Postprint: Biomechanical Characteristics of Approach Run and Takeoff in Male Pole Vaulters at Different Performance Levels

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Abstract

Objective: To investigate the specific performance of biomechanical indicators such as center of mass velocity, center of mass height, ground reaction force, and lower limb joint moments in male pole vaulters of different performance levels, attempting to understand the overall characteristics of athletes at different levels and to identify the features of the transition between approach run and takeoff in high-level athletes.

Methods: A large-scale three-dimensional motion capture system and three force plates were used to collect kinematic (200 Hz) and ground reaction force (2,000 Hz) data from elite male pole vaulters, and the biomechanical indicators of 5 first-level athletes, 4 master athletes, and 3 international master athletes were analyzed and compared. Non-parametric independent samples Mann-Whitney U one-tailed tests were employed for pairwise comparisons of the same biomechanical indicators among the international master athlete group, master athlete group, and first-level athlete group, while non-parametric paired samples Wilcoxon signed-rank one-tailed tests were used for pairwise comparisons of the corresponding biomechanical indicators among the second-to-last step, last step, and takeoff for all athletes.

Results: Significant differences were found in biomechanical indicators such as center of mass velocity, center of mass height, ground reaction force, and lower limb joint moments during the last two steps of approach run and takeoff among pole vaulters of different levels; significant differences also existed among the corresponding biomechanical indicators of the second-to-last step, last step, and takeoff.

Conclusion: Based on the data from this study, male pole vaulters exhibited biomechanical characteristics that varied with performance level, with indicators such as center of mass velocity and ground reaction force in international

master athletes reflecting their superior athletic capabilities. The significant differences in corresponding biomechanical indicators including center of mass velocity, center of mass height, and ground reaction force among the second-to-last step, last step, and takeoff reflect the technical transition characteristics of pole vaulting, demonstrating the kinematic and kinetic features of the transition from approach run to takeoff in pole vault.

Full Text

Preamble

We consider the standard supervised learning framework where the goal is to learn a predictive function $f : \mathcal{X} \to \mathcal{Y}$ from a training dataset $\mathcal{D} = \{(x_i, y_i)\}_{i=1}^n$. The learning problem is formulated as empirical risk minimization, where we seek parameters θ that minimize the objective function:

$$L(\theta) = \frac{1}{n} \sum_{i=1}^{n} \ell(f(x_i; \theta), y_i) + \lambda R(\theta)$$

Here, $\ell(\cdot, \cdot)$ denotes the loss function measuring prediction error, while $R(\theta)$ represents a regularization term with weight $\lambda \geq 0$ to control model complexity.

The optimization problem is formally defined as:

$$\theta^* = \arg\min_{\theta \in \Theta} L(\theta)$$

subject to the following constraint on the hypothesis space:

$$\Omega(\theta) \leq C$$

where $\Omega(\cdot)$ quantifies model capacity and C is a predefined complexity budget.

The expected generalization error under the true data distribution $\mathcal{P}$ is given by:

$$\mathbb{E}_{(x,y)\sim\mathcal{P}}[\ell(f(x; \theta^*), y)]$$

During optimization, we employ stochastic gradient descent with the following parameter update rule:

$$\theta_{t+1} = \theta_t - \eta_t \nabla_\theta L(\theta_t)$$

where $\eta_t > 0$ is the learning rate at iteration t.

Convergence is declared when the gradient norm satisfies:

$$\|\nabla_\theta L(\theta_t)\|_2 \leq \epsilon$$

for some small tolerance threshold $\epsilon > 0$, indicating that the optimization has reached an approximate stationary point.

Note: Figure translations are in progress. See original paper for figures.