Why do people swing the arms from back to front when they perform a vertical jump?

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Introduction
We know empirically that one can jump higher with the aid of arm swings and some people think that this is because the trunk is pulled upward by the up-going arms. This intuitive interpretation on the arm swing effect would be correct if the arms were raised independently by some external forces and then pulled up the trunk. However, the arm movements and the other parts of the body are closely interrelated. When the arms are pulling the trunk upward, the trunk is pulling the arms downward. So the pulling of the trunk by the arms does not contribute to the extra rise of the center of mass (CM) of the body. The energy flow from the arms to the trunk is conspicuous in the latter half of the propulsive phase (the period between the times at the lowest and the takeoff) but the other way around in the first half. We must give consideration to the total work done by all the joints throughout the propulsive phase to gain an insight into the effect of arm swings on the vertical jump height.

It has been pointed out that the upward acceleration of the arms creates a downward force on the body at the shoulders that slows the rate of the shortening of the leg muscles, which would result in enhanced muscle tension and larger vertical ground reaction forces (Feltner et al., 1999). If the upward acceleration is essential, however, why do people swing the arms from back to front (in shoulder flexion direction) when they perform a vertical jump? The main reason may be that one can raise the arms higher by shoulder flexion than by shoulder (extreme) extension. We cannot reach high places if we swing the arms backward! Apart from this anatomical (and practical) constraint, does the back-to-front direction of an arm swing have any other mechanical advantages?

Another study of the authors’ showed that an arm swing augmented the work done by the hip joint torque in the propulsive phase of jumping. Not only the vertical component but also the horizontal component of the shoulder joint force ($F_{\text{shoul}}$) must be taken into account to evaluate the hip joint torque as described below.

Assumptions: One can calculate the hip joint torque by formulating the equation of motion for either the thigh or the trunk. From the equation of motion of the trunk, the hip joint torque $T_{\text{hip}(-\text{trunk})}$ is obtained as

$$
T_{\text{hip}(-\text{trunk})} = \dot{L}_{\text{trunk}} - R_{\text{hip}} \times F_{\text{hip}(-\text{trunk})} - R_{\text{shoul}} \times F_{\text{shoul}(-\text{trunk})} - T_{\text{shoul}(-\text{arm})}
$$

(1)

where $T_{\text{hip}(-\text{trunk})}$: the hip joint torque applied to the trunk, $L_{\text{trunk}}$: the angular momentum of the trunk, $R_{\text{hip}}$: the relative position of the hip joint to the CM of the trunk, $F_{\text{hip}(-\text{trunk})}$: the hip joint force applied to the trunk, $R_{\text{shoul}}$: the relative position of the shoulder joint to the CM of the trunk, $F_{\text{shoul}(-\text{trunk})}$: the shoulder joint force applied to the trunk, $F_{\text{shoul}(-\text{arm})}$: the shoulder joint force applied to the arms ($=-F_{\text{shoul}(-\text{trunk})}$), $T_{F}$: defined as $R_{\text{shoul}} \times F_{\text{shoul}(-\text{arm})}$: $T_{\text{shoul}(-\text{trunk})}$: shoulder joint torque applied to the trunk, and $T_{\text{shoul}(-\text{arm})}$: shoulder joint torque applied to the arms ($=-T_{\text{shoul}(-\text{trunk})}$). If we put

$$
R_{\text{shoul}} = (X, Y), \quad F_{\text{shoul}(-\text{arm})} = (F_{x}, F_{y})
$$

then $T_{F}$ may be expressed as

$$
T_{F} = R_{\text{shoul}} \times F_{\text{shoul}(-\text{arm})} = \begin{pmatrix} \dot{X}F_{y} - \dot{Y}F_{x} \end{pmatrix}_{\text{TF,v}} \begin{pmatrix} XF_{y} \end{pmatrix}_{\text{TF,h}}
$$

(2)
Eqs. (1) and (2) mean that mathematically, contribution of the shoulder joint to the hip joint torque is divided into two components: the shoulder joint torque applied to the trunk ($-T_{\text{shoul}}$) and the torque created about the CM of the trunk by $F_{\text{shoul}}$ applied to the trunk ($-R_{\text{shoul}} \times F_{\text{shoul}}$) is equal to $T_{\text{shoul}}$ and may be interpreted as torque needed to extend the hip joint, resisting the force applied to the trunk which is associated with the acceleration of the CM of the arm.

If the magnitudes of $T_{\text{shoul}}$ and $T_F$ are moderate, these torques can be proper loads to the hip joint, and increase the hip joint torque. $T_F$ is also divided into two parts, i.e., $T_{F,h}$, which is derived from the horizontal component of $F_{\text{shoul}}$, and $T_{F,v}$, which is derived from the horizontal component of $F_{\text{shoul}}$. $R_{\text{shoul}} = (X, Y)$ is the relative position of the shoulder joint to the CM of the trunk, and both $X$ and $Y$ are positive during most part of the propulsive phase if we set the coordinate axes as Figure 1. So the torque ($T_{F,v}$) created by the vertical component ($F_y$) of the force ($F_{\text{shoul}}$) applied to the arm (from trunk via shoulder) and the torque ($T_{F,h}$) created by the horizontal component ($F_x$) of $F_{\text{shoul}}$ are positive (i.e., in the hip extension direction) terms for the hip joint torque when $F_y > 0$ and $F_x < 0$, respectively. Considering that the CM of the arms traces roughly a circle (seen from the shoulder), the vertical component $F_y$ takes the positive maximum value when the CM of the arm is at about the lowest position, and the horizontal component $F_x$ takes the negative maximum value when the CM of the arm is in front. So, if we swing the arms forward, $T_{\text{shoul}}$, $T_{F,h}$ and $T_{F,v}$ will act on the trunk to tilt it forward in most part of the propulsive phase of jumping and be a “load” to the hip extensor muscles. On the other hand, if we swing the arms backward, $T_{\text{shoul}}$ and $T_{F,h}$ will cancel the effect of $T_{F,v}$ to tilt the trunk forward and lower the “load” on the hip extensor muscles. These load changes associated with arm swings may affect the performance of jumping.

The aim of the experiment on this study was to investigate the effect of arm swings on the jump height focusing on the direction of arm swings.

**Methods**

After adequate warming up and practice, four healthy male subjects performed squat jumps for maximal height from a force platform three different ways in random order: squat jump with no arm swing (SJ), squat jump with a backward arm swing (SJBA), and squat jump with a forward arm swing (SJFA). With arm swing jumps, the subjects first raised and sustained the arms front (SJBA) or back (SJFA), then swung the arms backward or forward at their preferred timing (Figure 2).

**Results and Discussions**

Figure 3 shows the average jump height (displacement of the CM from the standing position) and the total work done by the lower extremity joints (ankle, knee, and hip) in the propulsive phase. The jump

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*Mathematically, these terms are added in calculating the hip joint torque. However, needless to say, the hip joint torque in a jump with an arm swing is not equal to the sum of these terms and the torque obtained in a jump without an arm swing.*
heights were $46.7 \pm 6.7$ cm (SJ), $51.2 \pm 7.8$ cm (SJBA), and $56.1 \pm 5.0$ cm (SJFA) and the work by the lower extremity joints were $526 \pm 72$ J (SJ), $565 \pm 88$ J (SJBA), and $581 \pm 76$ J (SJFA) (mean ± s). As shown in Figure 3, there were significant differences both in the jump heights and in the lower extremity work (Bonferroni test) between the conditions (Figure 3). Both backward and forward arm swings improved the jump height significantly, but forward arm swings enhanced the jump height more than backward arm swings. It was also confirmed that the work by the lower extremity joints was affected by arm swings.

![Figure 3](image)

**Figure 3:** The average jump height (displacement of the CM from the standing position) and the total work done by the lower extremity joints (ankle, knee, and hip) in the propulsive phase for each condition. *: $p < 0.05$, **: $p < 0.01$ (Bonferroni test)

2: Figure 4 shows $T_{\text{shoul}(\rightarrow \text{arm})}$, $T_{F,h}$ and $T_{F,v}$ in SJBA and in SJFA for one subject. Variation of $T_{F,v}$ (green line) was similar for both conditions, and its peak appeared at about the middle of the propulsive phase. On the other hand, $T_{\text{shoul}(\rightarrow \text{arm})}$ (red line) and $T_{F,h}$ (blue line) varied opposite for each condition, respectively and the resultant (black line) were reduced in the latter half of the propulsive phase on the backward-arm-swing condition (the right figure). This load reduction may have “idled” the lower extremity extensor muscles, which led to the smaller work by the lower extremity joints compared with the forward-arm-swing condition.

![Figure 4](image)

**Figure 4:** Red line: shoulder joint torque, Blue line: torque created about the CG of the trunk by the horizontal component of the shoulder joint force, Green line: torque created about the CG of the trunk by the vertical component of the shoulder joint force, Black line: the resultant of the three. The unit of the vertical axes is Nm. The transverse axes represent time in seconds. The origin of time ($t = 0$) indicates the instant of takeoff.

Reference