MEN'S AND WOMEN'S POLE VAULT AT THE SYDNEY 2000 OLYMPIC GAMES WITH RESPECT TO MECHANICAL ENERGY AND ANGULAR MOMENTUM

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The purpose of this study was to identify differences between male and female pole vaulters with regard to the athlete's mechanical energy and angular momentum on elite level. On the basis of 3-D kinematic data of the pole vault finals at the Sydney Olympic Games the athlete's mechanical energy and angular momentum have been calculated. The development of the total, kinetic and potential energy shows similar characteristics for men and women. The initial energy of the vault, the energy at maximum pole bend position and the final energy are significantly higher for male athletes, while the energy gain produced by the athletes during the vault shows no significant differences. The angular momentum is higher for the female vaulters during the initial pole bend and the bar clearance.

KEY WORDS: pole vault, mechanical energy, angular momentum, kinematics.

INTRODUCTION: At the Sydney 2000 Games the women's pole vault has been an Olympic event for the first time. The women's world record and the general level of performance have been clearly increased over the last few years. Nevertheless there is a lack in scientific studies of the women's pole vault. The pole vault in general has been focus of numerous studies concerning various aspects of this discipline. Arampatzis et al. (1997) found a high correlation between final energy and maximum centre-of-mass height for male vaulters at the Athens World Championships in Athletics in 1997. On the basis of these findings they analysed the energy exchange between vaulter and pole to explain the jump height. Ekevad & Lundberg (1995, 1997) outlined the relevance of the energy exchange for jump performance. A promising aspect concerning a biomechanical impact on the training process seems to deal with energetic considerations (Arampatzis et al. 1999). Angulo-Kinzler et al. (1994) used the vaulter's angular momentum to explain technical advantages of the winning athlete at the Barcelona 1992 Olympic Games pole vault final. The purpose of the following study was to compare elite male and female vaulters with regard to a) the athlete's mechanical energy development during the vault, b) mechanical energy parameters and c) the development of angular momentum during the vault.

METHOD: The data were collected at the men's and the women's pole vault final at the Sydney 2000 Olympic Games. The jumps were recorded by four genlocked video cameras (50Hz) synchronised using LEDs (light emitting diodes). Two cameras recorded the movement from the second last ground contact to approximately the maximum pole bend position. The other two cameras recorded the following movement up to bar clearance. One camera of each pair was positioned under an angle of approximately 40° to the main plane of movement in direction of the movement. The second camera was positioned perpendicular to it on the same side of the run way. The three dimensional co-ordinates of an 12 segment model were calculated using the DLT method. The kinematic data were smoothed with a forth order low-pass Butterworth filter with an optimised cut off frequency for each point of the model ("Peak Motus" Motion Analysis System). The masses of the segments were taken from Clauser et al. (1969) and the inertial moments were calculated from Hanavan's model (Hanavan, 1964). Hand and lower arm were regarded as a single segment. For the calculation of the athlete's total mechanical energy see Schade et al. (2000). The energy parameters have been selected according to the phase structure of the vault developed by Arampatzis et al. (1997), which takes distinct energy oriented phases and the energy exchange between athlete and pole into account. The initial energy of the vault (*E-initial*) was defined to be the total mechanical energy of the athlete in the middle of the flight phase between TO2 and TD (Fig.1); it can be estimated that the mechanical energy stored in the athlete's elastic structures is negligible at this moment and therefor his total mechanical energy can be calculated with a sufficient accuracy. The final energy (*E-final*) was defined to be the mechanical energy at the instant of maximum centre-of-mass height. *E-decrease* describes the difference in mechanical energy of the athlete between E-initial and *E-MPB* (athlete's energy at maximum pole bend position), while *E-increase* is defined to be the difference between E-final and E-MPB. The differences in the energy parameters were tested using *t*-test for paired samples and the level of significance was set at $p<0.05$. For each, the men's and the women's final, the best jump of the first ten ranking vaulters have been selected for analysis.

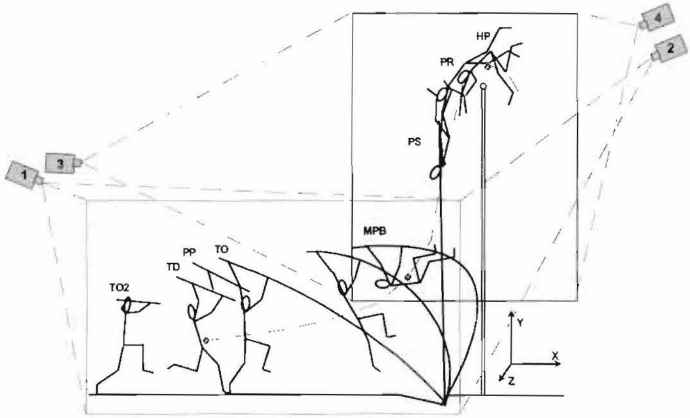

Figure 1. Events of the vault and camera positions (TO=take off, TD=touch down, PP=pole plant, MPB=maximum pole bend, PS=pole straight, PR=pole release, HP= highest point).

RESULTS AND DISCUSSION: The development of the mechanical energy showed a similar characteristic for men and women (Fig. 1), but initial and final total energy were much higher for the men. The men showed a greater decrease in their total energy until the maximum pole bend position (0 % in Fig. 1) indicating that they transferred more energy into the pole. In fact the men used much stiffer poles, even in relation to their body weight, and they also banded them harder than the women. The men also showed a greater increase in their total energy after the maximum pole bend position, which can be explained at least partly by a higher energy benefit from the recoiling pole, what could also be the reason for the smaller increase in kinetic energy of the women during the straightening of the pole.

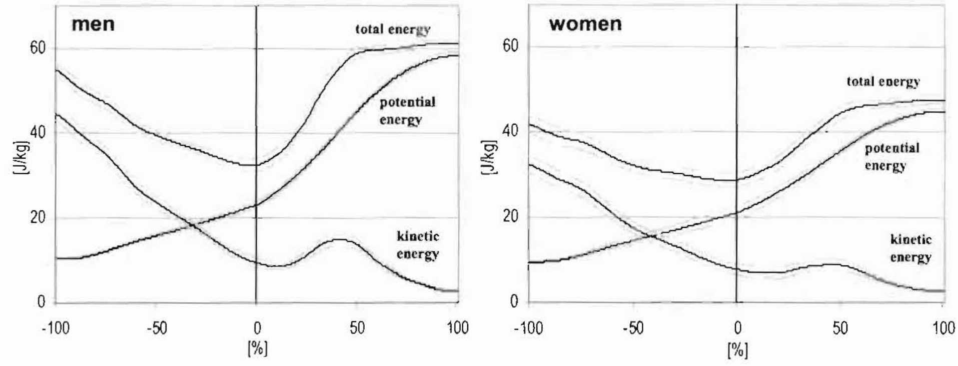

Figure 2. Mean and standard deviation of energy parameters for men (n=10) and women (n=10). The x-axis is normalised as follows: -100% up to 0% represents the phase between the middle of the last flight phase of the run up and the MPB position; 0% up to 100% represents the phase between the MPB position and the instant of maximum CM height.

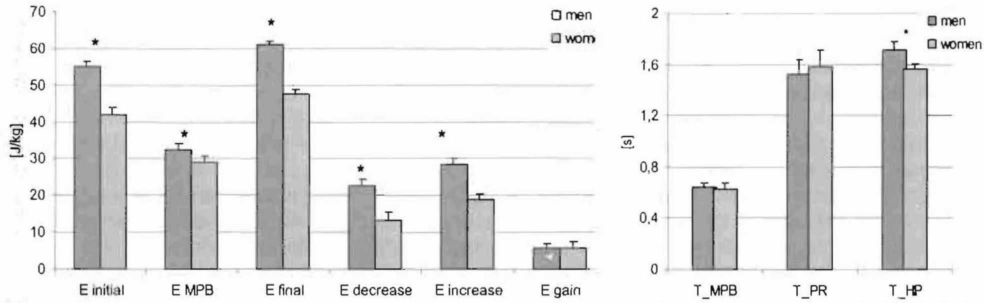

Figure 3. Comparison of energy parameters and time parameters (time between instant of E-initial and MPB=T_MPB, between E-initial and pole release=T_PR, between E-initial and instant of highest point of centre-of-mass=T_HP).

The men showed significantly higher values in the primary parameters E-initial, E-MPB and E-final, the same as in the secondary parameters E-decrease and E-increase (Fig.3). The energy gain (E-gain) was the same for the men and the women, which could lead to the conclusion, that both performed the same mechanical work during the pole phase. But the men had a much higher approach velocity and used much stiffer poles what should have lead to higher energy losses during the initial energy transformation. As a result they must have performed more mechanical work in the following pole phases to achieve the same energy gain as the women. Looking at the time parameters no significant differences could be investigated for T_MPB and T_PR. Only the time until the highest point was significantly longer for the men. The energy return from the pole enabled the men to achieve a long flight phase. For the women T_PR and T_HP were similar. In fact only few women performed a free flight phase.

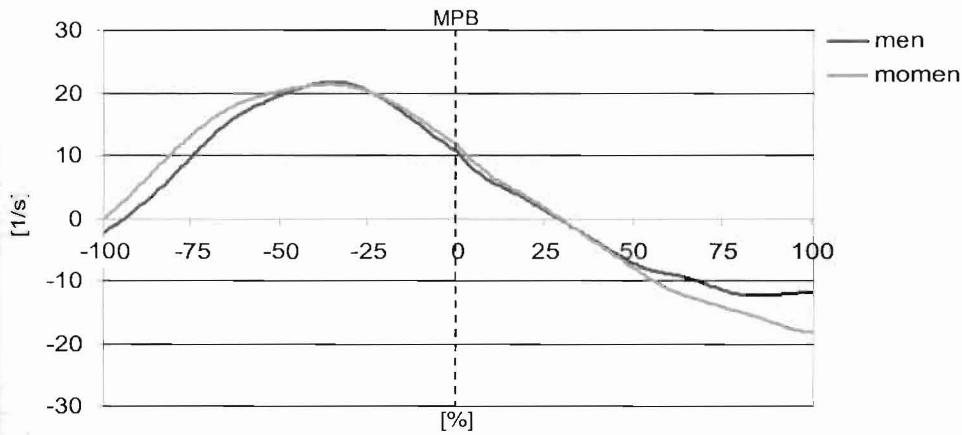

Figure 4. Normalised mean angular momentum about the transversal axis through the CM for men (n=10) and women (n=10); the values are given relatively to body mass and height, The x-axis is normalised as follows: -100% up to 0% represents the phase between the pole plant (pole hits the box) and the MPB position; 0% up to 100% represents the phase between the MPB position and the instant of maximum CM height.

The normalised angular momenta about a transversal axis through the CM are similar to those presented by Angulo-Kinzler et al. (1994). The maximum values were the same for men and women, but during the initial phase of the vault and during the bar clearance they were higher for the female vaulters (Fig. 4). In the first case this indicates that the women, compared to the men, are rather rotating about their hip axis than applying a momentum on the pole by working about the shoulder axis. As a result the women show a lower energy decrease (Fig. 3) and transfer less energy into the pole. The second case could mean that the female jumpers show a less effective bar clearance. As a result of a more consequent initial penetration into the pole the male vaulters show a negative angular momentum immediately after the pole plant.

CONCLUSION: It can be concluded that the behaviour of the female vaulters in the pole phase can rather be compared with a passive upward swing than with an active pole bending action. The male vaulters show an active behaviour and seem to take greater advantages of the elastic properties of the poles. The reasons could be one or a combination of the following points: different strength abilities in the shoulder-girdle, a tendency of the female vaulters to use inadequate stiff poles, a better pole planting technique of the male vaulters an as a result a more efficient rock back action.

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