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Influence of Kinematic Parameters on Pole Vault Results in Top Juniors

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A B S T R A C T

The aim of this research was to analyse the kinematic parameters and to ascertain the influence of those parameters on the pole vault result. The entity sample of the research consisted of successful vaults of 30 athletes, whose attempts were recorded at the European Junior Athletics Championships. The examinees performed the vaults as part of the qualification competition for the finale and the finale of the competition itself. The examinees were 17–19 years old, and the range of their top results was from 4.90 to 5.30 m. The results of the regression analysis showed a significant influence of the predictor variables on the effective pole vault height. The centre of body mass height was mostly influenced by the following variables: TS – takeoff velocity, LSS – last step velocity, PSS – penultimate step velocity, TAPR – trunk angle at the moment of the pole release. The following variables had lesser, but still a significant influence: CBMDM – centre of body mass distance at the pole release moment, and MCMVV – time of pole straightening. Generally, the information gained by this research indicates the significant influence of the kinematic parameters on the pole vault result. Therefore, the conclusion is that the result efficacy in the pole vault is primarily determined by the variables defined by the motor capabilities, but also by the indicators determining the vault activity realization technique. The variables that define the body position during the pole release (trunk angle and centre of mass distance) have the most significant influence on the vault performance technique, while the motor capabilities influence the last two run up steps velocity, take off speed and the time of pole straightening.

***Key words**: pole vault, kinematic parameters, juniors, regression analysis*

Introduction

An analysis of top quality juniors' competitive pole vaulting performance is the subject of this research. Pole vaulting is a complex track and field discipline in which particular sequential parts – phases have an important contribution to the final result. The performance efficiency will be improved if all the elements of the particular phases are performed satisfactorily, in a way that the positive transfers from the previous phase are transferred to each following phase until the final realisation.

As an athletic discipline, pole vaulting has always drawn people's attention, particularly since 1961, when the International Association of Athletics Federations formally approved the usage of flexible pole. Ever since that period until this very day, the men's world record had grown rapidly until it reached the height of 6.15 meters. Pole vaulting is a highly technical demanding motor activity, and many practical and theoretical information on it have been obtained by coaches and biomechanics.

Biomechanical findings, as well as application of the indicators of the kinematic parameters in a pole vaulter's training process, will significantly define his working modality, hence also determining the efficiency of the transformational process. There are a high number of factors that, through their interaction, influence the final result in pole vaulting, including an athlete's potential (his potential efficacy), his training, his coach's vocational experience and knowledge, the training conditions, as well as the condition of the development of motor programs (techniques). Seeking for the factors that determine successfulness in pole vaulting is the principal focus of biomechanical studies. In accordance with the above mentioned, a kinematic analysis of motion in pole

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vaulting implies a precise definition of spatial, temporal and spatial-temporal values, as well as of the relations existing between the movements in the structure of this athletic discipline. The spatial parameters include body position, movement direction, trajectory of movement points, course of action on the pole, and angular relations between levers in particular parts of pole vaulting. In contrast to the spatial parameters and their complexity, the temporal parameters include only performance of different parts, or of the overall structure, within a period of time.

The results of the kinematic analysis of particular parameters will offer a possible answer regarding the existence of a general technical model that top-quality juniors – pole vaulters – use. The technical performance of pole vaulting movement does not change in its structure during a pole vaulter's development. The greater demands in technique perfecting procedures, as well in physical competence development, occur only in subsequent junior and senior categories.

The complexity of mastering the pole vault technique is due to the fact that the vault is performed at the significant height with the help of an elastic support (pole). To master this motor activity technique, an athlete requires diverse physical preparation, mastering the wide complex of motor skills, knowledge and boldness[1,2]. Further on, this discipline is characterized by energy exchange, especially between kinetic and potential. A widely accepted opinion among coaches and sport scientists is that the run-up speed is the most important parameter among all the pole vault success determining factors[2–6]. The variations in running speed during run-up and the technical quality condition the choice of the length and the stiffness of the pole, as well as the grip height, determining the energy exchange pattern, occurring during the pole vault. Certain research has been done with the aim of better understanding of the relation between technical parameters and the result success in certain vaulting disciplines: Greg and Yeadon (2000)[7] for high jump, Bridget and Linthorne (2006)[8] for long jump, Gros and Kinkel (1986)[9], McGinnis (1997)[5], Zagorac et al. (2008)[10–11], Lui Y, Wu (1993)[12], Liu Zheng (2002)[13], Schade, Arampatzis, Bruggemann (2005)[14], Linthorne (2012)[4]. In the purpose of selection in athletics some researches investigated relations between some antropologic dimensions and results in jumps, sprints and throws: Bavčević and al. (2008)[15], Zagorac and al. (2008)[10].

The problem of this research is looking into the kinematic factors that determine successfulness in the pole vault. The main objective of this research is analyzing the kinematic parameters and determining their influence upon the flexibility of pole vaulting results of the best European juniors, age 17–19.

Sample and Methods

Entity sample

The entity sample in this research consisted of the vaults made by 30 junior pole vaulters whose successful vaults were taped during the European Athletics Junior Championship in 2009. The examinees performed their vaults as a part of the qualifying competition before entering the finals, and during the final part of the championship. The examinees were 17 to 19 years old, and the range of their top results varied from 4.90 to 5.30 meters.

Kinematic parameters:

1	PSL	Penultimate step length
2	LSS	Last step velocity
3	LSL	Last step length
4	PSS	Penultimate step velocity
5	TOS	Take-off velocity
6	HDCMP	Horizontal distance between the take-off leg toes and the extreme point of the box at the moment of plant before the take-off moment
7	TLA	Trunk lean angle
8	TLMP	Trunk lean at the moment of plant
9	PLAP	Pole lean angle at the moment of plant
10	TOA	Take-off angle
11	DUGLT	Distance between the upper grip (of the fist) and take-off leg toes at the moment of take-off
12	BCMHT	Body CM height at the moment of take-off (H1)
13	MDCMB	Minimum distance between the centre of mass and plant box
14	TMDCMB	Time to achieve minimum distance between the centre of body mass and plant box
15	MPB	Maximum pole bend in %
16	TMPB	Time to achieve maximum pole bend
17	BRP	Backward body rotation after the moment of plant
18	MCMVV	Maximum body CM vertical velocity at the time of pole straightening
19	TUHR	Time of the upper hand release
20	DCMP	Distance between the centre of body mass and pole at the pole release moment
21	GH	Grip height
22	TAPR	Trunk angle at the moment of pole release in relation to the horizontal
23	TMCMH	Time to achieve maximum body CM height
24	ATL	Angle between the trunk and legs at the bar clearance moment
25	MCMH	Maximum body CM height

The analysis of the data was analysed using an Ariel Performance Analysis System (APAS).

Data analysis

The values of the kinematic parameters obtained during this research were processed via a descriptive analysis which were calculated in the following values: Arithmetic mean (Mean), Minimum value (Min), Maximum value (Max), Standard deviation (SD), Indicator of distribution asymmetry (skewnes), Indicator of elongation (kurtosis). The normality of the variable distribution was calculated via a Kolmogorov-Smirnov test, with the possibility of making an error of p=0–0.5. The influence of the predictor variables was carried through via a multiple regression analysis.

Results and Discussion

Table 1 shows the basic descriptive parameters. It shows the results of the 25 variables describing the important parts of the technique of pole vaulting athletic discipline of the 71 successful vaults achieved at the European Athletics Junior Championship.

Hence, the descriptive statistic parameters (arithmetic means, standard deviations, minimum and maximum results, skewnes and kurtosis) have been calculated.

A further analysis of the descriptive indicators, as well as the Kolmogorov-Smirnov test values, determined the normality of the distribution of all the kinematic variables, with the possibility of making an error of p= 0.05.

The value of the average maximum height of the body mass centre was 525 cm. One vault reached the maximum height of 556 cm, which is 26 cm above the official top height. The results presented in Table 1 show that the successful vaults included the shortening of the last step length, compared with the results of the penultimate step length. This is accordant with the previous researches which claimed that vaulters shorten their last step in order to prepare their body for the take-off. A comparison of the step length with the IAAF World Athletics Junior Championship data[9] shows that the medium value for the first three athletes was 2.06 meters. The results of the 71 vaults had an average value of 2.00 meters. In percentage, the length of the last step was 10.23% shorter than the length of the penultimate step. The medium step length of the three best pole vaulters at the IAAF World Athletics Junior Championship in 1986 was 2.08 meters[9], while McGinnis reports that non-top-quality vaulters have the medium stride length of 2.07 meters. This research achieved the medium value of 2.08 meters. The penultimate step velocity determined by measuring the average CM horizontal speed in time needed to make the penultimate step. The horizontal CM velocity in the penultimate step was between 8.2 m/s for the lowest height cleared and 9.3 m/ps for the top height of 5.30 meters cleared. These measured speeds are signif-

TABLE 1
DESCRIPTIV STATISTICS OF VARIABLES

Variables	N	X	Min	Max	Varia	SD	Skew	Kurt
PSL	71	208.64	198	218	19.89	4.46	–0.23	–0.09
LSS	71	8.31	7.9	8.9	0.04	0.19	–0.33	–0.52
LSL	71	189.25	178	201	30.13	5.49	–0.37	–0.63
PSS	71	8.4	7.9	8.8	0.04	0.21	–0.09	0.08
TOS	71	8.43	8.2	9.3	0.10	0.31	0.48	–0.79
HDCMP	71	351.22	330	366	52.13	7.22	–0.24	–0.15
TLA	71	10.02	6	12	1.74	1.32	–0.40	–0.07
TLMP	71	2.95	2	5	0.73	0.85	0.22	–1.25
PLAP	71	32.69	31	34	0.50	0.71	0.28	–0.57
TOA	71	17.53	16	21	1.85	1.36	0.62	–0.39
DUGLT	71	223.42	215	233	22.30	4.72	0.17	–0.93
BCMHT	71	104.9	92	111	12.25	3.50	–0.71	1.34
MDCMB	71	189.27	171	216	117.10	10.82	0.58	–0.24
TMDCMB	71	0.34	0.24	0.44	0.00	0.03	–0.38	1.34
MPB	71	26.94	22	34	7.65	2.77	0.84	0.87
TMPB	71	0.47	0.36	0.58	0.00	0.04	–0.69	1.64
BRB	71	0.58	0.52	0.72	0.00	0.05	0.97	1.53
MCMVV	71	0.58	0.48	0.72	0.00	0.05	0.66	0.36
TUHR	71	1.42	1.24	1.6	0.01	0.08	0.01	–0.32
DCMP	71	63.93	32	85	126.14	11.23	–0.70	0.54
GH	71	4.43	4.19	4.7	0.03	0.16	–0.30	–1.44
TAPR	71	50.85	36	76	116.50	10.79	–0.09	0.12
TMCMH	71	1.44	1.32	1.62	0.00	0.07	0.49	–0.18
ATL	71	123.35	108	168	202.86	14.24	1.72	2.76
MCMH	71	5.25	4.92	5.56	0.02	0.15	0.53	0.45

N – number of jumps, X – arithmetic mean, SD – standard deviation, Min – minimal result, Max – maximal result, KS – Kolmogorov-Smirnov test, Skew – coefficient of asymmetry, Kurt – coefficient of kurtosis icantly lesser than those recorded at the IAAF World Athletics Junior Championship in 1986, where the recorded velocity ranged from 9.3 mps to 9.8 mps. The last step velocity is the rate of the horizontal velocity during the last step. It is determined the same way as the penultimate step velocity. The trunk angle is the measure of the trunk lean angle in relation to the horizontal surface of the rum-up at the moment of planting the pole upon the take-off. A small angle means the vaulter is leaning backwards, while a 90° angle means he's completely upright. The average values of the trunk angle obtained during this research were 10°, which is in accordance with the results obtained by many other researches. The centre of body height at the moment of take-off equals to H1 in Hay's partial model (1993)[16]. The range of the achieved CM heights at the moment of take-off ranged from the minimum of 92 cm to 111 cm, with the medium value of 104 cm. The horizontal distance between the left leg thumb and the extreme point of the box at the take-off moment is measured in order to get an impression of the vaulters position at run-up, in relation to the box. The differences in parameters between various subjects can be explained with the different grip heights – the higher the grip, the vaulter will be more distanced from the box. There are cases in which a vaulter increases the grip height by moving his upper hand upwards the pole for »one grip« height, from one vault to another. The achieved medium value was 315 cm, which is approximately the same to the results obtained by Baković and Antekolović in 2012[17], and by Gross and Kinkel in 1987[18]. The pole angle at the moments of plant and take-off is the angle between the pole and the run-up. The pole angle is influenced by the grip height and by the anatomical stature of the vaulter. A good quality vault is characterized by an increase of this angle between the moment of plant and the moment of take-off, as the vaulter rises up to take-off. The average pole angle was 32°, with the maximum value achieved being 34°. The take-off angle is calculated by using the result vector of the CM speed at the moment of take-off. The angle between this vector and the horizontal line from the CM is the take-off angle. The average value of the take-off angle is 17.53°, with its minimum value of 16° and maximum value of 21°. The achieved average value is within the framework of the data obtained by other researchers. The center of mass height during take-off according to Hay is marked as H1. This parameter is influenced by the athlete body stature, as well as the body position during take-off. The vaulter with relatively higher center of mass position at take-off has more potential energy. The minimum CM distance from the box, together with the time of achieving this minimum, indicates the center of mass path during swingphase. The average Maximum pole bend value was 26%, with maximum measured value of 33%. This parameter is also influenced by the pole stifness. Pole release trunk angle is the angle between the trunk and the horizontal at the moment of pole release. The 90 degrees angle means that the vaulter's hips are directly above the shoulders at the moment of pole release. McGinnis (1987) reports the average trunk angle of 46.5 degrees in elite vaulters. The average value of this research was 50.85 degrees. Upper grip hand release time and the maximum CM height time aremeasured from the take-off point, with the value of 0.0 sec. The maximum value was 1.6 seconds with the average value of 1.42 sec.

TABLE 2
REGRESSION ANALYSIS RESULTS

Variables	β	p
PSL	0.03	0.39
LSS	0.21	0.02
LSL	0.02	0.59
PSS	0.14	0.03
TOS	0.32	0.00
HDCMP	–0.05	0.32
TLA	0.03	0.32
TLMP	–0.08	0.02
PLAP	–0.02	0.56
TOA	0.10	0.16
DUGLT	–0.02	0.79
BCMHT	0.06	0.53
MDCMB	0.02	0.71
TMDCMB	0.09	0.07
MPB	–0.10	0.18
TMPB	–0.10	0.03
BRB	0.03	0.57
MCMVV	0.11	0.00
TUHR	–0.06	0.22
DCMP	0.09	0.03
GH	0.10	0.09
TAPR	–0.23	0.00
TMCMH	–0.03	0.67
ATL	–0.02	0.66
ρ	0.98	0.00
δ	0.96	0.00

β – regression coefficient, ρ – multiple correlation, δ – coefficient of determination, p – level of significance

With the total of 24 predictor variables, we acceded to defining the influences upon the pole vaulting effective height. The correlation of the overall system of the kinematic variables and successfulness in pole vaulting, i.e. the coefficient of the multiple correlation, amounts to 0.98, which explains the mutual variability between the predictor system and the criterion variable being 96% (Table 2).

The statistic significance was expressed by 8 predictor variables.

Among the predictor variables, the take-off speed variable had the highest regression coefficient. The speed and the depth of the take-off significantly influence the technique of all the rest – forthcoming elements of the vault: the phases of hanging, swinging, grouping and stretching, as well as crossing the bar. Moreover, a satisfactory performance of the take-off determines the rhythm of the following parts of pole vaulting.

The speed of the last (LSS) and the penultimate (PSS) steps influences the ultimate pole vaulting height. The influence is positive and statistically significant. It's perfectly understandable that high vaults require an exceptionally high level of the vaulter body's movement speed in the last sequences of the run-up, and the principal tasks of this part are 1) achieving the top horizontal speed before reaching the end of the run-up, and 2) achieving the least possible loss in speed during the plant of the pole into the box. A continual acceleration in the last four strides is an indicator of a perfectly demanding skill in this part of pole vaulting (lowering the pole and planting it into the box). Hence, for example, Sergey Bubka (according to Petrov, 2004)[19] develops the speed before the take-off: four strides before the take-off (9.5 m/ps), two steps before the take-off (9.7 m/ps) and right before the moment of take-off (9.9 m/ps).

The trunk lean at the moment of planting the pole into the box (TLMP) is negatively related to the pole vaulting effective height.

If the vaulter is overtly inside or outside, a significant loss in the horizontal speed will occur, and the upper hand will block or prevent the vaulter from slight generation of the vertical velocity. Hence, the parameters such as the distance between the take-off spot and the extreme point of the box, the trunk lean, the time of contact with the ground at the moment of take-off and the horizontal distance between the upper hand and the front part of the take-off leg can help in indentifying the vaulter's body position during the moment of plant and the take-off moment. Finally, in order to ensure an effective transmission of body energy upon the pole, a vaulter has to retain a »tense musculature« as long as possible. McGinnis (1997)[5] believes that top-quality vaulters have more upright trunk at the moment of plant and take-off than lower-rank vaulters.

The total pole bending time and the the time of the whole vault is somewhat increased with the growth of the sports results (mostly due to the elastic work of the pole). However, the increase of time should be achieved not by application of softer and »slower« poles, but by grip increase and stronger twist of the stiffer poles, thanks to more active vaulter action. The hanging and second swing time are equal in most vaulters, the swing (swing shortening with acceleration) lasts longer, and the »grouping« is halfway shorter than the swing. The relation of extended swing and fast »grouping« is a sign of efficient swing and good vault quality. In less proficient vaulters the hanging-swing action is short, the extended swing – long and passive, the swing acceleration is also short and the »grouping« lasts longer.

The results of this discussion suggest that the faster pole bend eventually contrubutes better result efficiency (higher lift of jumper center of mass).

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UTJECAJ KINEMATIČKIH PARAMETARA NA REZULTAT SKOKA S MOTKOM VRHUNSKIH JUNIORA

SAŽETAK

Cilj rada bio je analizirati kinematičke parametre te utvrditi utjecaj tih parametara na rezultat u skoku s motkom. U ovom istraživanju uzorak entiteta činili su uspješni skokovi 30 skakača s motkom čiji su pokušaji bili snimljeni na Europskom juniorskom prvenstvu. Ispitanici su izvesli skokove u okviru eliminacijskog natjecanja za finale i skokove u finalnom dijelu natjecanja.. Starost ispitanika je 17–19 godina, a raspon njihovih najboljih rezultata kretao se od 4.90 m do 5.30 m. Rezultati regresijske analize pokazali su znatan utjecaj prediktorskih varijabli na efektivnu visinu u skoku s motkom. Najveći utjecaj na visinu centra mase tijela imaju varijable BO – brzina odraza, LSS– brzina zadnjeg koraka, PSS – brzina predzadnjeg koraka te TAPR– nagib trupa u momentu napuštanja motke. Manji ali ipak značajan utjecaj na rezultat u skoku s motkom imaju i varijable DCMP– udaljenost centra mase tijela u momentu napuštanja motke, te MCMVV – vrijeme opružanja motke. Generalno, informacije dobijene u ovom istraživanju ukazuju na znatan utjecaj kinematičkih parametara na rezultat skoka motkom, Može se dakle konstatirati da rezultatska efikasnost u skoku motkom je prvenstveno određena varijablama koje su definirane motoričkim sposobnostima kao i pokazateljima kojima je određena tehnika realizacije aktivnosti skoka. Varijable koje definiraju položaj tijela prilikom napuštanja motke (nagib trupa i udaljenost centra mase) u najvećoj mjeri određuju tehničku izvedbu skoka, dok su motoričkim sposobnostima najviše određeni parametri brzine zadnja dva koraka zaleta, brzine odraza i vrijeme opružanja motke.