The effect of arm swings on vertical jumping
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Introduction
Many biomechanics researchers studied vertical jumps and reported that humans are able to jump higher by using countermovements of lower extremities. Most of these studies regarded the trunk and arms as one segment. However, in most jumps seen in daily and athletic activities, a rapid arm swing occurs simultaneously with the leg motion, which may also enhance the jump height. A few studies were done on jumps with arm swings. It has been reported that an arm swing enhances the jump height (Harman et al., 1990) and during the final two-thirds of the propulsive phase, the arm swing augments hip extensor torques by slowing the extension of the hip joint (Michael et al., 1999). However, differences in the work of each joint between the two conditions (with and without arm swings) were not considered in these studies.

The purpose of this study was to examine how the arm swing affects the lower extremity torque, power and work during the vertical jump and to gain an insight into the mechanisms that enable the arm swing to increase jump height.

Methods
After adequate warming up and practice, six healthy male subjects (height: 172 ± 8.85 cm; body mass: 68.8 ± 7.47 kg; mean ± s) jumped maximally from a force platform four different ways in random order: squat jumps with no arm swing (SJ), squat jumps with arm swings (SJA), countermovement jumps with no arm swing (CJ) and countermovement jumps with arm swings (CJA). All of them gave informed consents. With arm swing jumps, the subjects first raised and sustained the arms back, then swung the arms forward at their preferred timing. During jumps with no arm swing, the hands remained on the subject’s iliac crests (Fig. 1: SJ, SJA, CJ, CJA).

Before the experiment, we recorded each subject performing CJ in their preferred way by a high speed camera. The motions were replayed and the joints at the lowest position were marked on the screen. These marks were used as reference points for each subject to perform all jumps. The order of jumps was randomized and two-minute rest was allowed between the trials. The subjects performed four trials per each jump condition and the highest jump performance for respective conditions was used for the subsequent analyses. Ground reaction forces and cinematographic data were simultaneously recorded at 200 Hz. Torques, power and work of the hip, knee, ankle and shoulder joints, displacement of the body center of gravity (CG) and other biomechanical variables were calculated using the obtained kinematic and kinetic data.

Results and Discussions
1: The jump heights (displacement of the CG from the standing position; mean ± s) were 46.2 ± 7 cm (SJ), 55.9 ± 4.69 cm (SJA), 49.8 ± 5.41 cm (CJ) and 58.8 ± 4.53 cm (CJA). There were significant differences in the jump heights (Bonferroni test) as shown in Fig. 2. These results suggested that
both countermovements and arm swings significantly improved the jump height, but the arm swings enhanced the jump height more than countermovements. These findings are similar to those of Everett et al. (1991).

The total work by all the joints and the total work by the lower extremity joints (ankle, knee, hip) during the jump showed the similar tendency as that of the jump height (Fig. 2).

2: Significant differences in the peak value of the ankle torque were observed between SJ and SJA ($p = 0.0023$), and between CJ and CJA ($p = 0.0004$), respectively, and significant difference in the ankle work was observed between SJ and SJA ($p = 0.0069$) (one sided paired $t$-test)!

3: One sided paired comparison showed that arm swings augmented hip joint work significantly both for squat jumps ($p = 0.0177$) and for countermovement jumps ($p = 0.0293$) as shown in Fig. 3. Moreover, comparing SJA with CJ, the peak torque of hip joint in CJ was larger than in SJA ($p = 0.0414$), and on the other hand, the work by the hip joint in SJA was larger than in CJ ($p = 0.0138$) significantly. These results suggested that the effect of countermovement on the augmentation of the peak of the hip extensor torque was greater than that of the arm swings, while the effect of the arm swings was greater on the augmentation of the work than that of countermovement.

Figure 2: Ensemble averages of the jump heights in centimeters (left) and the total body work by all the joints in joules (right) for each condition.

Figure 3: Ensemble averages of the work by the hip joint in joules. Left: comparison between SJ and SJA ($p = 0.0177$). Right: comparison between CJ and CJA ($p = 0.0293$).
The arm swing contribution to the hip joint torque may be divided into two components, i.e., shoulder joint torque applied to the trunk \( (T_s) \) and the torque created about the CG of the trunk by the shoulder joint force applied to the trunk \( (T_f) \) (Fig. 4). The peak of the arm swing contribution (the sum of \( T_s \) and \( T_f \)) occurred at about the middle of the propulsive phase, which is considered to have restrained rapid decrease of hip joint torque (Fig. 5) and, although the hip joint angular velocity was reduced, the power of the joint (the product of torque and angular velocity) was augmented in the latter half of the propulsive phase.

Our study suggested that the arm swings contributed to the enhancement of the jump height not only by raising the CG of the arms but by augmenting the work of the lower extremity joints, especially of the hip and ankle joints.

**Figure 4:** Red line: the shoulder joint torque applied to the trunk, Blue line: the torque created about the CG of the trunk by the shoulder joint force applied to the trunk, Black line: the resultant of the two. The unit of the vertical axis is Nm. The transverse axis represents time in seconds. The green vertical line indicates the instant of the lowest of the CG. The origin of time indicates the instant of take-off.

**Figure 5:** A typical example of the torque (Nm), angular velocity (rad/s) and power (W) of the hip joint in CJ and CJA. The transverse axis represents time in seconds. The green vertical line indicates the instant of the lowest of the CG. The origin of time indicates the instant of take-off.

**Reference**