THE TWIST ROTATION IN HIGH JUMPING

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INTRODUCTION

During the high jump takeoff the athlete makes forces on the ground which determine the height of the parabola and the angular momentum of the body. Once in the air, the high jumper makes a twisting somersault rotation which leads to a supine layout position over the bar (Fig. 1a). Problems in the twist rotation can produce a tilted position, with one hip lower than the other (Fig. 1b); the lower hip limits the result of the jump. An undertwisted position with the hip of the lead leg lower than the hip of the takeoff leg at the peak of the jump is the most common problem. This research project studied the mechanisms that produce the twist rotation in high jumping, and the possible causes for an undertwisted orientation of the hips at the peak of the jump.

METHODS

Twenty high jumps were studied: five normal trials by men, and five by women; five markedly undertwisted trials by men, and five by women. Body landmark locations during the jumps were calculated using standard three-dimensional (3D) film analysis. The body was modeled as a 16-segment mechanical system (Zatsiorsky and Seluyanov, 1983; Zatsiorsky et al., 1990a, 1990b; parameter adjustments by de Leva, 1995). Center of mass location and angular momentum were calculated following a method based on Dapena (1978). The orientation of the longitudinal principal axis (minimum moment of inertia) was calculated following Hinrichs (1978).

The longitudinal principal axis of the body and the locations of the hips established a body reference frame defined by axes X_B, Y_B and Z_B. Z_B coincided with the longitudinal principal axis; X_B was mediolateral; Y_B was anteroposterior. The angle between the bar and a line normal to the vertical plane containing both hips at the end of the takeoff was computed. Positive values were assigned to this initial hip orientation angle η_{TO} when the hips faced away (counterclockwise) from the landing pit. At the peak of the jump, the projection of a vertical vector on the plane normal to the longitudinal axis defined the neutral ("face-up") twist orientation. The actual hip twist angle at the peak (τ_{PK}) was based on the angle between this neutral twist orientation vector and axis Y_B. (The value $\tau = 90°$ was arbitrarily assigned to the neutral twist orientation at the peak; in undertwisted jumps, $\tau_{PK} < 90°$.) Rotation from one frame to the next was determined by the Cardan angles (α, β, γ) of the three successive rotations about the X_B, Y_B and Z_B axes of the first frame that produced the orientations of the axes in the next frame. The third angle (γ) defined the twist rotation between the frames. The γ angles in all the frame intervals between takeoff and the peak were added to compute the cumulative twist rotation $\Delta\tau$ between takeoff and the peak. $\Delta\tau$ was subtracted from τ_{PK} to compute the hip twist angle at takeoff, τ_{TO}. (The values of τ_{TO} and η_{TO} generally are not the same. This is because the twist rotation needed to reach a face-up position at the peak of the

jump depends not only on the hip orientation at takeoff, but also on the 3D path followed by the longitudinal axis in its somersault rotation between takeoff and the peak.)

In each frame, the angular momentum vector **H** was projected on the longitudinal axis, Z_B, to compute the twisting component of angular momentum, H_T. A positive sign was given to H_T if the vector pointed toward the head. The angular velocity of twisting associated with H_T in each interval between frames was calculated as $\omega_T = H_T / I_L$, where I_L was the moment of inertia about the longitudinal axis. The product of ω_T and the interval duration yielded the amount of twist rotation produced by H_T during the interval. The amount of twist rotation produced by the twisting component of angular momentum between takeoff and the peak ($\Delta\tau_H$) was calculated as the sum of the twist rotations produced by H_T in the intervals between takeoff and the peak. The contribution of action and reaction rotations ("catting") to the twist rotation, $\Delta\tau_C$, was calculated as the difference between $\Delta\tau$ and $\Delta\tau_H$.

RESULTS AND DISCUSSION

The hip orientation relative to the bar at takeoff was similar in the normally-twisted men and women [$\eta_{TO} = 29 \pm 10°$ (men); 28 ± 4° (women)]. The average hip twist angle of the women at takeoff was somewhat larger than that of the men, although there was overlap between the two groups [$\tau_{TO} = 34 \pm 5°$ (men); 41 ± 7° (women)]. Between takeoff and the peak the women went through a slightly smaller twist rotation than the men, although there was overlap again [$\Delta\tau = 55 \pm 4°$ (men); 49 ± 7° (women)]. The larger twist rotation of the men compensated for their smaller initial twist angle; the twist angle at the peak was

essentially the same for both normally-twisted groups [$\tau_{PK} = 89 \pm 4°$ (men); 90 ± 3° (women)]. (Of course, this had to be so, since a τ_{PK} value near 90° was the selection criterion for inclusion in these groups.) The men achieved more of their twist rotation through the twisting component of angular momentum than the women [$\Delta\tau_H = 33 \pm 7°$ (men); 14 ± 8° (women)], while the women twisted more through catting [$\Delta\tau_C = 22 \pm 6°$ (men); 34 ± 5° (women)]. This was a clear difference between the two normally-twisted group samples. The most surprising finding was the large contribution made by catting to the twist rotation: Considering both groups pooled together, catting produced more than half of the total twist rotation.

Fig. 2 shows two typical normally-twisted jumps. Each image is seen from a direction normal to the plane formed by the resultant angular momentum vector and the longitudinal axis at that time. (The direction of the view changed with each successive image, keeping pace with the somersault of the longitudinal axis.) The single-headed and double-headed arrows represent the total angular momentum vector and the principal longitudinal axis, respectively; the line is the plane normal to the angular momentum vector. After takeoff the longitudinal principal axis tilted toward the plane in all subjects. The tilt (a clockwise rotation in Fig. 2) seemed to be due mainly to the counterclockwise rotations implicit in the lowering of the lead leg and the lifting of the trailing leg behind the body. The change in the orientation of the longitudinal axis reduced the twisting component of angular momentum. In the men, the longitudinal axis almost never reached the plane (Fig. 2a). But it did in almost all the women, and actually crossed to the other side (Fig. 2b). This reversed the sign of the twisting component of angular momentum, which made a negative contribution to the twist

rotation from there on. The smaller twist rotation achieved by the women through angular momentum ($\Delta\tau_H$) was due mainly to their smaller average twisting angular momentum between takeoff and the peak [$H_{T(AVG)} = 15.8 \pm 3.7 \quad 10^{-3}$ s^{-1} (men); $8.0 \pm 5.0 \quad 10^{-3}$ s^{-1} (women)]. The women compensated for this with more effective catting than the men.

The differences between the normally-twisted and undertwisted jumpers were not due to differences in the twist angle of the hips at takeoff, but to the subsequent rotation in the air. In the men, undertwisting was usually due mainly to a smaller amount of catting; in the women, to a smaller twisting component of angular momentum, ultimately traced to an excessive backward lean of the longitudinal axis at takeoff.

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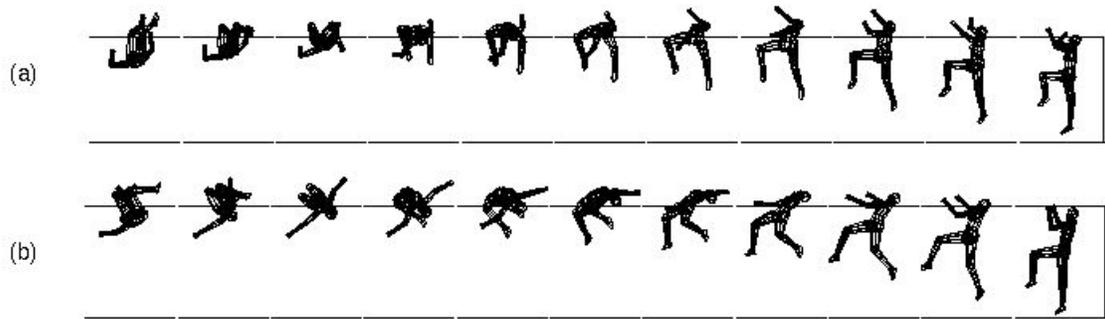
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Figure 1: Normal high jump (a); high jump with problems in the twist rotation (b).
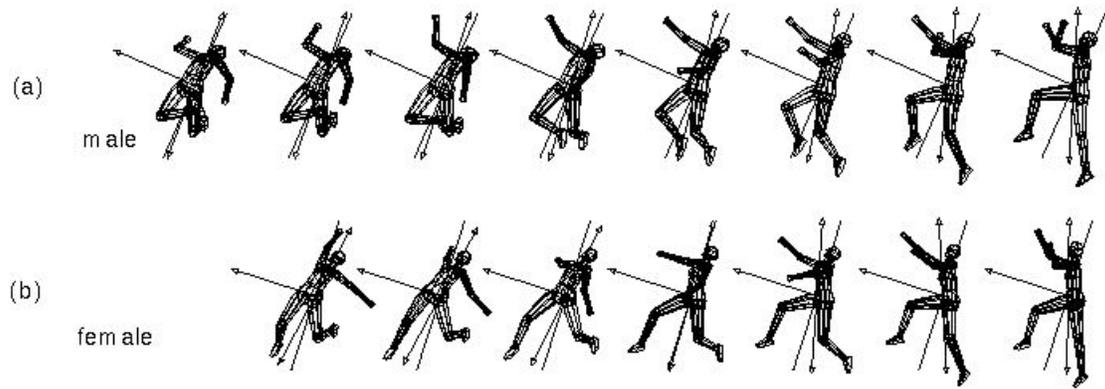

Figure 2: Typical jumpers, viewed normal to the plane containing the angular momentum vector and the longitudinal axis.