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Influence of Kinematic Parameters on Pole Vault Result in Top Junior Athletes

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A B S T R A C T

The aim of the research was to ascertain the level of correlation between some kinematic parameters and the result success in the pole vault, using the sample of the best European female junior athletes. A set of 11 kinematic parameters has been applied, according to the McGinnis[1] model, representing a predictor assemblage of variables. The maximum height vaulted presented a criterion variable. The research was conducted at the European Junior Athletics Championships in 2009. The entities were represented by the vaults in the final part of the competition. A general hypothesis of achieving a positive correlation between the system of predictor variables and the criteria had been set, and later confirmed. The results of the pole vault regression analysis confirmed the multiple correlations between the two groups of variables. The greatest influences on the prediction of pole vault success, regarding all the analyzed kinematic parameters, were the following variables: maximum pole bend, last stride speed and time of pole bend. The results were as expected, and can be used in kinesiology practice, especially during the technique learning process in young pole vaulters, but also in development of motor abilities relevant for success in this track and field discipline.

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

Introduction

Pole vault is one of the most attractive and most complex track and field disciplines. This discipline consists of jumping over a bar, achieved with the help of a pole. The evolution of pole vault technique depended mostly on the type of pole used (wood, bamboo, metal and fiberglass). At the end of the 20th century the pole vault experienced a world expansion in female athletes as well. Surely, better media coverage of athletic events during the great sports manifestations, such as the Olympic Games and the World and European Championships, had a positive influence on the growth of the popularity of this discipline. This can also be attributed to the fact that world record had been broken many times in the last two decades, both in male and female competition. The pole vault is a technically highly demanding motor activity, and a great deal of practical and theoretical information has been gathered by the coaches and biomechanics experts. Finding the pole vault determining and influential factors was the object of many biomechanical researches. The application of the kinematic measure system is an infallible method of determining the training condition, as well as the attainment of the vaulting technique in a pole vaulter. A detailed insight into the movement structure can be attained by the calculation of different kinematic parameters. The biomechanical analysis is a basic part of the scientific and the practical approach to the analysis of a certain athletic discipline.

In practice, minor differences in performing the motor stereotypes, that are crucial to the result, cannot be ascertained by the visual inspection of an expert. Besides the high temporal resolution of recording the signals, the biomechanical measuring enables the exact, quantified analysis, which is the standard in programming and controlling the training process. The sport techniques optimization process is based on the results of a certain biomechanics procedure. To apply the results and information attained by biomechanical analysis into the training process it is essential that the coaches and the athletes posses a certain level of education[2].

A need for the engagement of field experts is strongly felt, in order to have fast feedback for the coaches and the athletes, which could be successfully implemented into the training process.

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In general, the biomechanical analysis of pole vault is occasionally conducted in the projects related to great athletic manifestations (World Championship, European Championship, Olympic Games), where the characteristics of the best pole vaulters are ascertained.

The processes of finding pole vault success determining factors have been the subject of many researches. These researches can be categorized as following: 1) mathematical models and computer simulation and 2) kinematic and/or kinetic analysis of the observed pole vaulters. The aim of the first method is pole vault shaping and predicting. The advantage of second method is in measuring the real vault data, but on the other hand it is limited by the invasive nature of the materials used in research and evaluation of the competitive vault performance.

Steben (1970)[3] performed a research using eight junior athletes of a certain American college, and measuring 150 vaults. The following parameters were measured: speed prior to take-off, take-off speed, take-off leg contact time, left arm bending angle at the moment of take-off. The medium vaults value was used as a criterion variable. The gained results showed that the take-off speed was the most important independent variable.

Angulo-Kinzler, Kinzler, Ballius, Turro and Escoda (1994)[4] explained the general aspect of the pole vault biomechanics and presented the 3D analysis of the eight top ranked pole vaulters at the 1992 Barcelona summer Olympic Games. The authors concluded that all vaulters have shortened the step and had low positioned center of body mass while leaning at the penultimate step foot.

McGinnis, Lawrence, Bergman (1986)[5] consider that the coaches should take into consideration the vaulteržs take-off technique, so as to enable the best vault performance in the following phases (swing and rock back). Zagorac, Retelj, Katić (2008)[6] conducted a research with the aim of ascertaining the pole vault kinematic parameters in a certain Croatian pole vaulter. The regression analysis results showed that only one parameter (maximum pole bend) had a positive influence onto the criterion variable (maximum body center of mass height in a vault). In the study named »Biomechanical pole vault analysis« Schade, Arampatzis, Bruggemann (2000)[7] researched the behavior and the practical application of three criteria in elite pole vaulters, determined the influence of the start conditions and vaultersž behavior during pole vault phase, taking the result into consideration.

Arampatzis, Schade and Bruggemann, (1997)[8] conducted an extensive research with the following aims: (a) to research the athlete – pole interaction and the possibilities of the athletežs use of the pole elasticity, with the help of muscles and (b) developing the performance criteria during the vaulter – pole interaction.

Takamatsu, et al. (2000)[9] conducted an experiment whose aim was to research the flow of mechanical energy between the vaulter and the pole. The vaults were performed by vaulting from a special take-off platform. The kinetic energy of the vaulter and the pole energy was calculated in the same manner as some kinetic parameters. The aims of the project developed by Julien Frere, Maxime L'Hermette, Jean Slawinski and Claire Tourny-Chollet were collecting and modernizing the pole vault mechanical data, through presentation of a new model, including all the phases, and by emphasizing the performance factors of every phase, within the kinematic, energetic and kinetic processes.

Some studies analyzed the pole vault predicting success of certain basic and specific motor variables[10,11].

Other authors[4,12–14] were oriented towards the research by studying the Hay (1978)[15] partial heights model. This model could be clear and used as the selective subcategory of the maximum center of body mass height, but it depends on the technique and the anthropometric characteristics of the vaulter. Arampatzis et al. (1997)[8] defined three pole vault initial conditions parameters, as well as the vaulter's behavior during »pole phase« (vault phase after take-off and pole release).

Only one study dealt with the influence of pole carrying on the run-up coordination (Frere et al., 2009)[16]. This is surprising, since the pole run-up knowledge directly influences the training programs and consequently, the possibility of performance improvement by run-up improvement. Since 1975, the measuring of male pole vault run-up velocities have been performed relatively often, and evaluated every 3 to 5 years[17]. This measuring showed that there was no correlation between the competitive performance and the run-up speed in elite vaulters, and today this correlation became a standard in individual run-up speed evaluation.

The most popular and the most accepted theoretical model for pole vault technique is the Hay model, presented in a book called *The biomechanics of Sports Techniques* (1993)[18], in which four key phases of the pole vault are identified:

1. run-up phase
2. plant and take-off phase
3. swing phase (pole supported jump phase)
4. free flight and landing phase (crossing the bar)

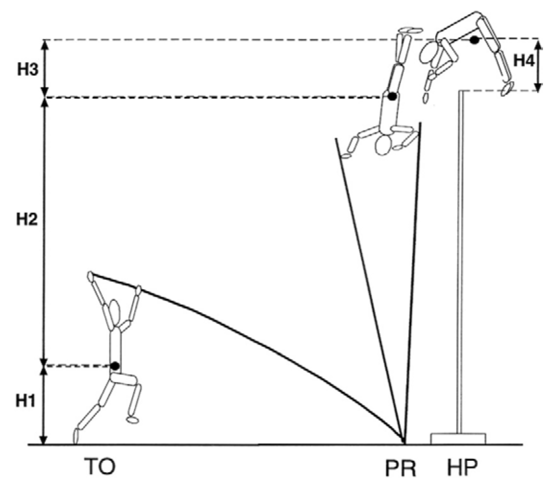

Fig. 1. The representation of partial heights (H1, H2, H3 and H4), according to Hey.

Sample and Methods

Entity sample

The entity sample of this research consisted of the successful vaults of 27 female pole vaulters whose vaults were recorded at the European Junior Championship in 2009. The examinees performed the vaults as a part of the qualifaction competition for the finals and the finals itself.

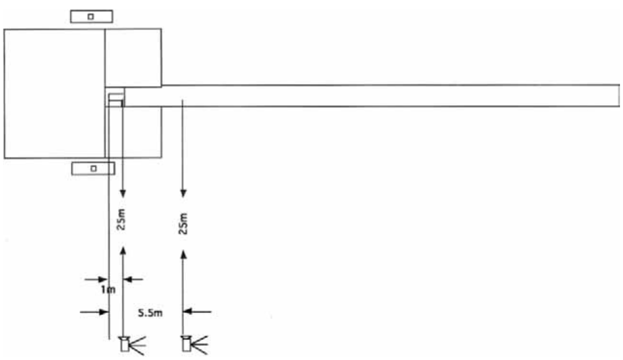

Fig. 2. The position of the cameras in relation to the vaulting area.

Collecting video data used in kinematic analysis

Two Panasonic S-VHS, W-M95 cameras have been used in filming the pole vault competition. The speed of the camera shutter was set at 1/500, with an opened focus. Figure 2 shows the position of the cameras.

The first camera was placed at the position where the optical axis cuts the plane of movement at the right angle, and the distance was 1 m from the end of the box. The distance between Camera 1 and the middle part of the track was 25 m. The camera was set at the height of 1.6 m. Camera 1 was focused on the filming of the last stride, as well as all the phases from the pole plant to the take-off.

Camera 2 was placed at the position where the optical axis cuts the plane of movement at the right angle, and the distance was 5,5m from the end of the box. The distance between Camera 2 and the middle part of the track was 25 m as well, and the distance from the ground was also 1.6 m. Camera 2 was set to film the last 4 strides before the take-off and the phases of plant.

Video calibration was performed using a black pole with white markers. The calibration was performed for the vertical and the horizontal directions before and after the filming.

The value of kinematic parameters collected in this research was processed using a descriptive analysis, calculating the following values: Arithmetic mean (Mean), Minimum value (Min), Maximum value (Max), Standard deviation (Std. Dev.)

The normality of variable distribution was calculated using a Kolmogorov-Smirnov test, with a conclusion error level of p=0.05.The influence of predictor variables on the criterion variable will be ascertained by the application of multiple regression analysis. As a part of multiple regression analysis the following parameters will be calculated:

The level of statistic significance set at level p=0.05

The statistic analysis will be conducted using Statistica 7.1 program package.

The variable assembly

The maximum vaulted height in the pole vault discipline will represent the criteria variable of this research (MVS).

The kinematic parameters will represent the group of predictor variables:

PSL	Penultimate stride length
PSS	Penultimate stride speed (m/sec.)
USL	Ultimate stride length
USS	Ultimate stride speed (m/sec.)
HDCMP	Horizontal distance between take-off leg toes and the extreme point of the box at the moment of plant before take-off moment
HGHTO	Upper hand grip height before the take-off moment
MPB	Maximum pole bend (%)
MDCMB	Minimum distance between centre of mass and plant box
TMPB	Time of achieving maximum pole bend
PST	Pole straightening time
MCMH	Maximum body CM height
TMCMH	Time of achieving maximum body CM height

Results and Discussion

Table 1 presents the four partial heights defined according to Hey. Therefore, the average values of all 34 pole vaults are presented. From the overall number of 34 vaults one athlete achieved the highest value in the criteria variable (maximum center of body mass lift) above 4.40 m, while the CM height of 3.85 was recorded in one vault.

The take-off was defined up to 0.0 seconds. The maximum pole bend (defined at the sequence when the pole tendon reached the shortest length) was achieved in the time interval of 0.42–0.60 seconds. The time of achieving the maximum center of body mass height was 1.36 s, in average. It was expected that the lowest vault height will consume the least time to end the vault. Only in one unsuccessful vault an athlete achieved a negative value for the time between the pole release and the highest CM position. The vaulter had a »negative flight« phase because she released the pole before the CM reached the highest point. In short, it was not possible to achieve higher CM height if there was no support from the pole.

Achieving the maximum horizontal speed is the aim of a run-up, as well as achieving the optimum take-off body position. Four parameters (Table 1) used in a research by McGinnis (1987)[1] were measured for the description of the run-up phase. The length of the penultimate stride is defined as a horizontal distance between the front part of the left foot in contact with the ground and the front part of the right foot at the time of the contact with the ground. The maximum penultimate stride length measured was 203 cm, and the minimum 169 cm. The arithmetic mean was 183 cm. In male juniors these values are higher; the average stride length at the World Junior Championship in 1987 was 208 cm[20]. The research showed that the pole vaulters shorten the last stride in order to achieve the take-off position.

The medium last stride length was 185 cm. The horizontal body CM speed at penultimate stride was on average 7.9 m/s. The speed of the last stride was not considerably smaller than in the penultimate stride, 7.79 m/s, meaning that there was no greater loss of speed while achieving the take-off position.

The horizontal distance between the take-off leg and the front edge of the plant box was measured in order to define the vaulters position on the run up area, in relation to the box. The medium value of this distance was 320 cm.

The angle of the pole during the plant and the take-off was measured as an angle between the pole and the run-up area. The pole angle also depends on the grip height, as well as on the morphological characteristics of the vaulter. The average of this angle in this research was 33 degrees.

Maximum pole bend is a measure of bending the pole, defined in percentage. The calculation is:

Variable	
PSL	Penultimate stride length
PSS	Penultimate stride speed (m/sec.)
USL	Ultimate stride length
USS	Ultimate stride speed (m/sec.)
HDCMP	Horizontal distance between take-off leg toes and the extreme point of the box at the moment of plant before take-off moment
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LP – length of pole, SL – shortest length

This is a measure showing the bend of the pole during the vault. This parameter is also influenced by the stiffness of the pole. McGinnis, (1987)[1]; Gross and Kunkel, (1986)[19] determined that the maximum pole bend was 26–33 percent. Female pole vaulters of this research achieved maximum pole bend ranging from 19 to 33 percent. The time achieved in maximum pole bending was 0.42 to 0.60 sec. The time of pole straightening was 0.48 to 0.66 sec. Top male junior athletes achieved similar values (0.54 sec for bending)[1,4,20].

Table 2 shows the regression analysis results (11 kinematic parameters with a criterion – maximum CM height over the bar). A significant multiple correlation has been achieved (R= 0.71), with the determination coefficient of R2 = 0.51. The highest predictor value in relation to the criteria variable is the maximum pole bend parameter, then the LSS variable – last stride speed, time of pole bend and the time of achieving the maximum center of body mass height. All the above mentioned beta-re-

TABLE 1
BASIC STATISTIC VARIABLE PARAMETERS

Variable	N	Min.	Max.	X	SD
HDCMP	34	272	340	320	12.84
PSL	34	169	203	183	9.33
USL	34	165	200	175	10.26
PSS	34	6.70	8.70	7.90	0.61
USS	34	6.30	8.70	7.78	0.46
HGHTO	34	205	266	235	12.26
TMPB	34	0.44	0.60	0.50	0.04
PST	34	0.48	0.68	0.57	0.05
MDCMB	34	1.10	1.35	1.26	0.08
TMCMH	34	121	178	140	9.79
MPB %	34	19	32	25	3.23
MCMH	34	385	440	410	18.24

N – number of jumps, X – arithmetic mean, SD – standard deviation, Min – minimal result, Max – maximal result

TABLE 2
REGRESSION ANALYSIS

Variable	β	p
HDCMP	–0.17	
PSL	0.35	x
USL	0.09	
PSS	–0.08	
USS	0.46	x
HGHTO	0.04	
TMPB	–0.40	x
PST	0.12	
MDCMB	–0.43	x
TMCMH	0.05	
MPB %	0.49	x
ρ	0.71	0.05
δ	0.51	0.05

x – significant beta regression coefficients, β – regression coefficient, ρ – multiple correlation, δ – coefficient of determination gression coefficients are significant on the 0.05 level of significance.

Pole bend occurs under the influence of the forces acting alongside the pole tendon axis (centrifugal and inertial force), appearing during the acceleration of the centre of gravity swing lift, directed sideways – opposite of the acceleration. The greatest pole bend is achieved when the vaulter's body is in the horizontal position, parallel to the ground. With augmentation of pole bend, the elastic forces activate in the pole, increasing with the bending of the pole. At the moment of the maximum pole twist, the bending forces and the elastic forces are equal, but since the vaulter's center of body mass, moving alongside the trajectory line, is coming closer to the axis of the pole, and the acceleration of his movement becomes negative, the pressure onto the pole decreases, and it starts to straighten. The period of strong action lasts from the moment of body straightening upwards alongside the pole, until the moment of pole release with right hand, after the pushing action. The period consists of the body straightening phase, twist pulling and pushing on the pole. Its efficiency is greatly influenced by the successful performance of the previous swing action period and usage of the straightening pole lifting strength. At the closing moment of grouping on the pole, and the beginning of the body straightening, the CM speed should not be lesser than the pole straightening speed. Trunk and legs lifting speed is up to 6 m/s[10]. During the vaulter straightening time, the pole has the greatest speed of upright straightening, so the combination of pole lifting force and vaulter's body straightening results in acceleration of the movement, achieving the greatest vaulter's vertical lifting speed. Surely, raising the pole grip is an indispensable condition for the greater pole bend and consequently, achieving high results. However, this should take place gradually, keeping in mind the parallel development of all the relevant motor abilities that would ensure the successful and efficient realization of this, above all, complex motor activity. Parallel optimization of the development of the »conditioning« elements, as well as the elements of pole vault technique, and the control of the applied methods efficiency in the overall development of young female pole vaulters is a way to ensure the efficiency of the process.

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UTJECAJ KINEMATIČKIH PARAMETARA NA REZULTAT SKOKA S MOTKOM VRHUNSKIH JUNIORKI

SAŽETAK

Istraživanje je provedeno s ciljem da se ustanovi stupanj povezanosti između nekih kinematičkih parametara i rezultatske uspješnosti u disciplini skok s motkom na uzorku najboljih europskih juniorki. U tu svrhu primjenjena je baterija od 11 kinematičkih parametara po modelu McGinniss i to je predstavljalo prediktorski skup varijabli. Maksimalno preskočena visina u skoku s motkom predstavljalo je kriterijsku varijablu. Istraživanje je provedeno na Europskom juniorskom prvenstvu 2009. Entitete su predstavljali skokovi finalnog dijela natjecanja. Postavljena je i generalna hipoteza da će se ostvariti pozitivna povezanost između sistema prediktorskih varijabli i kriterija, koja je i potvrđena. Rezultati regresijske analize skoka s motkom potvrdili su da postoji multipla povezanost između dva skupa varijabli. Najveći utjecaj u prognozi uspjeha u skoku s motkom od analiziranih kinematičkih parametara imaju varijable maksimalno savijanje motke, brzina zadnjeg koraka, vrijeme savijanja motke i vrijeme potremalne visine tijela. Rezultati su očekivani i logični te mogu poslužiti u kineziološkoj praksi, naročito u procesu usvajanja tehnike mladih motkašica te u razvoju motoričkih sposobnosti relevantnih za uspjeh u ovoj atletskoj disciplini.