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Influence of pole plant time on the performance of a special jump and plant exercise in the pole vault

Falk Schade [a], Adamantios Arampatzis [b,c,*]

[a] German Sport University of Cologne, Institute for Biomechanics and Orthopedics, Germany
[b] Humboldt-Universität zu Berlin, Department of Training and Movement Sciences Centre, Philippstr. 13, Haus 11, 10115 Berlin, Germany
[c] Centre of Sport Science and Sport Medicine Berlin (CSSB), Germany

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ABSTRACT

The purpose of this study was to examine the effect of the timing of the pole plant during the stance phase of the jump on the energy level of the vaulter/pole system at take-off for a special pole vault take-off exercise (Jagodin). We hypothesised that an earlier pole plant would increase the pole energy at take-off compared to the energy decrease of the vaulter during the jump and plant complex and so lead to a higher total energy of the vaulter/pole system at take-off. Six male pole vaulters experienced three Jagodins each with different pole plant time building three groups of vaults (early, intermediate, late pole plant). Kinematic data of vaulter and pole were recorded, as were ground reaction forces measured at the end of the pole under the planting box and under the take-off foot. These measurements allowed the energy exchange between the vaulter and pole to be determined. We found neither statistical significant differences in the mechanical energy level of the vaulter/pole system during take-off between the three groups nor a relationship between the timing of the pole plant and the energy level of the vaulter–pole system during take-off. We conclude that although the timing of the pole plant influences the interactions between the vaulter, the pole, and the ground, it does not affect the athlete's performance. Although a late pole plant decreases the loss of energy by the vaulter during the take-off, this is counterbalanced by a decrease in the energy stored in the pole at take-off.

1. Introduction

The quality of the interaction between athlete and sports equipment plays an important role in many sport activities (Arampatzis and Brüggemann, 1998; Arampatzis et al., 1999a). This is especially so in the pole vault, where the pole shows large deformations and has a high potential to store and return energy throughout the vault and so the interaction between vaulter and vaulting pole strongly influences performance (Dillmann and Nelson, 1968; Ekevad and Lundberg, 1995, 1997; Schade et al., 2000, Arampatzis et al., 2004; Schade et al., 2006).

It is well accepted that during the pole support phase, in addition to the approach run, the vaulter is not only able to add energy to the vaulter/pole system by means of muscular work, but also that a certain amount of mechanical energy is lost due to friction and deformation within the biological and mechanical system (Arampatzis et al., 2004; Schade et al., 2006). Especially the jump and the planting of the pole are believed to show considerable energy losses (Linthorne, 1994, 2000; Ekevad and Lundberg, 1997). However, the moment in time of the pole plant, when the pole becomes an elastic external support, is a crucial point international level coaches argue about. It is generally believed that pole plant should take place at the end of the stance phase of the jump to reduce energy loss and to improve pole vault performance (Angulo-Kinzler et al., 1994; McGinnis, 2000). Vitali Petrov, who is a former coach of the male and female world record holders, postulated a pole plant technique model at which the pole plant at the end of the stance phase of the jump, or even after take-off, is a key movement pattern in a good technique (Petrov, 2004). However, even highly successful pole vaulters show a wide interindividual range in the timing of plant, from planting the pole near to the instant of touch-down, through to planting the pole at the instant of take-off. The advantage of a later pole plant has not been scientifically proven yet. An earlier pole plant during the stance phase of the jump, for example, may increase the energy transfer to the pole through muscular work increasing the energy of the vaulter/pole system. However in athletic jumps the total energy of the vaulter's body decreases during the stance phase of the jump (Arampatzis and Brüggemann, 1999; Brüggemann and Arampatzis, 1999; Arampatzis et al., 1999b)

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* Corresponding author at: Humboldt-Universität zu Berlin, Department of Training and Movement Sciences Centre, Philippstr. 13, Haus 11, 10115 Berlin, Germany. Tel.: +49 030 2093 46047; fax: +49 030 2093 46046.
E-mail address: a.arampatzis@hu-berlin.de (A. Arampatzis).
URL: http://tbw.hu-berlin.de (A. Arampatzis).

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and thus may affect the energy of the vaulter/pole system negatively. In the pole vault the changes (i.e. decrease) in the vaulter's mechanical energy during the stance phase of the jump depend on the mechanical work of the ground reaction forces acting on both the take-off leg and the arms. Therefore an earlier pole plant may also result in a higher decrease of the vaulter's energy and thus affect the energy of the vaulter/pole system. To the best of our knowledge there is no study which investigated the effect of the timing of the pole plant on the energy level of the vaulter/pole system during the jump and plant complex.

In practice a special jump and plant exercise (Jagodin) is used, where approach run, jump, and pole plant have to be performed like in original vaulting. But immediately after take-off the vaulter tries to "freeze" his position in relation to his grip hands at the pole until the maximum pole bend position. Jagodins are chosen for improving jump and plant technique while avoiding irritations by anticipation of the following phases and therefore allow for a variation in the moment in time of pole plant. Additionally Jagodins lower the risk of serious injuries when changing movement pattern decisively compared with full approach vaults. Hence, Jagodins were chosen for analysis in the current study.

The purpose of this study was to examine the effect of the point in time of the pole plant on the energy level of the vaulter/pole system during the jump and plant complex for a special pole vault take-off exercise. We hypothesise that an earlier pole plant during the stance phase of the jump will increase the pole energy at take-off compared to the energy decrease of the vaulter and so lead to a higher energy level of the vaulter/pole system at take-off.

2. Methods

2.1. Theoretical considerations

The jump and plant complex in the pole vault is defined as the phase from touchdown to take-off of the last stance phase of the approach run. It contains a one-legged jump and the planting of the pole (Fig. 1). Pole plant is defined as the instant when the pole hits the rear barrier of the planting box. During this phase an interaction between vaulter, ground and pole occurs (Fig. 2). The initial energy for the jump and plant complex is generated during the approach run. It is defined as the vaulter's centre-of-mass energy at touchdown (E^{vaulter}-TD). Within the jump and plant complex E^{vaulter}-TD is partially converted: during the vaulter's interactions with the ground (jump) and the pole (plant) the direction of the centre-of-mass movement changes from horizontal to a partially vertical component, the vaulter jumps up, and energy is transferred to the pole (E^{pole}-TO). Pole plant can take place during different moments in time of the jump leading to more or less synchronous interactions between vaulter, pole and ground. The final energy of the vaulter is defined as the vaulter's centre-of-mass energy at take-off (E^{vaulter}-TO). The vaulter can change the mechanical energy level of the vaulter/pole system during the jump and plant complex by means of muscular work that can be energy production and energy dissipation (compare Arampatzis et al., 2004), which occur during the interaction with the ground as well as during the interaction with the pole.

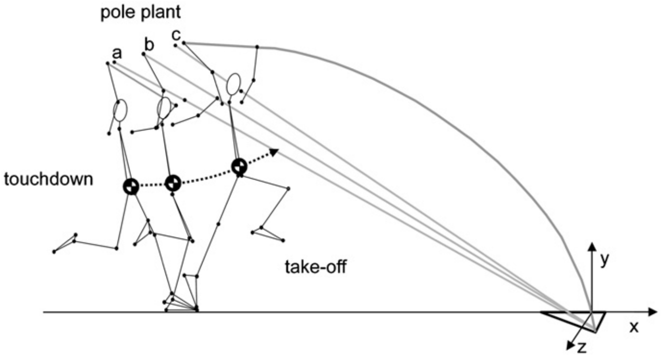

Fig. 1. Diagram of the jump and plant complex in the pole vault and the variation in the timing of the pole plant during the stance phase of the jump (touchdown = touchdown of the support leg, pole plant = pole tip hits the rear barrier of the planting box, take-off = take-off of the support leg; a = pole plant at the beginning of the stance phase of the jump, b = pole plant in the middle, c = pole plant at the end).

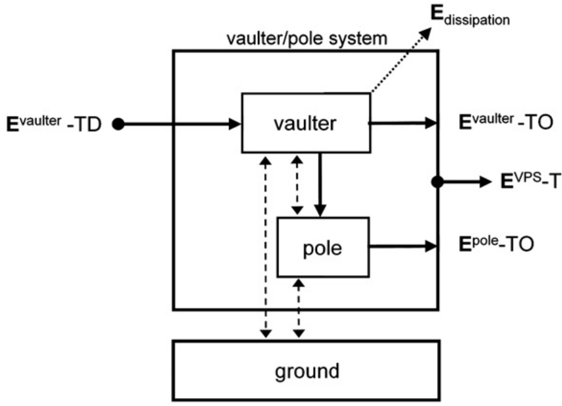

Fig. 2. Energy transfer and interaction between athlete, pole and ground during the jump and plant complex in the pole vault. For a given vaulting pole the mechanical energy level of the vaulter/pole system during this phase is influenced by the initial energy (E^{vaulter}-TD) and the movement behaviour; solid lines = energy transfer; dashed lines = interaction between elements (E^{vaulter}-TD = energy of the vaulter at touch-down; E^{vaulter}-TO = energy of the vaulter at take-off; E^{pole}-TO = energy of the pole at take-off; $E_{dissipation}$ = energy dissipation within the vaulter; E^{VPS}-TO = energy of the vaulter/pole system at take-off).

Consequently the performance of the jump and plant complex can be evaluated by the energy of the vaulter/pole system at takeoff (E^{VPS}-TO, Fig. 2); it depends on the initial energy of the vaulter and the movement behaviour during the jump and plant phase. The fraction of the energy transferred to the pole compared to the energy decrease of the vaulter can be evaluated by the change of the mechanical energy level of the vaulter/pole system (ΔE^{VPS}; i.e. $\Delta E^{\text{VPS}} = E^{\text{VPS}}$-TO minus E^{vaulter}-TD), which is the algebraic sum of W_{jump}, W_{plant} and E_{pole} (W_{jump} = work of reaction forces on support leg, W_{plant} = work of reaction forces on planting box, and E_{pole} = strain energy of the pole).

2.2. Experimental setup

Six male vaulters participated in this study (height: 1.89 ± 0.03 m, weight: 83.5 ± 3.25 kg). Vaulter A, B, and C are decathletes (personal best 4.35 m, 4.60 m, and 4.90 m). Vaulters D, E and F are pole vault specialists (personal best 5.35 m, 5.80 m, and 6.00 m). They were told to vary the timing of pole plant during a common pole vault exercise ("Jagodin", Fig. 3). The need to reduce the risk of injuries eliminated complete vaults and full approach runs for this experimental design and advised Jagodins and sub-maximal approach runs even though the transfer of the results to competition vaulting might be limited. The vaulters performed 3 to 6 Jagodins using sub-maximal approach distance (10–14 steps), which was 2 to 4 steps shorter than their original contest approach. Grip heights and pole stiffness were the same as for complete sub-maximal vaults, but lower than for competition vaults. For analysis 3 trials of each subject were selected that showed the individually earliest and latest pole plant with respect to the touchdown of the take-off foot and the trial with the pole plant closest to the middle between these two (Fig. 4). The vaulter's movement was recorded by one high speed video camera (250 Hz). Two additional video cameras (250 Hz) recorded the movement of the two grip hands on the pole. Two Kistler force platforms recorded the ground reaction force at the take-off position and under the planting box. For a detailed description of data capture and handling please see the appendix presented in the online version of this paper. Fig. 3 gives an example of the filtered ground reaction forces measured under takeoff foot and planting box.

The total energy of the vaulter was calculated as follows:

$$E_{CM} = mgH_{CM} + \frac{m\boldsymbol{v}^2{}_{CM}}{2} \tag{1}$$

where m is mass of the vaulter; H_{CM} height of the vaulter's centre of mass; $\boldsymbol{v}_{CM}$ velocity of the vaulter's centre of mass.

During the jump and plant complex the vaulter applies a compressive force and a bending moment to the upper end of the pole while the bottom end is free to pivot in the planting box (Hubbard, 1980; Griner, 1984). Therefore the energy stored in the pole was calculated using the following formulas (Arampatzis et al., 2004):

$$E_{pole} = \int \boldsymbol{F}_p d\boldsymbol{r} + \int \boldsymbol{M} d\boldsymbol{\beta} \tag{2}$$