DIFFERENTIATION OF THE ENERGETIC PARAMETERS BETWEEN MALE AND FEMALE ELITE POLE VAULTERS

Trenton Warburton[1,2,3], Andrew Lyttle[1,4], Ralph James[3] and Jacqueline Alderson[2]

Western Australian Institute of Sport, Perth, Australia[1]
School of Sports Science, Exercise and Health, The University of Western Australia (UWA), Perth, Australia[2]
School of Physics, UWA, Perth, Australia[3]
School of Computer Science and Software Engineering, UWA, Perth, Australia[4]

This study aimed to examine whether differences were evident in the average energetic waveforms and energy summary results between four male and four female elite pole vaulters. Full body DXA scans and 3D body surface scans were conducted for each of the athletes to allow subject specific body segment inertial parameters to be calculated. A total of 67 vaults were recorded across the 8 vaulters, with a 3D kinematic analysis being performed on each vault. Translational and rotational kinetic energy; and gravitational potential energy were derived from this analysis and used to calculate total vaulter energy. Average summary energy values and energetic waveforms were compared between the male and female vaulters. Significant differences were found in some of the initial energy values as well as variables related to the pole extension phase.

KEY WORDS: kinetic energy, potential energy, statistical parametric mapping.

INTRODUCTION: Effectiveness in pole vault is heavily reliant on the efficient transfer of energy throughout the vaulting phase. The overall principle of this energy transfer is not complex with the runway approach used to generate the initial kinetic energy (KE). This is transferred into strain energy, stored in the pole when the pole is positioned into the pole plant box and the momentum of the vaulter acts to bend the pole. This strain energy is converted into gravitational potential energy (GPE) of the vaulter as the pole bends and then recoils returning the energy stored to the vaulter. The effective production, storage and application of these energies are necessary for success. Velocity in the run-up enables the vaulter to create the initial energy for the vault. The basic reason for using a pole in the pole vault event is to convert the KE of the vaulter developed during the run-up into GPE in the vaulter to clear the bar. The more efficient these sequential transformations, the more energy can be regained from the pole in later phases. Previous investigations have presented differences between males and females (Schade et al., 2004) though it is generally believed that their technical models are becoming more similar in recent years.
Previous energy studies have investigated a breakdown of the energy phases within the pole vault through calculating the athlete’s total body energy (Arampatzis et al., 2004; Schade et al., 2006). To track the energy through the vault, the vaulting sequence can be broken down using specific points at which the energies can be calculated, with the point of maximum pole bend (MPB) separating the phases (Arampatzis et al., 2004). Important energy parameters calculated in the first part leading up to MPB include; the initial energy of the athlete, the energy of the athlete and the pole at the point of MPB, the work of the athlete up until MPB and the energy of the total system at MPB. After the MPB through to the point of maximum height is the second part of the interaction between the vaulter and the pole (Arampatzis et al., 2004; Schade et al., 2006); the energy components calculated in this phase included the final energy of the athlete; the energy added by the athlete during the phase; energy loss in the pole; and total energy gained by the athlete from the initial energy.
Energy flow impacts on the performance of the pole vault, and the degree of skilled ‘technique’ influences this flow. Ideally, there will be a smooth energy flow through the vault, with efficient transitions between the major energy contributions. However, thus far, studies

have sought to reproduce and analyse energy at discrete phases of the vault, rather than a comparative waveform analysis of the various energy flows throughout the entire vault. The use of statistical parametric modelling (SPM) has allowed this direct comparison of waveforms, rather than discrete summary variables, to further understand the periods in the waveforms where significant differences may be evident (Robinson et al., 2014). This study sought to determine if any differences occur in both summary energy variables and energy waveforms, between elite male and female pole vaulters.

METHODS: Four male pole vaulters (age 25.7±6.2yrs, height 187.8±4.7cm, mass 83.6±5.4kg) and 4 female pole vaulters (age 21.1±5.9yrs, height 170.5±4.7cm, mass 59.6±2.9kg), who were of national level or higher participated in the study. Full body DXA scans and 3D body scans performed for each athlete allowed subject specific body segment inertial parameters (BSIP) to be calculated following processes outlined by Rossi et al., 2013. A total of 67 successful vaults were recorded across the 8 participants over multiple testing sessions. For each successful vault, a 3D kinematic analysis using manual digitising was conducted from six individual video views surrounding the pole vault area, along with a calibration volume encompassing the total vault volume. The 3D digitising was performed using APAS Motion Analysis System at 50Hz and filtered using a dual pass Butterworth filter at a cut-off frequency of 5Hz.
For each vault, the resultant 3D kinematics allowed for the calculation of the required energy parameters throughout the vault. The subject specific BSIP derived from the individual's 3D body scan and DXA mass scan information was used in all of the energy calculations for greater athlete specificity. These energy parameters included the rotational and the translational kinetic energy; and the gravitational potential energy and were all normalised to body mass. These values were used to derive the mass normalised, total vaulter energy with all energy comparisons conducted on the averaged male and female vaulters' results. The total energy was quantified at discrete points in the vault aligning with the initial energy at the mid-point of the last stride (Initial); pole plant (PP), maximum pole bend (MPB), pole extension (PS) and vaulter's peak height (PH). Calculated summary values included energy decrease (Initial – MPB), increase (PH - MPB) and energy gain (PH - Initial). Full waveforms of the body mass energy components and total energy over the entire vault were also produced and were time normalised over the duration of the vault from the point of initial energy until peak height. Simple paired t-test comparisons were performed on the summary values between the averaged male and female results. The open source one-dimensional statistical parametric mapping package (SPM1D (33)) was used for comparisons of waveform data in Matlab® (Ver. 7.8.0.347). The SPM was computed at each point in the normalised time series for the energy components and total energy waveform data, forming a statistical parametric map (Robinson et al., 2014). This allowed a determination of both levels of significance across the total waveform and areas within the curves that were significantly different. The statistical significance value was set at 0.05.

RESULTS: The results of the study are presented graphically below. Figure 1 displays the average energy for male (n=4) and female (n=4) pole vaulters at discrete time points during the vaulting phase. Males presented significantly higher mass normalised initial energy, as well as at pole straight and peak height leading to significantly greater calculated energy increase and gain. The continuous waveform data for males (a) and females (b) of the energy components is shown in Figure 2 with each individual component compared using SPM shown in Figure 3. Significant difference between males and females was found for gravitational potential energy in the relative time regions from 0-16% and 58-100% of the vault ($p=0.013$, $p<0.001$).

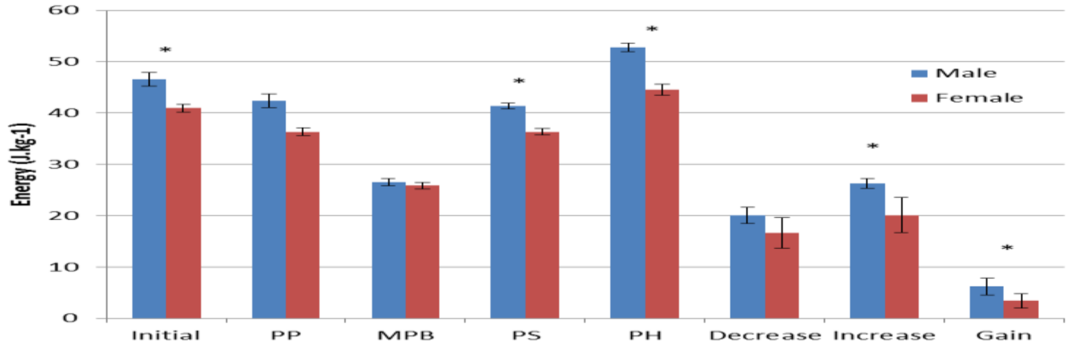


Figure 1: Comparison of summary energy at discrete time points in the vault: initial; pole plant; maximum pole bend; pole extension; and peak height as well as the calulated energy decrease, increase and total gain. Significant differences are denoted above the individual columns.

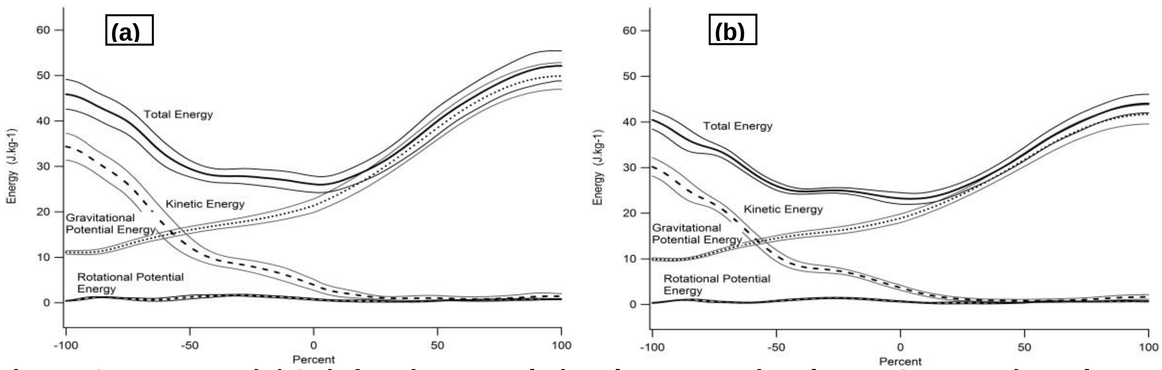
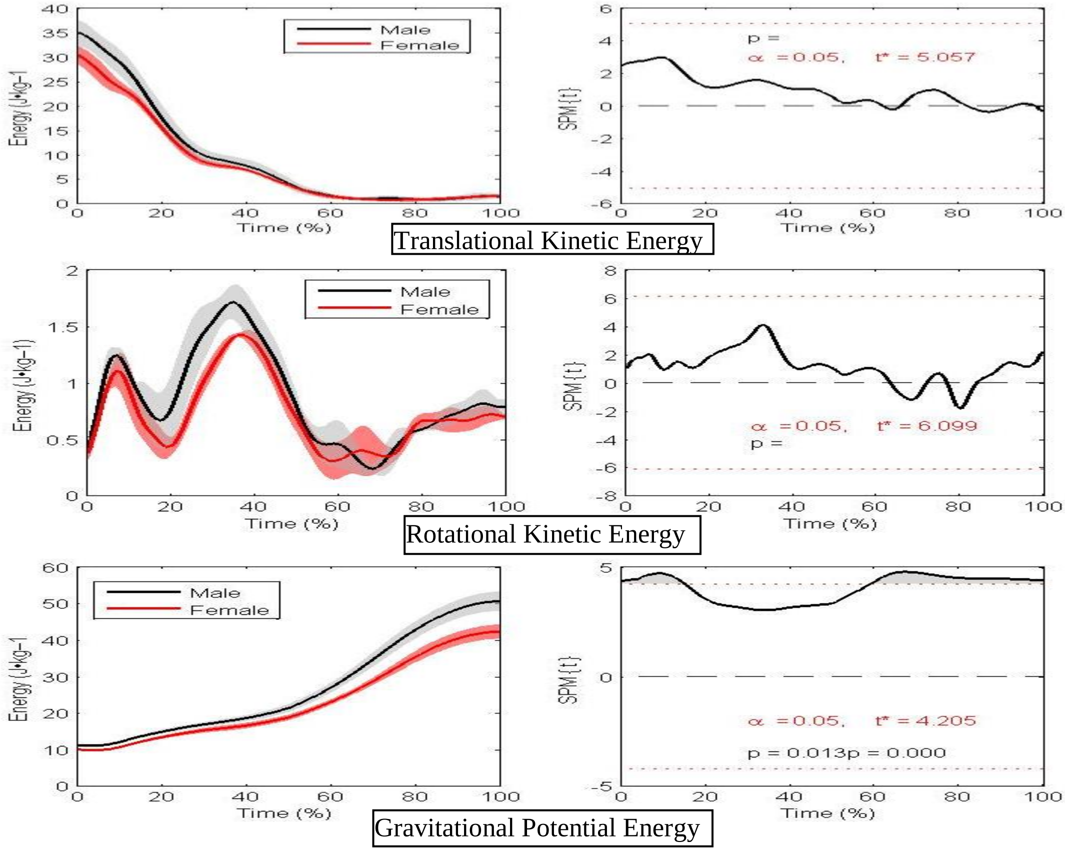
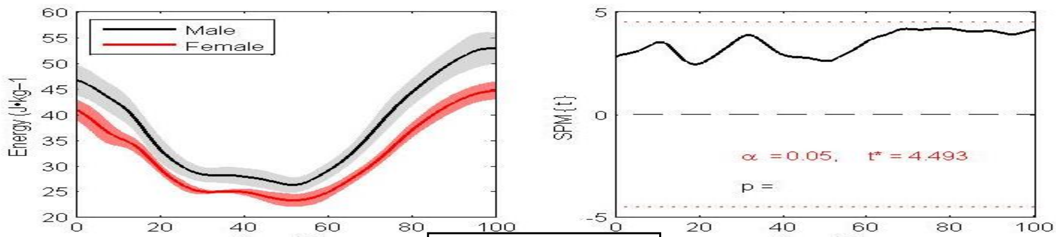


Figure 2: Average (+/-SD) for the Translational KE; rotational KE; GPE; and total average energy waveforms for the male (a) and female (b) pole vaulters. The x-axis is normalised, where -100% to 0% represents the phase between the initial energy and maximum pole bend; 0% to 100% represents the phase between maximum pole bend and the point of peak height.





Total Vaulter Energy

Figure 3: SPM Analysis Results of the Translational kinetic; rotational kinetic; gravitational potential; and total average energy waveforms for the male and female pole vaulters.

DISCUSSION: Analysis of the summary energy values demonstrated statistically significant differences in mass normalised total vaulter energy occurred between males and females at the discrete points of the mid-point of the last stride; when the pole first recoils to full extension and at peak vaulter height. These differences were also coupled with significant differences in the calculated energy increase from maximum pole bend until peak height and the total effective gain from the initial discrete value until peak height. This analysis demonstrated that, even when correcting for weight differentials, the male vaulters had a relatively greater kinetic energy from the approach leading to increased initial total energy. They were also able to perform relatively more work on the pole in the extension phase to translate this initial energy in increases through this phase of the vault, leading to significant increase in total energy increase in pole extension and total overall gain throughout the vault.
The average mass normalised energy curves for the males and females indicated that, despite some qualitative differences in magnitudes, the energy waveforms followed a similar pattern; indicative of a similar technical model being employed by both groups.
For the SPM analysis of the energy components and total energy waveforms, the only significant difference was found with males displaying significantly greater gravitational potential energy. This may have been a result of the greater centre of mass height and strength for males to achieve a high take-off projection angle and drive that is not accounted for when normalising just mass. The males would then also subsequently record increased heights in the inverted body position in pole extension affecting the GPE. Although the SPM analysis of the total vaulter energy analysis approached significance, it may be that the relatively low subject numbers in this study formed a precluding factor.

CONCLUSION: An improved understanding of the energy components and flow throughout the vaults allows the biomechanist to have an increased level of understanding on the mechanisms involved in this highly technical event. Although this study demonstrated that some differences between male and female elite vaulters exist in the total energy at discrete points, the waveform analysis displayed a more limited prevalence of statistical significance.

REFERENCES:

Arampatzis, A., Schade, F., & Brüggemann, G.-P. (2004). Effect of the pole–human body interaction on pole vaulting performance. *Journal of Biomechanics*, 37(9), 1353-1360.
Robinson, M.A., Donnelly, C.J., Tsao, J. & VanrenTerghem, J. (2014). Impact of knee modeling approach on indicators and classification of anterior cruciate ligament injury risk. *Medicine and Science in Sport and Exercise*, 46(7), 1269-1276.
Rossi, M., Lyttle, A., El-Sallam, A., Benjanuvatra, N., & Blanksby, B. (2013). Body segment inertial parameters of elite swimmers using DXA and indirect methods. *Journal of Sports Science and Medicine,* 12, 761-775.
Schade, F., Arampatzis, A., Bruggemann, G, & Komi, P. (2004). Comparison of the men's and the women's pole vault at the 2000 Sydney Olympic Games. *Journal of Sports Sciences*, 22(9), 835-842.