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Original paper

Using EMGs and kinematics data to study the take-off technique of experts and novices for a pole vaulting short run-up educational exercise

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Abstract

This study attempts to characterise the electromyographic activity and kinematics exhibited during the performance of take-off for a pole vaulting short run-up educational exercise, for different expertise levels. Two groups (experts and novices) participated in this study. Both groups were asked to execute their take-off technique for that specific exercise. Among the kinematics variables studied, the knee, hip and ankle angles and the hip and knee angular velocities were significantly different. There were also significant differences in the EMG variables, especially in terms of (i) biceps femoris and gastrocnemius lateralis activity at touchdown and (ii) vastus lateralis and gastrocnemius lateralis activity during take-off. During touchdown, the experts tended to increase the stiffness of the take-off leg to decrease braking. Novices exhibited less stiffness in the take-off leg due to their tendency to maintain a tighter knee angle. Novices also transferred less energy forward during take-off due to lack of contraction in the vastus lateralis, which is known to contribute to forward energy transfers. This study highlights the differences in both groups in terms of muscular and angular control according to the studied variables. Such studies of pole vaulting could be useful to help novices to learn expert's technique.

Keywords: Athletic sport; Pole vaulting; Motor control; Electromyography; Range of motion; Expert-novice

1. Introduction

The pole vault is one of four jumping events in track and field. It is broken down into six phases: the *approach*, the *plant and take-off*, the *swing and row* phase, the *rockback*, the *turn* and the *fly-away*.[1] The athletes' principal challenge lies in using their horizontal velocity to obtain optimal vertical velocity[2] so that their pole bends to lift them over the bar. Energy transfer during the pole vault has already been studied.[3–5] However, there is limited kinematic and physiological data comparing novice and expert pole vaulters. Research has sought to improve pole vaulting techniques by identifying performance criteria as well as by describing the forces exerted by the vaulters on the pole and the forces generated by the pole itself. The take-off phase has been identified[4] as the principle parameter for success in pole vaulting. It is during this phase that the kinetic energy created during the approach and then stored in the pole is transferred to the vaulter, allowing them to pass over the bar. The potential internal energy of the pole, combined with the muscular effort of the lower limbs, propels the pole vaulter to the highest possible point. Thus, this essential take-off phase must be controlled to permit the most efficient exchange of energy.[6] To the best of our knowledge, there has been no experimentation on how pole vaulters' muscle recruitment helps manage the energy transfer needed to execute a jump, though this has been studied for the long jump.[2] Identifying the specific pattern of coordination that is used by expert vaulters should increase our understanding of the muscular activity employed during pole vaulting by expert and novice athletes to produce such movement. This could then help novices improve their

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take-off technique, better prepare themselves for competition, and improve their performance. To this end, this study was designed to characterise the EMG activity and kinematics of the lower limbs during expert and novice pole vaults during a pole vaulting short run-up educational exercise that focuses on the take-off, especially at the lower limb level.

2. Methods

Nine healthy athletes participated in this study, which was conducted according to the Helsinki guidelines. After informed consent was obtained, the subjects were divided into two groups. The novice group was composed of four unranked novice athletes (169 cm ± 4; 60 kg ± 6; 23 years ± 1) who had been practicing the pole vault for less than 1 year. The expert group was composed of five ranked elite athletes (178 cm ± 6; 71 kg ± 6; 21 years ± 1) who had all competed nationally in the event.

The athletes performed one stage of a pole vault – an educational exercise used by coaches to teach and improve take-off technique – and data was collected on this task. During the exercise, all athletes used the same pole for a three-step run-up. It was recommended that all pole vaulters use the same pole for the educational exercise to avoid introducing such a dependant variable into the study. Using this task for data collection was done to eliminate the potential effect of the run-up on task performance. Participants were asked to complete 15 min of trial runs to familiarise themselves with the protocol. Each athlete completed the required take-off task 10 times in order to ensure that at least five usable trials, selected by an expert pole vault coach, would be obtained.

Kinematics data were collected using an 8-camera Vicon Peak motion analysis system (Vicon Peak, Oxford, UK) and recorded at 120 Hz, digitally filtered and smoothed using a 2nd order Butterworth low-pass filter (cut-off frequency: 6 Hz). To define the different pertinent body segments, reflective markers were placed on both sides of the body at different heights on the lower limbs: pubis, iliac spine, lateral knee, lateral ankle, lateral foot and calcaneus.

EMG activity was recorded using a pre-amplified bipolar electrode (Biochip, Elmatek, France) connected to the motion analysis system to allow EMG and kinematic data acquisition to be synchronised. These electrodes were placed on the take-off leg's muscle motor points on the *biceps femoris* (BF), *vastus lateralis* (VL) and *gastrocnemius lateralis* (GL). EMG data were recorded at 1080 Hz and filtered using a 2nd order Butterworth band-pass filter (20–300 Hz). The signal was expressed as a percent of maximal dynamic contraction (MDC). This standardisation was used to normalise the effect

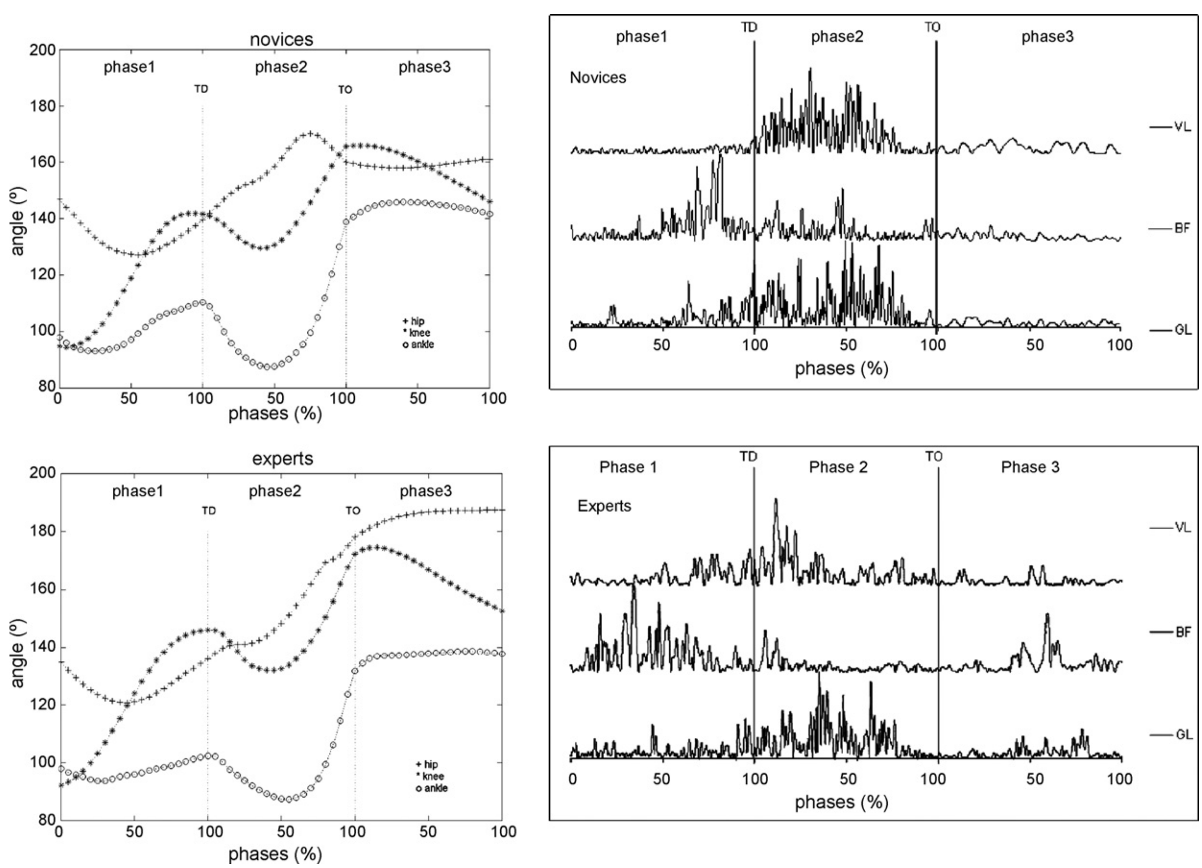

Fig. 1. Average hip, knee and ankle angles during the three steps (expressed in percentages) (A) of novices and (B) of experts. Evolution of filtered and rectified EMG data for the vastus lateralis (VL), the biceps femoris (BF) and the gastrocnemius lateralis (GL). Each step is expressed in percentages (C) for novices and (D) for experts.

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on the signal of variations in impedance among the athletes and in quality for each of the electrodes used.

Every trial for each subject was broken down into three phases. The first phase was the final stride of the *approach*. The second phase began when the take-off foot landed on the force plate (touchdown: TD) and ended when this foot lifted off the force plate (take-off: TO). The force plate (Logabex, Giat-Industrie Society, Toulouse, France) only allowed the take-off phase and time of contact to be determined. The third phase began just after the foot left the force plate and ended when the vaulter gathered the body to jump. Each phase was expressed as a percentage, i.e. normalised according to the duration (0–100%) of each phase.

Non-parametric Mann–Whitney *U*-tests were used ($p \leq 0.05$) to evaluate the differences in significance between novices and experts. They were performed for the joint angle, angular velocity and EMG data.

3. Results

Fig. 1 shows the articular evolution of the three joint angles studied in novices (A) and experts (B) respectively.

Hip angles for the experts and novices were quite similar until 75% of phase 2 was reached. At that point, a decrease in hip angle for novices was seen, while hip angle in experts continued to increase until they stabilised near the middle of phase 3. Knee angles for both experts and novices were similar. Knee angle increased until the foot was positioned for TD, decreased in the first part of phase 2 and then increased before ultimately decreasing during phase 3. However, there were differences in the ankle angles of novices and experts, especially by the time actual TD and TO occurred. The experts' values were both smaller than those of novices.

Fig. 1 shows the evolution of the electromyographic activity of novices (C) and experts (D) for *VL*, *BF*, and *GL* during the three phases.

The *VL* was recruited later in novices than in experts, but continued to contract until the end of phase 2. GL activity was similar for both novices and experts, i.e. active in the first half of the phase 1 and during most of phase 2. However, for the expert, it appeared that the activity diminished during phase 3. The *BF* activity shows the strongest difference. For the novices, it was active from the midpoint of phase 1 to the midpoint of phase 2. However for the experts, *BF* was active during phase 1, but not in phase 2, and became active once again in phase 3.

A statistical Mann–Whitney *U*-test ($p < 0.05$) performed for TD and TO showed significant differences in the angles of the knee and ankle, as well as in the angular velocities of the knee and hip. The other variables studied did not show any significant differences (Table 1).

These results demonstrate that, at the moment when the foot is positioned (TD), the knee angle is more obtuse in experts ($145° \pm 13.3$) than in novices ($141° \pm 5.3$), $p = 0.023$.

Table 1
RMS values for the muscular activity, angles and angular velocities with standard deviation for the two subject groups, at touchdown and take-off moments and during phases 1, 2 and 3 ($p \leq 0.05$).

	Experts	Novices	*p*
Angle (°) at touchdown			
Knee	145° ± 13.3	141° ± 5.3	0.023
Ankle	101° ± 6.9	110° ± 8.7	0.0003
Angle (°) at take-off			
Hip	178.5° ± 6.6	160° ± 4.2	<0.0001
Knee	172° ± 3.6	166° ± 10.6	0.017
Ankle	131° ± 9.3	139° ± 8.2	0.003
Angular velocity (rad s^{-1}) at take-off			
Hip	−0.66. ± 0.44	0.12 ± 0.08	0.0007
Knee	0.71. ± 0.24	0.26. ± 0.47	0.0019
RMS for phase 1			
Vastus lateralis	396 ± 194	176 ± 76	0.0001
Biceps femoris	514 ± 140	257 ± 96	0.0001
RMS at touchdown			
Biceps femoris	7 ± 4	14 ± 12	0.01
Gastrocnemius	16 ± 10	26 ± 13	0.01
RMS for phase 2			
Vastus lateralis	794 ± 243	463 ± 109	0.00001
RMS at take-off			
Vastus lateralis	10 ± 11	4 ± 3	0.01
Gastrocnemius lateralis	5 ± 7	7 ± 6	0.03
RMS for phase 3			
Vastus lateralis	182 ± 152	75 ± 27	0.0009
Biceps femoris	326 ± 150	230 ± 235	0.0043

The ankle angle, on the other hand, tends to be more acute in experts ($101° \pm 6.9$) than in novices ($110° \pm 8.7$), $p = 0.0003$. At TO, the knee angle is more obtuse in experts ($172° \pm 3.6$) than in novices ($166° \pm 10.6$), $p = 0.017$, while the ankle angle is more acute in experts ($131° \pm 9.3$) than in novices ($139° \pm 8.2$), $p = 0.003$. Furthermore, the hip angle is more obtuse in experts ($178.5° \pm 6.6$) than in novices ($160° \pm 4.2$), $p < 0.0001$. The novices have an angular velocity at the hip of $+0.12\ \text{rad s}^{-1}$ with a standard deviation of 0.08, whereas the experts have a velocity of $-0.66\ \text{rad s}^{-1}$ with a standard deviation of 0.44, $p = 0.0007$. The angular velocity at the knee is higher for experts ($0.71\ \text{rad s}^{-1} \pm 0.24$) than for novices ($0.26\ \text{rad s}^{-1} \pm 0.47$), $p = 0.0019$.

These results indicate a difference in articular control during TD and TO, which must be studied using an electromyographic approach.

The Root Mean Square values (RMS) of the electromyographic signal for each muscle were calculated for the three phases. This statistical test highlighted significant differences between experts and novices ($p \leq 0.05$) for the *VL* during all three phases and for the *BF* during phase 1 and phase 3, indicating variations in muscle control. The RMS values were also calculated at TD and TO with a framing interval of ±2% for each moment. Statistical testing indicated significant differences ($p \leq 0.05$) between experts and novices at TD for the *BF* and the *GL* and at TO for the *VL* and the *GL*.

4. Discussion

The aim of this study was to characterise the EMG activity and kinematics of the lower limbs during expert and novice pole vaults, focusing on the take-off, especially at the lower limb level. Among the kinematic variables studied, the knee and ankle angles, as well as the angular velocities at the hip and knee, were significantly different between novices and experts. The electromyographic data indicates that *vastus lateralis* (*VL*) and *biceps femoris* (*BF*) activity was, in general, significantly different between experts and novices. More specifically, the activity of the *BF* and the *GL* at touchdown (TD) and the activity of the *VL* and the *gastrocnemius lateralis* (*GL*) at take-off (TO) are both significantly different.

Although pole vaulting has been studied for quite some time, investigations have focused on experts in order to improve the understanding the biomechanical aspects of their performance. However, such studies were conducted on the whole pole vault. The present investigation focused on the lower limb action at the time of take-off and established relationships between kinematic data and electromyographic data for that kind of exercise. The present study presents new results on the differences that exist between experts and novices during a pole vaulting short run-up educational exercise employed to teach the fundamentals of the take-off in pole vaulting. Such differences could explain the failures of the novices. The study also investigated the muscle recruitment in pole vaulting – an element that has not yet been investigated to the best of our knowledge.

In order to highlight what occurs during the second phase, we refer to the intermediary period between landing and pushing – the “backward-sweeping”. During phase 2, athletes first halt their movement by using the pole plant, and the energy transfer occurs in the lower extremities.[7,8] This improves ground contact time in an effort to increase the force and velocity available to the athletes when they begin pushing to move themselves up and over the bar.

Phase 1: The landing foot must be positioned correctly for efficient backward-sweeping. For this, the experts avoided closing the knee angle to allow maximum conservation of kinetic energy created by the movement. Our results for the pole vault concur with those published[9,10] in terms of the approach, and the actual jump.[11] It could be suggested that positioning the foot ahead of the body at the end of the last stride helps to promote the development of vertical velocity, which could be concomitant to the loss in horizontal velocity that occurs in the subsequent phase. The experts in our study appear to have optimised this part of phase 1, since their leg stiffness, in terms of knee angular variation locking, is more marked than in the novices. In addition to the knee angle, ankle angle is also important to the success of the backward-sweeping. Research has shown that a more acute ankle angle improves the energy restitution necessary for a successful jump.[2] In our study, the angle of the ankle joint of expert vaulters tended to be more acute than in novices, who tended to have “crushed” ankle angles in the take-off leg. It may be concluded that the position of the foot at touchdown helps to lower the athlete’s centre of gravity. It then helps to place the leg well in front of the expert’s body, which may allow the centre of gravity to go over the landing support and enable the take-off limb to store elastic energy. The athlete does not push off a support, but rather rebounds using the muscular tension caused by the spring back elasticity of the muscles. The difference in the way experts and novices activate their muscles is highlighted in phase 1. During this phase, the *VL* and *BF* in experts seem to contract earlier than in novices in preparation for the backward-sweeping. In addition, experts stabilise the knee joint earlier than novices do. Furthermore, some novices do not even activate the *VL* and the *BF* at the same time during phase 1. These novices therefore could not perform an efficient backward-sweeping.

Phase 2: Executing a pole vault requires the pole to bend during the take-off phase, when energy is transferred from the athlete to the pole.[3,4,7] The continued widening of the experts’ angles contributes to the continuity of the energy transfer. Because the angles stop evolving at TO in novices, the continuity of the energy transfer diminishes. Thus, widening the angles can be viewed as optimizing energy transfer because the widening limits energy absorption. The optimised evolution of the experts’ joint angles is also likely the result of the optimisation of muscle activity.[11] At the transition point between phase 1 and phase 2 (TD), both experts and novices exhibit the simultaneous contraction of the *VL* and *BF* muscles, thus confirming our hypothesis that the joint is stabilised.

The EMG pattern, i.e. the muscle recruitment for the expert probably occurred because they positioned their take-off foot with a more extended knee angle at touchdown as the running speed increased. This pattern of muscle recruitment suggests that the knee extension was required to support the body weight. It could be hypothesised that the VL contribute to acting as a knee extensor more in the experts than in the novices, thereby halting knee flexion against body weight. It is possible that such VL activity for the experts generates a greater vertical velocity at take-off. The end of the *VL* activity explains, to some extent, why the knee angle of novices stops widening, whereas the continued activity in the expert group explains the continued widening of the knee angle. All this could help the athlete increase the amplitude of the movement and transform the initial horizontal energy into potential vertical energy in the pole. The decrease of *VL* activity in the novices could correspond to the moment that the pole is planted in the take-off box, and thus to the pole’s resistance to the prolonged muscle activity of the vaulter. The prolonged activity of the experts is an effective means of transmitting energy to the pole, and is absent in novices.

Phase 3: There is also a difference between the experts and the novices during phase 3, mostly in terms of *BF* activity. This muscle is active throughout take-off in experts but not in all novices. The purpose of the experts’ muscle activity is to prolong the effect of the take-off, in terms of energy, in an effort to transmit energy to the pole. Novices must learn to

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prolong this muscle's activity in order to use the pole and its stored energy to raise their bodies up and over the bar.

5. Conclusion

It should be noted that this was a study of educational pole vault jumps. Athletes need to use their competition run-up length, pole length and pole stiffness. In doing so, they would then perform a take-off that is representative of what they do in competition. The decision to use the same run-up and pole for all athletes means that the expert athletes almost certainly did not perform in a way that represents their normal take-off techniques. The jumps analysed in this study probably bear little resemblance to competition vaults, but they do help understand the reason why there are so many differences between athletes of different levels. Consequently, this study highlights, for the first time, the muscular activity and kinematics of this short run-up educational exercise. It emphasises the novices' segmented evolution, which does not conform to the requirements of pole vaulting. The differences in the opening and closing of the angles of the knee and ankle in particular, and the corresponding muscular activity, show the influence that training and the study could have on expert pole vault take-offs. In general, novices have delayed kinematics and muscle recruitment compared to experts, demonstrating that experts play a more active role in their pole vault jumps.

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