BIOMECHANICS OF HORSE JUMPING

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INTRODUCTION: During jumping, the body of the horse changes its direction of angular movement twice and hence has to undergo the necessary accelerations/decelerations in order to perform the jump. Clayton (1989) described the terminology and the phases of horse jumping. The aim of this study was to calculate the angular acceleration of the horse's body, the path of the center of gravity, and provide an explanation for jump failures.

METHODS: Video-films were made during an international tournament. The fence chosen for this analysis was a square oxer of 1.6m height and 1.2m distance between the elements (rails). A Sony DXC-9100 video camera (100 fr/s) and video software (Adobe Premiere 4.2) were used. For 33 horses we measured the angle of a reference line (crupper - withers) relative to the environment. The angular data set vs. time was splined (non-linear least squares, under the consideration of linear segments) and first and second differentiations were carried out for the calculation of the angular velocity and acceleration using Mathematica 3.0. The path of the center of gravity (constructed according to Sprigings and Leach, 1986) during the suspension phase was also analyzed by means of a parabolic function. The used co-ordinate system was: x = cranial direction (direction of linear motion), y = dorsal direction, z = direction to the right. The angular impulse (D) of the suspension phase was calculated from the body mass (m), radius of gyration (k), and angular velocity (ω):

$$D = m\,k^2\,\omega \qquad (1)$$

As the radius of gyration of a thin rod of length l (rotation axis through center) is: $k = 12^{-.5}\,l$,i.e., 0.288 l, and of a sphere of diameter d is: $k = 10^{-.5}\,d$, i.e., 0.316 d, k of the horse body was assumed to be 30% of the body length.

RESULTS: The course of both angle (φ) and velocity (ω) vs. time can be divided in 3 phases (Figure 1): A) lift of the body ($\Delta\varphi \sim +0.6$ rad, $\Delta t \sim 0.32$ s, $\omega_{max} \sim +3.2$ rad/s), B) take off, jump suspension, and landing ($\Delta\varphi \sim -1.2$ rad, $\Delta t \sim 0.75$ s, $\omega_{max} \sim -1.6$ rad/s), and C) descent of the body ($\Delta\varphi \sim +0.6$ rad, $\Delta t \sim 0.32$ s, $\omega_{max} \sim +3.2$ rad/s). Related to angular acceleration, 5 phases can be distinguished (Figure 1): phase 1: acceleration in order to lift the body, 1a) initiated by the front limbs and 1b) continued by the rear limbs, with zero acceleration during a short time span between 1a and 1b (suspension between approach stride 1 and take off, "last gallop jump"). Phase 2: deceleration of body lift and acceleration of negative angular motion of the jump suspension (generated by the rear limbs). Phase 3: zero acceleration during jump suspension. Phase 4: deceleration of jump suspension and acceleration of body descent (front limbs). Phase 5: deceleration of body descent (rear limbs). The mean values of angular accelerations (α) of phases 1-5 (in rad/s^2) were: phase 1a: +30, phase 1b: +20, phase 2: -55, phase 3: 0, phase 4: +40, phase 5: -30. The angular impulse of the suspension phase

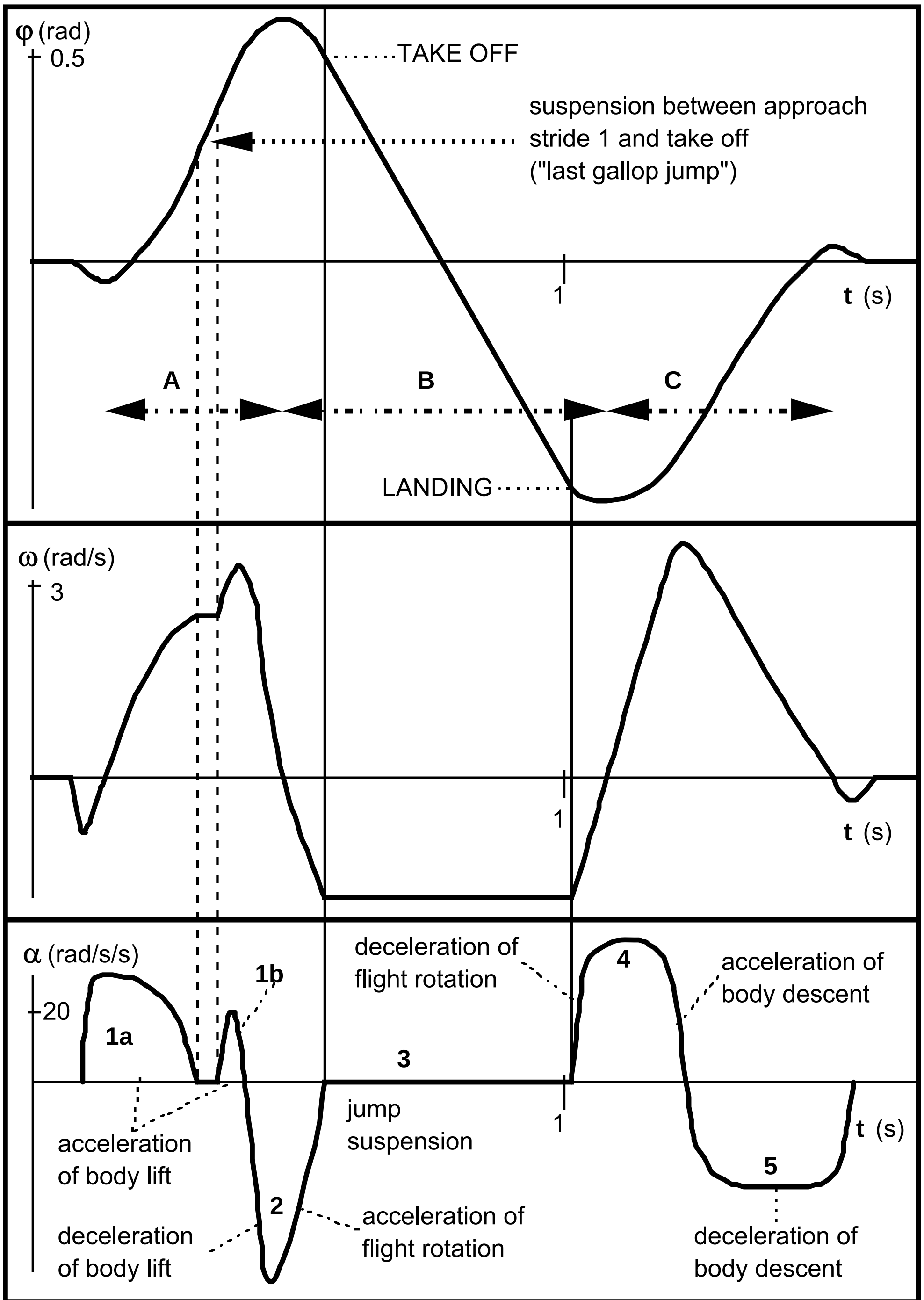

Figure 1: Schematic illustration of change of angle, angular velocity, and acceleration of the horse's body with respect to time (phases A-C & 1a-5 cf. text).

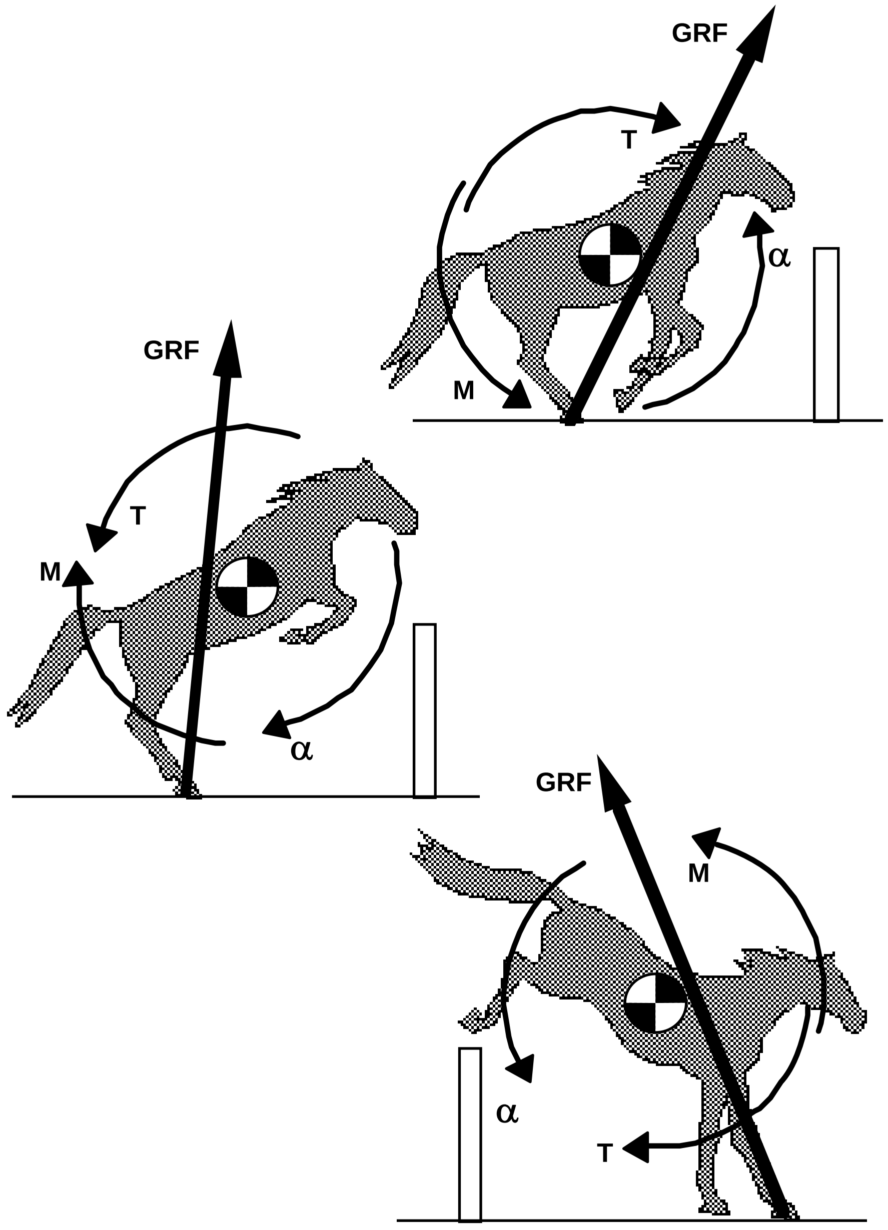

Figure 2 — Three phases of the jump (see text): body lift (phase 1b), take off (phase 2), and body descent (phase 4).

amounted to 200-300 Nms. When rails were knocked over by the front limbs, this was mainly due to the jump-off position, the angular body lift and the path of the center of gravity. When rails were knocked over by the hind limbs this was due to flexion in the hip joint instead of extension.

DISCUSSION: During body lift, the angular acceleration (α) is positive (phases 1a + 1b), causing a negative torque (T, free moment due to inertia moment, $T = m k^2 \alpha$), which has to be balanced by a positive moment (M; Figure 2). The latter is generated by the ground reaction forces (GRF) of the hind limbs, which pass in front of the center of gravity of the horse's body. Likewise the angular acceleration of the body descent (phase 4) is positive, hence the ground reaction forces (of the forelimbs) equally pass in front of the center of gravity (Figure 2). Phase 2 (Figure 1), however, has a negative angular acceleration, the ground reaction forces (of the hind limbs) consequently pass behind the center of gravity (Figure 2). Before take off, the ground reaction forces increase their direction angle (phase 1: in front of the center of gravity, phase 2: behind).

CONCLUSIONS: Decisive factors for horse jumping are the acceleration during body lift (phases 1a and 1b), the take off position, the path of the center of gravity, and the limb movements, especially for high fences and high speeds (for a reduced winning time). The measurement of the mentioned parameters by means of a video technique is hence a valuable tool for aptitude tests.

REFERENCES:
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