Purpose

The aim of this study was to examine the kinematics and kinetics of the body during countermovement vertical jumps performed both with and without an arm swing. Specifically, the study sought to determine if an arm swing can augment the ability of the lower extremity musculature to generate tension, as measured by the resultant joint torques at the hip, knee and ankle.

Hypotheses

None

Participants

Twenty-Five members (14 males, 11 females) of the 1995 Pepperdine University men’s and women’s volleyball teams

Relevant Procedures

Each participant was videotaped performing five trials of countermovement vertical jumps from a force platform both with and without a bilateral arm swing.

- Before performing the jumps, each participant was given detailed instructions and allowed a brief period of practice.
- All jumps were initiated from a stationary upright posture and, during the jumps with no arm swing; the hands remained on the subject’s iliac crests.
- The order of the jumps was randomized and 1± 2 min rest was allowed between trials.
- The first two trials per condition that were performed correctly were used for the subsequent analyses.

Owing to physical limitations within the laboratory, the distance between the camera and the participants was limited to 1.35 m and two video cameras were required to record the motions of the participants.

- The cameras were positioned on the right side of the participants with their optical axes oriented perpendicular to the sagittal plane of the athletes.
- Camera 1 was located at a height of 0.72m and camera 2 at a height of 2.47m.
- The cameras were genlocked to synchronize their instants of exposure and their respective fields of view overlapped by approximately 30 cm.
- Thus the two cameras (shutter speeds 1/1000 s; sampling rate 60 Hz) provided a field of view (approximately 1.5 X 3.5 m) large enough to record the motions of the participants.
To aid the interpretation of the kinetic and kinematic data, the jump was divided into four periods (A-D) using five instants (see Fig. 3):

- (1) $t_{FM}$, the time of first movement was subjectively determined as the instant the magnitude of the vertical component of the ground reaction force decreased approximately 5 N below the participant’s body weight;
- (2) $t_{NV}$, the instant of maximum negative vertical velocity of the centre of mass;
- (3) $t_{LP}$, the instant of minimum vertical displacement of the centre of mass of the body;
- (4) $t_{PV}$, the instant of maximum positive vertical velocity of the centre of mass of the body; and
- (5) $t_{TO}$, the instant of take-off.

At $t_{NV}$ and $t_{PV}$, the vertical acceleration of the body’s centre of mass ($a_{zG}$) equals zero.

**Independent Variables**

Jump Type: with arm swing, without arm swing

**Dependent Variables**

- $\min. s_{zG}$ (%)
- $s_{zG}$ at take-off (%)\text{a}
- $v_{zG}$ at take-off (m - s\(^{-1}\))
- $\max. - v_{zG}$ (m - s\(^{-1}\))
- $\max. a_{zG}$ (m - s\(^{-2}\))
- $\max. a_{zARM}$ (m - s\(^{-2}\))
- $\max. a_{zHT}$ (m - s\(^{-2}\))
- $\max. a_{zHTA}$ (m - s\(^{-2}\))
- time $v_{zG}$ equals zero ($t_{LP}$) (s)
- time $t_1$ (s)
- time $t_2$ (s)
- time of max. positive $v_{zG}$ ($t_{PV}$) (s)
- time of take-off ($t_{TO}$) (s)
Results

The jumps with an arm swing had a larger vertical velocity of the body centre of mass \( (v_{zG}) \) at take-off and the body’s centre of mass was located at a higher relative position above the ground (Table 1).

The vertical velocity of the body’s centre of mass at take-off was 12.7% larger in the arm-swing versus no-arm-swing jumps (Table 1).

43% of the increase in jump height was due to the arms being in a raised position at take-off and 57% of the increase was due to effects associated with the arm motion that occurred before take-off.

The net vertical impulse exerted on the jumper between the instant of minimum vertical displacement of the centre of mass and take-off is due to the net force made on the jumper and the time that the net force acts. As indicated by the temporal data (Table 1), the time between \( t_{LP} \) and the instant of take-off was nearly identical in the arm-swing and no-arm-swing jumps.

Thus, differences in the net impulse exerted on the jumper in the arm-swing versus no-arm-swing jumps must be a result of changes in the vertical component of the ground reaction force \( (F_Z \text{ in Table 2}) \).

Examination of the kinematic and kinetic data for the lower extremity indicated no significant differences in the kinematic and kinetic data associated with the ankle.

The arm swing augments the ability of the hip and knee musculature to create extensor torques during the propulsive period of the jump.

- The arm swing placed the hip extensor muscles in physiological conditions that favored the generation of large muscular tensions and torques.
- The arm swing also allowed the athletes to increase the extensor torque at the knee by 28% between the instant of minimum vertical displacement of the centre of mass and \( t_2 \) and when the knee extensor muscles were in concentric conditions.


Table 1  Linear kinematic data for body and segment centres of mass and temporal data  
(mean ± s)

<table>
<thead>
<tr>
<th></th>
<th>Arm swing</th>
<th>No arm swing</th>
</tr>
</thead>
<tbody>
<tr>
<td>min. (s_{xG} ) (%)(^a)</td>
<td>40.9 ± 3.3</td>
<td>38.4 ± 3.9(^a)</td>
</tr>
<tr>
<td>(s_{xG} ) at take-off (%)(^a)</td>
<td>71.1 ± 1.7</td>
<td>67.8 ± 1.8(^a)</td>
</tr>
<tr>
<td>(v_{xG} ) at take-off (m \cdot s(^{-1}))</td>
<td>2.75 ± 0.28</td>
<td>2.44 ± 0.23(^a)</td>
</tr>
<tr>
<td>max. (-v_{xG} ) (m \cdot s(^{-1}))</td>
<td>-1.16 ± 0.32</td>
<td>-1.26 ± 0.31(^e)</td>
</tr>
<tr>
<td>max. (a_{xG} ) (m \cdot s(^{-2}))</td>
<td>14.4 ± 2.8</td>
<td>12.4 ± 2.2(^a)</td>
</tr>
<tr>
<td>max. (a_{xARM} ) (m \cdot s(^{-2}))</td>
<td>82.4 ± 16.8</td>
<td>18.6 ± 4.6(^a)</td>
</tr>
<tr>
<td>max. (a_{xHT} ) (m \cdot s(^{-2}))</td>
<td>18.0 ± 3.4</td>
<td>15.9 ± 3.0(^d)</td>
</tr>
<tr>
<td>max. (a_{xHTA} ) (m \cdot s(^{-2}))</td>
<td>18.3 ± 3.8</td>
<td>15.9 ± 3.0(^d)</td>
</tr>
<tr>
<td>time (v_{xG} ) equals zero (t_{xG} ) (s)</td>
<td>9.68 ± 0.04</td>
<td>9.67 ± 0.04</td>
</tr>
<tr>
<td>time (t_1 ) (s)(^b)</td>
<td>9.77 ± 0.03</td>
<td>9.76 ± 0.03</td>
</tr>
<tr>
<td>time (t_2 ) (s)(^b)</td>
<td>9.87 ± 0.02</td>
<td>9.86 ± 0.02</td>
</tr>
<tr>
<td>time of max. positive (v_{xG} ) (t_{pv} ) (s)</td>
<td>9.96 ± 0.01</td>
<td>9.96 ± 0.01</td>
</tr>
<tr>
<td>time of take-off (t_{xG} ) (s)</td>
<td>10.00 ± 0.00</td>
<td>10.00 ± 0.00</td>
</tr>
</tbody>
</table>

\(s_{xG} \) = vertical linear displacement of the centre of mass of the body (G);  
\(v_{xG} \) = vertical linear velocity of the centre of mass of the body;  
\(a_{xG} \) = vertical linear acceleration of the centre of mass of the body;  
\(a_{xARM} \) = vertical linear acceleration of the centre of mass of the arm segment (ARM);  
\(a_{xHT} \) = vertical linear acceleration of the centre of mass of the head and trunk segment (HT);  
\(a_{xHTA} \) = vertical linear acceleration of the centre of mass of the head, trunk and arm segment (HTA).

\(^a\) Percentage of standing height;  
\(^b\) \(t_1 = t_{xG} + 1/3 (t_{pv} - t_{xG})\);  
\(^c\) \(t_2 = t_{xG} + 2/3 (t_{pv} - t_{xG})\).

\(^d\) Experiment-wide \(P \leq 0.05\) (per comparison \(P \leq 0.0005\)).  
\(^e\) Per comparison \(P \leq 0.05\).