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Differences in Some Kinematic Parameters between Two Qualitatively Different Groups of Pole Vaulters

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A B S T R A C T

The basic aim of this research was to determine the differences of kinematic parameters in two qualitatively different groups of young pole vaulters. With this purpose, a research was conducted in which the video records from a competition were acquired. The sample of entities (N=71) consisted of successful vaults of 30 pole vaulters, whose attempts were recorded at the European Junior Championship in Novi Sad, held on 23–26th July 2009. The examinees performed the vaults as a part of the elimination competition for the finals, and during the final part of the competition. The age of examinees was from 17 to 19 years, and the span of their best results was from 4.70 to 5.30 meters. The kinematic analysis was conducted according to the standards of APAS procedure (Ariel Performance Analysis System, USA), determining 25 kinematic variables necessary for further analysis. The entities (vaults) were divided into two categories (qualitative classes) based on the expert knowledge. Group 1 consisted of successful vaults up to 4.90 m (N=46), while group 2 consisted of successful vaults whose height was more than 4.90 m (N=25). The discrimination analysis determined the parameters differentiating the vaults of different quantitative classes. Also, it was confirmed that the result efficiency in pole vault was primarily determined by the variables defined by motor abilities, as well as the indicators determining the vault performance technique.

Key words: *kinematic parameters, pole vault, juniors, differences*

Introduction

Finding the adequate model of pole vault, in which the modalities of training process, as well as performance technique and demanding values that influence pole vault success are identified, is the main problem that sport coaches and biomechanicians have to deal with. The elite pole vault achievements depend on many factors, such as morphological characteristics and motor abilities. Also, the application of certain biomechanic models of vault technique elements realization would attribute to better result efficiency.

Because of the complexity of pole vault discipline, understanding its mechanics, in which several factors are performed in sequence and/or simultaneously, is the basis of good quality performance. These factors mostly refer to pole vaulter's speed, his kinetic or potential energy of and pole strain energy, force and torque that the vaulter applies, as well as pole design. Performance of vault with a flexible pole (fiberglass and carbon) was an enticement to a large number of research[1–26] with the aim of securing a complete analysis of this discipline for the researchers, coaches and athletes. These researches are often used in work with beginners, with the purpose of learning the elite technique.

In the sense of long term preparation of a vaulter, beginning from the development of motor abilities, as well as learning and acquiring the technique of pole vault, it is important to determine the state of achieved levels. If the kinematic parameters during pole vault performance are determined, a clear definition of the actual state, based on which the evaluation of validity of the technical level of a complex motor activity such as pole vault is performed, would be enabled. It is almost impossible to perform a fast and precise analysis of vault performance technique by experts and coaches using only the visual method. Therefore, the application of biomechanical systems is absolutely necessary so as to obtain reliable and

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precise information, which would serve as a model in further procedures of the training process. In pole vault practice, and in other sports activities, it is extremely important to collect and analyze the relevant parameters in elite pole vaulters, during competitive performance. Creation of the biomechanical samples of technical performance of elite juniors` vaults surely can serve as an ideal standard of comparison for the future vaulters – juniors on their path towards the realization of elite results in senior competition. Surely, a good education of coaches and athletes in the area of biomechanics and theory of training could attribute to more efficient and faster progress in achieving maximum elite results.

Biomechanicians and pole vault coaches often ask »Which is the most optimum model of pole vault technique? Can cooperation between biomechanicians and coaches improve the result of an individual, as well as their motor abilities, by applying new models of studying and teaching pole vault?« The insight into published works showed a generalization of pole vault model technique. In practice, this means the acquisition of technique that was acquired by most vaulters, regardless of the fact if this model was appropriate for the individual. Every elite pole vaulter and coach has his own training philosophy, although many experts do not approve of it. Such philosophies are evaluated depending on the success of the individual.

The most widely accepted division of pole vault by coaches and experts is the seven phases division: run up, transition with hand lifting in the last three steps, take off, which includes pole plant, swing phase, nesting, inversion position, and clearing the bar. However, this division of movement differs from author to author in the area of mechanical approach. Hay shaped the pole vault in which the total height of vault was divided into four levels[27]. This model was useful in identifying certain basic performance factors influencing these height divisions, such as morphology and position of the vaulter's body at H1, vertical speed at pole release at H3, and the position of the vaulter's body in the free flight phase at H4. Also, the pole length and the amount of potential energy that is transferred to the vaulter from the pole during pole release can influence the H2 part of the height. Lately, the pole vault model was shaped using the energetic approach that includes the interaction between pole and vaulter[28–30]. Regarding the fact that the best European junior vaulters (representatives of leading pole vault »schools«: German, Russian, French, Polish…) were recorded with the aim of collecting data for this research, the question was: which school would prove to be dominant? Which parameters would contribute to the definition of pole vault success, and which kinematic parameters would be most successful in differentiating the successful ones from less successful entities? The answers to these questions would contribute to the better understanding of this athletic discipline and would fill in the knowledge that would enable more efficient managing of the process of long term preparation of pole vaulter.

Sample and Methods

Sample of entities

The sample of entities in this research consisted of successful vaults of 30 junior pole vaulters, whose successful vaults were recorded at the European Junior Championship, held on 23–26th July 2009 in Novi Sad. The examinees performed the vaults as a part of the elimination competition for the finals, and during the final part of the competition. The age of the examinees was from 17 to 19 years, and the span of their best results was from 4.70 to 5.25 meters.

The entities (vaults) were divided into two categories (qualitative classes) based on the expert knowledge (elite biomechanicians and pole vault coaches). The experts considered that the qualification norm of 4.95 m was the result that divided the vaulters into two categories: more successful and less successful. The experts' opinion was that in achieving certain levels of pole vault results the certain values of kinematic parameters were also responsible.

The entities (vaults) were divided into two categories used in discrimination analysis:

G1 – group of vaults up to 4.90 m;

G2 – group of vaults over 4.90 m.

Collecting video records used in kinematic analysis

Camera 1 Camera 2 (position of cameras at the height of 1.6 m)

Two Panasonic S-VHS, W-M95 video cameras were used in recording the pole vault competition. The speed of the camera aperture was set to 1/500, with the opened focus. Figure 1 shows the position of cameras.

The optical axis of first camera was set at the right angle to the movement direction, and the distance was 1 m from the end of the box. Distance between the camera 1 and center of the path was 25 m. The camera was set to the height of 1.6 m. The focus of camera 1 was the last step,

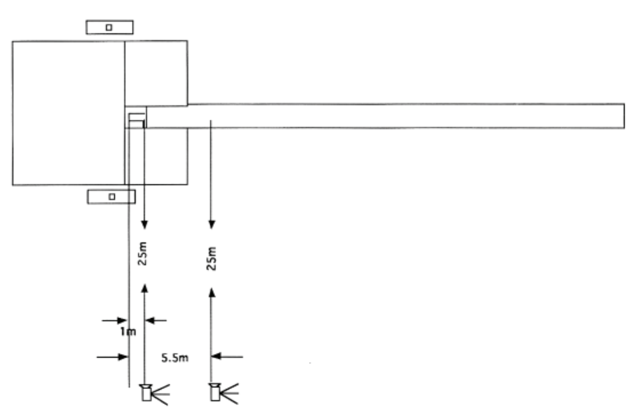

Fig. 1. Position of cameras in relation to the vaulting area.

as well as all the phases from pole plant until take off. The optical axis of camera 2 was set at the right angle to the movement direction, and the distance was 5.5 m from the end of the box.

The distance between Camera 2 and the end of the box was also 25 m, while the distance from the ground was also 1.6 m. Camera 2 was focused on recording the last four steps before takeoff and pole plant phase. The video calibration was performed with the help of black pole with white markers. The calibration was performed for the vertical and horizontal directions before and after the recording. The data on the horizontal and vertical speed were obtained using the APAS system. The filtered information was transferred into an Excel document. Twenty five parameters, referring to the body position and time of performing pole vault phases, were calculated.

Group of variables

Data analysis

The values of the kinematic parameters recorded at the vaulter's left sagittal body plane at the run up phase (recorded with 1st camera) in 2D system and the vaulter's left and right sagittal plane during the pole bend phase, straightening and release and bar clearance (recorded with 2nd camera) in 2D system, collected in this research, were processed using the descriptive analysis in which the following values were calculated (Table 1):

– Arithmetic mean (X)
– Minimum value (Min)
– Maximum value (Max)
– Standard deviation (Std. Dev.)
– Indicators of distribution asymmetry (Skewness)
– Elongation indicator (Kurtosis)

The discrimination analysis was used to determine the difference between the group of entities and the contribution of kinematic variables to the difference. The basic descriptive variables parameters were calculated for each group (arithmetic mean and standard deviation) as well as the parameters of discrimination analysis.

The level of statistical significance was set to p=0.05. The statistical analysis was conducted using the Statistica 7.1 software program.

TABLE 1
DISPLAY OF POLE VAULT KINEMATIC PARAMETERS

Nr.	Abb.	Description of variables	Measuring unit
1.	PSL	Penultimate step length	cm
2.	LSS	Last step speed	m·s⁻¹
3.	LSL	Last step length	cm
4.	PSS	Penultimate step speed	m·s⁻¹
5.	SCMTO	Speed of body mass center after take off	m·s⁻¹
6.	HDCMTT	Horizontal distance between take off leg toes and the end point of box at the moment of leg setting before takeoff moment	cm
7.	TLA	Trunk lean angle	°
8.	TLPP	Trunk lean at the moment of pole plant	°
9.	PLAPP	Pole lean angle at the moment of pole plant	°
10.	TOA	Take off angle	°
11.	DUFFLTO	Distance between upper fist and fingers of take off leg at moment of take off	Cm
12.	HBCMTO	Height of body mass centre at take off moment (H1)	Cm
13.	MDCMB	Minimum distance between body mass centre and plant box	Cm
14.	TMDBMB	Time of achieving minimum distance between body mass centre and plant box	S
15.	MPB	Maximum pole bend %	%
16.	TMPB	Time of maximum pole bend	S
17.	BRB	Body rotation backwards from the moment of pole plant	°
18.	TPS	Time of pole straightening	S
19.	TUFR	Time of upper fist release	S
20.	DBMPR	Distance between body mass centre and pole at the moment of pole release	Cm
21.	GH	Grip height	Cm
22.	TLPRH	Trunk lean at the moment of pole release regarding the horizontal	°
23.	MHBCM	Maximum height of body mass centre	Cm
24.	TMCMH	Time of achieving maximum body mass centre height	S
25.	ATLPC	Angle between trunk and legs at the moment of pole clearing	°

Results and Discussion

Differences of 2D kinematic parameters variables between entities of different qualitative classes

Based on the effective vaults heights, the entities were divided into two groups. The first group of entities consisted of vaults up to 4.90 m, second group of vaults over 4.90 m. The entities were grouped according to the values defined by the expert knowledge. Vaults of heights up to 4.90 m were characterized by a very good quality of motor status and kinematic indicators of pole vault realization. On the other side, the vaults whose height was more than 4.90 m were characterized by an elite level of all the indispensable pole vault components in the observed variables (Table 2).

TABLE 2
DISPLAY OF THE BASIC DESCRIPTIVE PARAMETERS OF KINEMATIC VARIABLES FOR THE GROUPS OF ENTITIES (G1, G2) AND RELATED F AND DF VALUES

Variables N= 71	G1 (N=46)		G2 (N=25)		F	p	Df
	$\overline{X}$	SD	$\overline{X}$	SD			
PSL	207.63	4.59	210.52	3.57	0.59	0.45	–0.12
LSS	8.28	0.13	8.41	0.14	3.34	0.02	–0.37
LSL	189.02	5.83	189.68	4.87	2.02	0.16	–0.02
PSS	8.22	0.14	8.49	0.14	3.07	0.03	–0.41
SCMTO	8.20	0.16	8.47	0.17	4.30	0.01	–0.58
HDCMTT	348.73	6.57	345.00	6.08	0.08	0.78	–0.20
TLA	10.28	1.25	6.00	1.32	1.47	0.23	0.10
TLPP	3.13	0.88	2.64	0.70	2.56	0.12	0.11
PLAPP	32.56	0.71	32.00	0.64	0.55	0.46	–0.09
TOA	16.84	0.84	18.80	1.22	3.71	0.02	–0.36
DUFFLTO	220.76	3.16	228.32	2.77	2.61	0.01	–0.45
HBCMTO	103.20	2.90	108.04	2.01	3.35	0.00	–0.34
MDCMB	186.52	8.86	194.32	12.37	2.40	0.06	–0.14
TMDCMB	0.35	0.02	0.32	0.03	1.21	0.09	0.13
MPB	25.65	1.91	29.32	2.52	2.21	0.05	–0.31
TMPB	0.48	0.03	0.47	0.04	1.96	0.17	0.04
BRB	0.59	0.04	0.57	0.03	0.00	0.98	0.09
TPS	0.59	0.05	0.57	0.04	0.24	0.52	0.06
TUFR	1.42	0.06	1.42	0.09	0.70	0.46	–0.02
DBMPR	62.58	12.46	66.41	8.16	2.03	0.02	–0.06
GH	4.40	0.17	4.55	0.12	3.59	0.06	–0.11
TLPRH	34.89	9.40	36.12	8.57	0.83	0.37	0.24
TMCMH	1.43	0.07	1.44	0.04	0.49	0.28	–0.02
ATLPC	125.82	15.76	118.80	9.60	0.33	0.57	0.09
MHBCM	5.16	0.08	5.40	0.10	0.59	0.45	–0.12

$\overline{X}$ – arithmetic mean, SD – standard deviation, F – value based on which the difference significance was tested, (p) – error with which the hypothesis on the existence of statistically significant difference was accepted, Df – correlation of variables and discriminative function

Analysis of arithmetic means of variables between the groups shows the difference in most of the observed variables. The differences in maximum pole bend (MPB), trunk lean at the moment of pole release (TLPRH), take off angle (TOA), trunk angle at the moment of release (TLA), speed of body mass center after takeoff (SCMTO), speed of penultimate and last step (LSS and PSS) and grip height (GH) were especially emphasized. The differences were noted in the maximum body mass centre distance from box after takeoff (TMDCMB), time of achieving this distance (TMDCMB), and the height of body mass centre (HBCMTO) variables.

The detailed inspection of results of arithmetic means between the groups shows that higher speed of last and penultimate step, faster take off, higher take off angle of centre of mass, as well as the higher position of body mass centre, were necessary in achieving better results in pole vault. Also, faster take off, greater pole bend and greater centre of mass horizontal distance from the box was indispensable. Many researchers confirmed these conclusions in previous researches[31,32].

The canon discrimination analysis determined a significant difference between the groups of results up to 4.90 m and those over 4.90 m in the area of kinematic variables, with the coefficient of canon discrimination of 0.93 (Table 3). In the process of determining the individual attribution of each variable to the difference between the groups, a statistically significant contribution of eight variables was determined: LLS – last step speed, PSS – penultimate step speed, SCMTO – speed of body mass center after takeoff, TOA – take off angle, DUFFLTO – Distance between upper fist and fingers of take off leg at moment of take off, HBCMTO – height of body mass centre at the moment of take off, MPB – maximum pole bend in % and DBMPR – distance between body mass centre at the moment of pole release. Since only two groups of entities participated in the research, only one discriminative function was obtained.

The detailed analysis of discriminative function structure showed which variable was most important in groups' differentiation. The difference between the groups was mostly contributed by the speed of centre of body mass after takeoff (–0.58), height of grip on the pole at the moment of take off (–0.45) and penultimate step speed (–0.41) variables. These variables significantly correlated with the discriminative function and were joined by the last step speed (–0.37), height of body mass centre at moment of take off (–0.34), take off angle (–0.36) and maximum pole bend (–0.31) variables.

Based on the Mahalanobis square distances and the belonging F – values, the differences between the group centroids were confirmed. Insight into Table 3, which enables bringing conclusions on the p=0.01 level of error, proves that these differences were statistically significant. (Table 3)

TABLE 3
DISCRIMINATIVE FUNCTION

F	λ	Rc	Wilks' λ	χ^2	df	p
1	7.069278	0.935988	0.12392	117.975	25	0.00

Eigen-value (λ) – the characteristic value of discriminative functions, (Canonic R) – coefficients of cannon correlation (discrimination), values of Wilks lambda (Wλ), the percentage of the explained variance (λ%), Chi – square test (χ^2), df – number of degrees of freedom, p – level of significance of discriminative function

Table 3 shows the characteristic values of the discriminative function (λ), canon correlation (Rc), Wilks' Lambda, χ^2- test, degrees of freedom (DF) and level of significance (p).

The obtained discrimination function was significantly better in differentiating better vaulters from the lower quality ones on the 0.01 level of significance. With an extremely high canon correlation (0.93), it was possible to conclude that 25 kinematic variables were successful in differing the groups of entities. (Table 4)

TABLE 4
POSITION OF GROUP CENTROIDS ON THE DISCRIMINATIVE FUNCTION

Group	DF
G_1:1	1.9369
G_2:2	–3.5640

Considering the fact that the G1 group was positioned on the positive pole and the G2 group on the negative pole of the discriminative function, the statistically significant correlations with the variables had negative sign, and it can be concluded that group G2 was better than G1 in the following variables: last step speed (LSS), penultimate step speed (PSS), speed of body mass center after takeoff (SCMTO), take off angle (TOA), distance between upper fist grip and take off leg toes at the moment of take off (DUFFLTO), height of body mass centre at the moment of take off (HBCMTO), maximum pole bend in % (MPB) and distance between body mass centre and pole at pole release moment (DBMPR).

This research offered a number of variables which differed the groups of entities (higher from lower quality) in the 2D area. After conducting the result analysis on the sample of pole vaulters, the H hypotheses could be accepted and it could be determined that there were statistically significant difference in observed variables between higher and lower quality pole vaulters.

Also, it was confirmed that the result efficiency in pole vault was primarily determined by the variables which were defined by motor abilities, as well as indicators which determine the pole vault technique.

Conclusion

The basic aim of this research was to determine the parameters differentiating vaults of different quantitative classes.

The sample of entities was represented by 30 elite juniors, whose vaults were recorded at the European Junior Championship in 2009. In total, 71 successful vaults were analyzed. The age of examinees was 17 to 19 years.

The analysis of descriptive parameters showed that all the variables had optimum distribution.

The obtained discriminative analysis values showed that one of the set aims of this research was fulfilled – the attempt of determining the possible differences in kinematic parameters. Also, this research offered a number of variables which differed the groups of entities. After conducting the result analysis using the sample of pole vaulters, the existence of statistically significant difference in the observed variables between higher and lower quality vaulters could be confirmed.

Generally speaking, the information obtained in this research indicated the significant influence of kinematic parameters on the pole vault result, while the results suggested a differentiation of groups of entities.

It can be concluded that the result efficiency in pole vault was primarily influenced by the speed parameters (last two run up steps speed, speed of body mass center after takeoff), as well as indicators that determined the vault activity realization technique.

The variables defining the distance between body mass centre and pole at the moment of pole release, take off angle, maximum pole bend, grip height, as well as body mass centre height at the moment of take off largely determine the technical vault performance. All the mentioned variables largely differentiated higher from lower quality pole vaulters.

The obtained results were in concordance with the scientific knowledge on the influence of kinematic parameters on pole vault result and they enable better understanding of the mentioned kinematic factors which determine efficient pole vault as a whole.

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RAZLIKE U NEKIM KINEMATIČKIM PARAMETRIMA IZMEĐU DVIJE KVALITATIVNO RAZLIČITE SKUPINE SKAKAČA S MOTKOM

SAŽETAK

Osnovni cilj ovog istraživanja bio je utvrditi razlike u kinematičkim parametrima kod dvije kvalitativno različite skupine mladih skakača s motkom. S tim ciljem provedeno je istraživanje za koje su pribavljene video snimke s natjecanja. Uzorak (N=71) sastojao se od uspješnih skokova tridesetoro skakača s motkom, čiji su pokušaji snimljeni na Europskom juniorskom prvenstvu u Novom Sadu, koje se održalo od 23. do 26. srpnja 2009. godine. Skokovi su izvođeni kao dio eliminacijskog natjecanja za finale te tijekom zadnjeg dijela natjecanja. Dob skakača je između 17 i 19 godina, a najbolji rezultati kreću se između 4,70 m i 5,30 m. Kinematička analiza provedena je prema standardima procedure APAS (Ariel Performance Analysis System, SAD) i tim je putem utvrđeno 25 kinematičkih varijabli nužnih za daljnju analizu. Entiteti (skokovi) podijeljeni su u dvije kategorije (kvalitativne klase) na temelju stručnog znanja. Skupina 1 sastojala se od uspješnih skokova do 4,90 m (N=46), dok se skupina 2 sastojala od uspješnih skokova visine iznad 4,90 m (N=25). Diskriminacijskom analizom utvrđeni su parametri prema kojima se razlikuju skokovi različitih kvantitativnih klasa. Osim toga, potvrđeno je da učinkovitost rezultata u skoku s motkom prvenstveno određuju varijable vezane uz motoričke sposobnosti, kao i indikatori tehnike pri izvedbi skoka.