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# Energy assessment during pole vaulting using inertial motion capture: a preliminary study

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## 1. Introduction

Pole vaulting is a challenging Olympic discipline that requires speed, strength and technical skills. In order to achieve the best possible performance, the athlete uses the pole of his choice in terms of both length and stiffness. Thus, the athlete-pole interactions must be highly efficient to transform a horizontal displacement into a vertical one. To investigate energy conversion over the time during support phase, 2D video-based approaches is generally preferred but 3D video analysis and motion capture can be also used in rare case. The aim of this preliminary study was to verify the possibility to quantify the pole vaulter's energy transfers in practice using a system with multiple inertial sensor units (IMU).

## 2. Methods

### 2.1 Experimental data

Data were collected from a junior pole-vaulter (1.78m and 59 kg). 11 trials have been performed using a 4.30 m pole and a crossbar at 3.50 m height. Four successful trials were completed and used for the analysis. During trials, kinematics was collected using the Xsens MVN Awinda® system (Xsens Technologies B.V, Enschede, The Netherlands) composed of 17 body worn IMUs sampled at 60 Hz. In addition, 100 Hz video were captured from the perpendicular of the

take-off position to enable comparison between both approaches.

### 2.2 Variable and energy definitions

Pole-vault jump is typically divided into several distinct phases: the run-up phase, the take-off phase, the pole bending phase and the pole straightening phase, the pole deflexion, and the bar clearance. In this study, we focused only on a period, starting from the take-off (*TO*) and the maximum height (*MH*) reached by the jumper's centre of mass ( $CoM_z$ ).

The instant  $t_{TO}$  was defined as the instant at which the vertical position of the marker of the last support foot became positive. The instant  $t_{MH}$  was defined when  $CoM_z$  was maximal corresponding to the maximal height reached by the athlete. The athlete's kinetic translational energy ( $E_{kin}$ ) was computed considering only the translation of the centre of mass (centre of mass model) whereas the potential energy ( $E_{pot}$ ) is defined as following (Schade et al., 2006):

$$E_{kin} = \frac{1}{2}mv^2 \quad E_{pot} = mgh$$

Where  $v$  is the velocity of the center of mass and  $m$  the mass of the athlete,  $h$  is the elevation of the center of mass. These formulas allowed the calculations of energy at *TO* ( $E_i$ ) and *MH* ( $E_f$ ) and the energy balance between *TO* and *MH* ( $E_{gain}$ ).

### 2.2 IMU measurements and Model

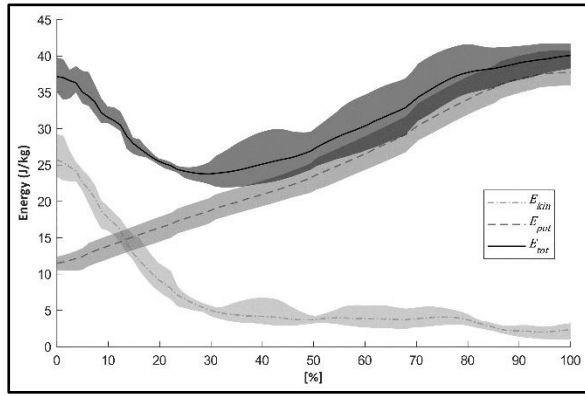
The inertial system enabled to reconstruct a 3D full body osteoarticular model composed of 23 segments. Anthropometric measurements and IMU placement were conducted following the manufacturer's recommendations (Schepers et al., 2018). A calibration procedure was carried out, including a static pose (N-pose) and a dynamic phase (walking trial) according to the Xsens MVN Analyze User Manual. The XVN fusion algorithm was used to assess accelerations, orientations and joint kinematics.

### 2.3 Video measurements

Video captured were analysed using Kinovea software (Version 0.9.5) to calculate speed and pelvis elevation at *TO* and *MH*. A prior 2D calibration of the volume has been made to allow distance calculations.

## 3. Results and discussion

The results of measurement from both technologies are displayed in the Table 1. Energies evolution from *TO* to *MH* determined with Xsens MVN can be observed in the Figure 1.



**Figure 1.** Time-normalized evolution (from TO to MH) of the mean, maximum and minimum of energies normalized to body mass.

**Table 1.** Energy at TO ( $E_i$ ), MH ( $E_f$ ) and their differences ( $E_{gain}$ ) calculated by Xsens MVN and video analysis.

Technique	$E_i$ (J/kg)	$E_f$ (J/kg)	$E_{gain}$ (J/kg)
MVN	$37.2 \pm 2.3$	$40.1 \pm 1.6$	$2.91 \pm 3.1$
Video	$38.7 \pm 0.7$	$41.1 \pm 0.9$	$2.34 \pm 0.4$
Difference	$-1.55 \pm 2.5$	$-0.99 \pm 1.2$	$0.56 \pm 2.7$
%	- 4.0%	-1.4%	24.3%

Our preliminary results highlighted similar values from both technologies for  $E_i$ ,  $E_f$ , and  $E_{gain}$ . An underestimation of  $E_i$  (-4.0%) and  $E_f$  (-1.4%) have been observed primarily due to a lower kinematic energy calculated by Xsens MVN. Surprisingly, despite the MVN system calculating speed in three dimensions, as opposed to the two-dimensional analysis provided by video analysis, we anticipated lower kinematic parameters from video analysis. This discrepancy could potentially be attributed to the smoothing and/or filtering processes implemented by the manufacturer. Moreover, the results indicated that inter-trial variation observed through video analysis was more consistent, suggesting higher reproducibility. However, these differences and standard deviations appear to be significant enough to allow for comparison between elite athletes, both male and female (Schade et al., 2004).

Regarding  $E_{gain}$  even if the difference between two methods observed similar deviations, this error represented 24% of difference. More investigations are required in order to clarify the possibility to use this parameter based on Xsens MVN technology. Based on these results, the next step will be to include a large sample of athletes to investigate the difference

between athletes and get a better understanding of the sensibility of this method.

Finally, studies based on IMUs in pole vaulting are scarce (Miranda-Oliveira et al., 2022). Therefore, a perspective will to compare and validate the inertial motion capture results with a gold standard based on optoelectronic motion capture system on a large data base composed of different types of vaulters (age, gender, level) and evaluate the sensitivity of these methodologies to discriminate changes in athletes' behaviour.

## 4. Conclusions

The present preliminary investigation provides insights into the investigation of energy transfer during pole vaulting using body-worn sensors and low invasive instrumentation for in-situ application.

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## Conflict of Interest Statement

There are no known conflicts of interest associated with this publication.

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