by muscles is converted to mechanical energy of a participant. Therefore, in the vertical jump, achieving high jump height is almost equivalent to achieving a large amount of mechanical energy by achieving large amount of work done by muscles.

From a work–energy theorem perspective, Lees, Vanrenterghem, and Clercq (2004) and Hara, Shibayama, Takeshita, and Fukashiro (2006) examined the role of arm swing during vertical jumping. For example, Hara et al. examined how arm swing affects the lower extremity work using vertical squat jumping with and without arm swing (SJA, SJ). They concluded that the increase of jump height with arm swing resulted mainly from the increase of the lower extremity work (the work by the hip and ankle), which is considered to have been brought about by the additional load on the lower extremity due to the arm swing.

Although the influences of both arm swing and countermovement on jump performance have been examined by many researchers, it is still unknown how the combination of both strategies affect joint work and jump performance. By using both arm swing and countermovement simultaneously, the effects could be additive, multiplicative, or perhaps negative. Therefore, the interaction between the two strategies has yet to be fully understood with respect to joint work.