Maximal rotational power in twist jumps

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Introduction

Since the original work of Davies and Rennie (1968) most of the literature about vertical jumping dealt with the ability to generate the maximum linear power, e. g. to generate the maximum height during the flight phase of the jump (e. g. Cavagna et al. 1968; Thys et al. 1972; Asmussen and Bonde Petersen 1974; Komi and Bosco 1978). No attention has been paid so far to the capacity of the same muscles to produce a vertical jump with maximal twist, a performance associated with many activities as volleyball, basketball, figure skating and classic ballet. The analysis of such complex motor act relies on the dual role of the lower leg muscles: a) to generate enough vertical power so to stay in flight as long as possible and b) to produce the maximal rotational speed at take-off. The aim of this study was to investigate if the trade off in using the same muscles and joints for a combined purpose impairs the effectiveness in one of the tasks when the other is favoured.

Methods

Experiments were performed on 10 physically active female subjects of 24.7 ± 6.7 years of age, 61.8 ± 10.5 kg body mass and 163.3 ± 5.7 cm body height. They were asked to jump, with the arms on the hips, over a dynamometric platform (Kistler, Switzerland) while the moment about the vertical axis ($M_z, N \cdot m$) and the ground reaction force ($F_z, N$) were acquired as a function of time:

\begin{equation}
M_z(t) = I_z(t) \cdot \alpha_z(t) \tag{1}
\end{equation}

\begin{equation}
F_z(t) = m \cdot a_z(t) \tag{2}
\end{equation}

were $I_z$ is the moment of inertia about the vertical axis (kg $\cdot$ m$^2$), $m$ is the mass of the subject (kg), $\alpha_z$ is the angular acceleration (rad $\cdot$ s$^{-2}$) and $a_z$ the linear acceleration (m $\cdot$ s$^{-2}$).

The rotational ($w_R, W$) and the vertical ($w_V, W$) power were computed as:

\begin{equation}
w_R(t) = M_z(t) \cdot \omega_z(t) \tag{3}
\end{equation}

\begin{equation}
w_V(t) = F_z(t) \cdot v_z(t) \tag{4}
\end{equation}

were $\omega_z$ and $v_z$ are the angular (rad $\cdot$ s$^{-1}$) and vertical (m $\cdot$ s$^{-1}$) speeds, respectively. In turn:

\begin{equation}
\omega_z(t) = \int_0^t \alpha_z(t) dt = \frac{\int_0^t M_z(t) dt}{I_z} = \frac{1}{I_z} \int_0^t M_z(t) dt \tag{5}
\end{equation}

\begin{equation}
v_z(t) = \int_0^t a_z(t) dt = \frac{\int_0^t F_z(t) dt - mg}{m} = \frac{1}{m} \int_0^t F_z(t) dt - gt \tag{6}
\end{equation}

assuming (for sake of simplicity) that $I_z$ is constant during the jump. Hence, in order to calculate the
rotational power, the moment of inertia should also be measured. The moment of inertia ($I_z$) is also defined as:

$$I_z = m\rho_z^2$$  \hfill (7)

where $m$ is the body mass (kg) and $\rho_z$ is the radius of gyration (m) about the body centre of mass and the vertical axis. The radius of gyration was measured according to the following rationale.

The average angular speed of the body ($\omega_z$, which should correspond to the take-off rotational speed) can be obtained from the difference between the feet orientation at take-off ($\theta_{TO}$) and landing ($\theta_{LD}$), divided by the flight time ($t_{FL}$):

$$\omega_z(t_{TO}) = \frac{\theta_{LD} - \theta_{TO}}{t_{FL}}$$  \hfill (8)

whereas flight time could be calculated as:

$$t_{FL} = \frac{2v_z(t_{TO})}{g} = \frac{2}{mg} \int_0^{t_{TO}} F_z(t)dt - 2t_{TO}$$  \hfill (9)

From Eq. 5 (with $t = t_{TO}$) and Eq. 8:

$$I_z = \frac{1}{\omega_z(t_{TO})} \int_0^{t_{TO}} M_z(t)dt = \frac{t_{FL}}{\theta_{LD} - \theta_{TO}} \int_0^{t_{TO}} M_z(t)dt$$  \hfill (10)

Hence, from Eqs. 7 and 10 the radius of gyration could be measured as:

$$\rho_z = \sqrt{\frac{t_{FL}}{m(\theta_{LD} - \theta_{TO})} \int_0^{t_{TO}} M_z(t)dt}$$  \hfill (11)

The radius of gyration was measured in a preliminary set of experiments by asking the subjects to jump, rotate and land with the feet at 90° ($\theta_{LD} - \theta_{TO} = 90°$) on the right (CW) or on the left (CCW). Five jumps were recorded in each condition and the corresponding average values of $\rho_z$ were utilized in order to calculate $I_z$ and hence $w_R$ (CW or CCW).

The maximal voluntary jumps were performed in the following conditions: vertical jumps with counter movement (CMJ), squat jumps (SJ), rotational jumps (maximal twists) on the left (CCW) and on the right (CW) in which the counter movement in both the vertical and horizontal direction was allowed. Each type of jump was repeated 5 times and the best jump in each condition was selected and utilized for further analysis. The subject maintained the arms on the hips throughout the all manoeuvres (flight included).

**Results & Discussion**

The radius of gyration was found to be of 9.1 ± 0.7 cm (CW) and 7.4 ± 0.9 cm (CCW), the average (individual) CV values being 0.052 and 0.084, respectively. Maximal vertical power in CMJ ($w_V$) was found to be about 20% higher than in SJ (53.3 ± 9.9 and 41.7 ± 5.7 W·kg$^{-1}$, respectively). During the rotational jumps the maximal vertical power was further reduced to 35.6 ± 3.0 and 36.6 ± 2.4 W·kg$^{-1}$.
(CW and CCW, respectively); the corresponding values of maximal rotational power ($w_R$) being $7.1 \pm 2.2$ and $9.9 \pm 2.9$ W·kg$^{-1}$ (CW and CCW, respectively). Peak power was attained first for rotation and then for elevation, the delta time between the two being $133 \pm 37$ and $137 \pm 27$ ms (CW and CCW, respectively).

The trade off in using the same muscles and joints was found to impair the effectiveness of the vertical jumps, as hypothesized. Indeed not only the values of maximal vertical power were reduced in respect to a "pure" vertical jump (either CMJ or SJ) but also the sum of the rotational and vertical power during CW and CCW jumps was found to be lower than during CMJ.

References