Calculating elastic energy to decipher the athlete's work during pole vaulting

Johan Cassirame*[1,2], Laurent Royer-Dangerville[3], Lucas Garbellotto[3], and Julien Frère[4]

[1]Université Marie et Louis Pasteur, UFR STAPS, Laboratoire C3S UR-4660, F-25000 Besançon, France – Université de Franche-Comté – France

[2]SAS Mtraining, RD division, 25480 Ecole Valentin, France – Mtraining – France

[3]SAS Mtraining, RD division, 25480 Ecole Valentin, France – Mtraining, R – France

[4]University Grenoble Alpes, CNRS, Grenoble INP, GIPSA-Lab, 38000 Grenoble, France – Univesity Grenoble Alpes – France

Résumé

INTRODUCTION

Pole vault performance is closely linked to an athlete's ability to convert energy from run-up speed into vertical elevation. Energy gain (Egain), defined as the difference between initial and final mechanical energy, has been proposed as an index reflecting the muscular work performed during the jump phase (1). While kinetic (Ekin) and potential (Epot) energy of the athlete's center of mass can be estimated easily using motion capture techniques, the elastic strain energy stored in the pole (Epole) remains more difficult to quantify, especially in competition settings. To address this challenge, we developed a dedicated device and method to assess Epole by analyzing chord reduction over various grip positions and force required to bend the pole. This new methodology permit us to compute total energy during jump phase and then estimate additional energy provided by athletes himself. This study aims to compare Egain with a more comprehensive approach that integrates Epole.

METHODS

During official competitions (2020–2024), pole vaults were recorded in the sagittal plane at 100 Hz (Panasonic, Kadoma, Japan), aligned with the take-off axis. Before each event, the environment was calibrated using a reference frame, with the deepest point of the planting box set as the origin of the 2D coordinate system. The athlete's mechanical energy (Eathlete = Ekin + Epot) was estimated based on the horizontal and vertical positions of the pelvis, obtained through manual pose estimation. The upper extremity of the pole was also manually digitized to determine chord reduction using Kinovea software 0.9.5 (Joan Charmant & Contributors, Bordeaux, France) (2).

In collaboration with ESSX, poles were dynamically bent up to 35% chord reduction using a dedicated bending machine (Mtraining, Ecole-Valentin, France) equipped with a dynamometer (K-Link, Kinvent, Montpellier, France) to measure force along the chord reduction (3). Pole stiffness was derived from the force-chord relationship and used to compute Epole. The total energy difference (Ediff) was defined as the difference between the lowest and highest values of the {athlete + pole} system's total energy during the jump phase.

*Intervenant

Twelve jumps from different female athletes (clearance heights: 4.05–4.83 m) were analyzed to compare Egain and Ediff.

RESULTS

The analysis showed that Egain values (633.8 ± 239.5 J) were significantly lower than Ediff values (906.2 ± 233.8 J, $p < 0.001$). Moreover, inter-athlete variability was high, with differences between Egain and Ediff ranging from 16.7% to 109.6%.

CONCLUSION

Our findings highlight the importance of incorporating Epole in energy balance assessments to better capture the athlete's contribution during the vault. As a net value, Egain accounts for energy losses and thus significantly underestimates the actual work performed by the athlete through muscular effort during pole interaction. Future studies should further investigate the relationships between key technical phases such as swing and rock back to better understand energy transfer, loss, and input at each stage.

1. Schade F et al. G. (2000). Influence of different approaches for calculating the athlete's mechanical energy on energetic parameters in the pole vault. Journal of Biomechanics, 33(10), 1263-1268.

2. Cassirame J et al. . (2024). Clustering technical approaches of elite and world-class pole vaulters based on 10 years of measurement during competitions. Journal of Sports Sciences, 42(11), 971-980.

3. Cassirame J, Insight in the energies of pole vault. Padova Pole Vault Convention #2025. Padova, Italy. January 2025.