VARIABILITY OF HIGH JUMP KINEMATIC PARAMETERS IN LONGITUDINAL FOLLOW-UP

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Abstract:

The aim of this research was to determine the basic kinematic parameters of the high jump as well as the impact of changes in kinematic parameters on the height of the jump, and finally to determine the variability of kinematic parameters in longitudinal research. By means of kinematic analysis 25 kinematic parameters were acquired for seven jumps performed in the time span of three years by an elite Croatian female high jumper. By analysis of the kinematic parameters and the height of the jump the parameters which correlated the most with the height of the jump were acquired. Those were: *height of the flight of CG* (H2), *vertical velocity of CG at the end of the take-off* (VVETO), *height of the hips above the bar* (HHIP), *take-off angle* (ANTO), *take-off duration* (DTO), *angle at the moment of entering the take-off* (ANETO), *maximal height of CG at the moment of crossing the bar* (CGMAX), *horizontal velocity of CG in the penultimate stride in the run-up* (HV2RU). The values of certain kinematic parameters increased with the increase in the height of the jump, while values of other kinematic parameters decreased with the increase in the height of the jump. Basic kinematic parameters that increased with the height of the jump were *height of the flight of CG* (H2), *vertical velocity of CG at the end of the take-off* (VVETO), *height of the hips above the bar* (HHIP), *take-off angle* (ANTO), *maximal height of CG at the moment of crossing the bar* (CGMAX) as well as *horizontal velocity of CG in the penultimate stride in the run-up* (HV2RU), while the values of kinematic parameters *take-off duration* (DTO) and *angle at the moment of entering the take-off* (ANETO) decreased with the increase in the height of the jump. By analyzing the kinematic parameters of all the observed jumps it was determined that all the parameters varied with the increase in the height of the jump. Parameters that had the highest variability with regard to the height of the jump were: *length of the penultimate stride in the run-up* (SD = 18.90), *distance between CG and bar projection at the moment of the take-off leg positioning* (SD = 15.24), *distance between take-off point and the bar projection* (SD = 11.78) and *the length of the last stride during the run-up* (SD = 11.11). The lowest variability was observed in the parameter *take-off duration,* which is the duration of contact between the take-off leg and the surface, indicated by the 0.007 value of standard deviation.

Key words: *longitudinal research, high jump, kinematics, kinematic parameters, Croatian female high jumper*

DIE VARIABILITÄT VON DEN KINEMATISCHEN PARAMETERN DES HOCHSPRUNGS IN EINER LONGITUDINALEN FORSCHUNG

Zusammenfassung:

Das Ziel dieser Forschung war, sowohl die basischen kinematischen Parameter des Hochsprungs als auch den Einfluss deren Änderungen auf die Höhe des Sprunges zu bestimmen, zusammen mit der Variabilität von kinematischen Parametern in einer longitudinalen Forschung. Mittels einer kinematischen Analyse wurden 25 kinematischen Parametern für sieben Hochsprünge, die in einer Zeitspanne von drei Jahren von einer kroatischen Spitzenhochspringerin ausgeführt wurden, analysiert. Die Analyse von kinematischen Parametern und der Höhe des Sprunges resultierte mit den Parametern, die mit der Sprunghöhe am meisten korrelieren. Diese Parameter waren: *Flughöhe des Schwerpunktes* (H2), *vertikale Schnelligkeit des Schwerpunktes am Ende des Absprungs* (VVETO), *die Höhe von Hüften über der Latte* (HHIP), *Absprungwinkel* (ANTO), *Absprungdauer* (DTO), *der Winkel im Moment des Hineingehens in den Absprung* (ANETO), *maximale Höhe des Schwerpunktes beim Überspringen der Latte* (CGMAX), *horizontale Schnelligkeit des Schwerpunktes des* *vorletzten Schrittes während des Anlaufs* (HV2RU). Die Werte von einigen kinematischen Parametern steigern mit der Steigerung der Sprunghöhe, während die Werte von anderen kinematischen Parametern senken mit der Steigerung der Sprunghöhe. Die basischen kinematischen Parameter, die mit der Sprunghöhe steigern, sind: *Flughöhe des Schwerpunktes* (H2), *vertikale Schnelligkeit des Schwerpunktes am Ende des Absprungs* (VVETO), *die Höhe von Hüften über der Latte* (HHIP), *Absprungwinkel* (ANTO), *maximale Höhe des Schwerpunktes beim Überspringen der Latte* (CGMAX) und *horizontale Schnelligkeit des Schwerpunktes des vorletzten Schrittes während des Anlaufs* (HV2RU). Die Werte von kinematischen Parametern *Absprungdauer* (DTO) und der *Winkel im Moment des Hineingehens in den Absprung* (ANETO) senken mit der Steigerung der Sprunghöhe. Mittels der Analyse von kinematischen Parametern von allen Sprüngen, die beobachtet wurden, wurde festgestellt, dass alle Parameter im Zusammenhang mit der Sprunghöhe variieren. Die Parameter mit der höchsten Variabilität waren: *die Länge des zweiten (vorletzten) Schrittes während des Anlaufs* (SD = 18,90), *die Distanz zwischen dem Schwerpunkt und der Lattenprojektion im Moment der Positionierung des Absprungbeines* (SD = 15,24), *die Distanz zwischen dem Absprungspunkt und der Lattenprojektion* (SD = 11,78) und *die Länge des letzten Schrittes während des Anlaufs* (SD = 11,11). Die niedrigste Variabilität zeigte sich in dem Parameter: *Dauer des Absprungs,* die die Dauer des Kontaktes zwischen dem Absprungbein und dem Boden darstellt (SD = 0,007).

Schlüsselwörter: *longitudinale Forschung, Hochsprung, Kinematik, kinematische Parameter, kroatische Hochspringerin*

Introduction

The application of kinematic measurement systems in track-and-field is an unavoidable method in the training effects diagnostics of athletes which enables the acquisition of relevant information concerning the athlete's physical condition as well as his/her technique. By calculating linear and angular transition, velocity and acceleration, it is possible to attain a detailed insight into the technique which enables the effective tracking, programming and control of the training process in various track-and-field events. The high jump performed using the Flop-Fosbury technique is based on crossing the bar with the back turned towards it, with the height of a jump being determined by the rotation of certain body segments around the center of gravity at the moment of clearing the bar (Čoh, 1992). The structure of a high jump can be divided into: run-up phase, take-off phase, flight phase as well as landing phase. Within those phases the kinematic parameters relevant for the movement efficiency are analyzed. So far in research involving the kinematic parameters of the high jump in female athletes the most frequently analyzed has been the technique of jumps performed at the Olympics, world championships, European championships as well as at the other track-and-field competitions. The majority of authors point out that, even with the elite athletes, the technique of the jump has the individual characteristics and influences of various segmental movements on the movement of the whole body (Ritzdorf, Conrad, & Loch, 1989; Brüggemann & Loch, 1992; Hommel, 1993). Despite the fact that relatively large body of research has dealt with the high jump analysis, in the available literature we were unable to find a single one which would be based on a longitudinal follow-up of technique development in female jumpers from their career beginning all the way to their world-class achievements. Using the longitudinal approach in high jump technique research it is possible to follow and determine the changes in kinematic parameters as well as their influence on the technique development over a larger time span. Within the last couple of years an elite Croatian female high jumper has accomplished respectable results at an international level. In that period the subject had an improvement of her personal best from 180 cm in the year 2000, to 200 cm in the year 2003. In order to determine the background of her major results the registration of seven jumps at various heights was performed over a three-year time period.

This research is based on the longitudinal follow-up of kinematic parameters and their changes in the analyzed jumps, with the anthropological features (with the exception of body mass and body height) and other aspects of the training process that surely influence the overall motor efficiency of the jump not being taken into account. The aim of this research was to determine the basic kinematic parameters of the high jump as well as the influence of changes in the basic kinematic parameters on the jump height, and also to determine the variability of kinematic parameters in the longitudinal research.

Methods

The subject of this research was an elite Croatian high jumper and for the purpose of this research her seven jumps in the period from February 19, 2000 to July 7, 2003 were analyzed. The collection and acquisition of video recordings necessary for kinematic analysis were performed at six competitions and training sessions using two digital JVC DVL 9800 cameras that use 60 Hz frequency.

- The first jump was recorded on February 19, 2000, during a training session in Zagreb in which the subject cleared 180 cm.

- The second jump was recorded on June 9, 2002, during a competition in Zagreb in which the subject cleared 190 cm.
- The third jump was recorded on December 21, 2002, during a competition in Nova Gorica, Slovenia, in which the subject cleared 193 cm.
- The fourth jump was recorded on March 1, 2003, during a training session in Ljubljana, Slovenia, in which the subject cleared 195 cm.
- The fifth jump was recorded on May 21, 2003, during a competition in Zagreb in which the subject cleared 195 cm (the same height as in the previous jump).
- The sixth and seventh jump were recorded on July 7, 2003, during a competition in Zagreb, and for the purpose of this research two successful jumps were analyzed in which the subject cleared 195 and 200 cm, respectively.

The research covered the analysis of 25 kinematic parameters that are most frequently used in high jump technique analysis. These are the following parameters:

1. HB - height of the bar (cm),
2. L2SRU - length of the penultimate stride in the run-up (cm),
3. L1SRU - length of the last stride during the run-up (cm),
4. DTPBP - distance between take-off point and bar projection (cm),
5. DCGBPLP - distance from the centre of gravity (CG) and the bar projection at the moment of the take-off leg positioning (cm),
6. DTO - duration of take-off (ms),
7. HV3RU - horizontal velocity of CG in the third stride during the run-up (m/s),
8. HV2RU - horizontal velocity of CG in the second stride during the run-up (m/s),
9. HVLP - horizontal velocity of the body's CG at the moment of the take-off leg positioning (m/s),
10. HVTO - horizontal velocity of CG at the end of the take-off (m/s),
11. VBLP - vertical velocity of CG at the moment of the take-off leg positioning (m/s),
12. VVETO - vertical velocity of CG at the end of the take-off (m/s),
13. RESV - resultant velocity (m/s),
14. CG3S - height of CG in the third stride during the run-up (cm),
15. CG2S - height of CG in the second stride during the run-up (cm),
16. CGLP - height of CG at the moment of the take-off leg positioning (cm),
17. CGAMORT - height of CG in amortization (cm),
18. CGETO - height of CG at the end of the take-off, H1 height of CG (cm),
19. CGMAX – the maximal height of CG at the moment of crossing the bar (cm),
20. HHIP - height of the hips above the bar (cm),
21. ANAMORT - angle of amortization (°),
22. ANETO - angle at the moment of entering the take-off (°),
23. ANTO - angle of the take-off (°),
24. H2 - H2 height of CG, that is height of the flight of CG (cm),
25. H3 - H3 height of CG, that is height above the bar (cm).

Acquisition as well as processing of the kinematic parameters were performed according to APAS (Ariel Performance Analysis System) procedure standards that include frame grabbing, digitalization, 3D transformation, data filtering and kinematic parameters calculation. Data processing was performed using the Statistica for Windows 7.0 software package for basic descriptive parameters, correlations as well as the Kolmogorov-Smirnov test for testing the normality of distribution.

Results

Descriptive statistics included calculating the basic descriptive parameters of 25 kinematic parameters of all of the analyzed jumps in this research (Table 1).

Height of CG, that is *height of the flight of CG* (H2) represented the difference between the *maximal height of CG* (CGMAX) and *height of CG at the end of the take-off* (CGETO), and with our subject it was 54.1 to 65.7 cm (SD = 3.96). The values of the analyzed parameter increased with the increase of jump height, and in the 200-cm performance H2 height increased by 17.6% compared to the 180-cm jump. The increase in H2 *height of CG* (H2) was more a consequence of an increase in *maximal height of CG* (CGMAX), given the fact that the height of the center of gravity is determined by the anthropometric characteristics of the jumper.

For the purpose of kinematic analysis it is necessary to take into account the subject's body height and body weight, and with regard to the height of the jump, the values of the subject's body mass and body height are presented (Table 2).

In order to determine the basic kinematic parameters of the high jump, or, more precisely, to determine the kinematic parameters that have the highest correlation with jump performance, the correlations between the average values of the kinematic parameters in all of the measurements with the height of the jump were calculated (Table 3).

Table 1. Basic descriptive parameters (see explanations of abbreviations and measurement units in the text)

KINEMATIC PARAMETERS	MEAN	MINIMUM	MAXIMUM	SD
HB	192.57	180.00	200.00	6.29
L2SRU	223.40	196.80	246.90	18.90
L1SRU	217.03	200.90	234.50	11.12
DTPBP	85.57	74.20	102.00	11.78
DCGBPLP	135.40	124.50	160.90	15.25
DTO	0.18	0.18	0.20	0.01
HV3RU	6.87	6.14	7.54	0.52
HV2RU	6.90	6.23	7.57	0.53
HVLP	6.13	5.73	6.50	0.32
HVTO	4.57	4.12	5.02	0.29
VBLP	0.27	0.02	0.47	0.22
VVETO	3.41	3.06	3.75	0.22
RESV	5.71	5.28	5.90	0.22
CG3S	103.53	97.70	109.70	4.13
CG2S	99.07	94.50	104.80	3.38
CGLP	97.63	94.90	100.50	1.82
CGAMORT	108.01	100.70	114.80	5.75
CGETO	135.93	131.40	138.50	2.76
CGMAX	197.79	190.50	203.90	4.95
HHIP	207.30	193.00	213.80	7.10
ANAMORT	147.39	144.90	150.40	1.99
ANETO	33.64	31.00	38.00	2.50
ANTO	36.93	32.50	40.80	2.48
H2	62.19	54.10	65.70	3.97
H3	5.57	1.00	11.00	3.87

Table 2. Body height and body mass

HEIGHT OF THE JUMP (cm)	BODY HEIGHT (cm)	BODY MASS (kg)
180	188	62
190	193	73
193	193	72
195	193	72
195	193	72
195	193	72
200	193	72
MEAN	192.28	70.71
MINIMUM	188.0	62.0
MAXIMUM	193.0	73.0
SD	1.88	3.86

Table 3. Correlations between the avarage values of the kinematic parameters in all of the measurements and the height of the jump ($p<0.05$)

KINEMATIC PARAMETERS	HEIGHT OF THE JUMP
L2SRU	0.51
L1SRU	-0.53
DTPBP	-0.66
DCGBPLP	-0.62
DTO	**-0.89**
HV3RU	0.66
HV2RU	**0.79**
HVLP	0.71
HVTO	-0.60
VBLP	-0.39
VVETO	**0.90**
RESV	-0.14
CG3S	0.04
CG2S	0.37
CGLP	-0.39
CGAMORT	0.13
CGETO	0.08
CGMAX	**0.80**
HHIP	**0.90**
ANAMORT	-0.18
ANETO	**-0.82**
ANTO	**0.90**
H2	**0.91**
H3	-0.63

For the purpose of analyzing the changes in kinematic parameters in all of the observed jumps the differences between the highest (200 cm) and the lowest (180 cm) jump performance were calculated (Table 4).

In the following graphs the values of the basic kinematic parameters of all of the observed jumps (run-up, take-off and flight phase) are presented.

Height of the hips above the bar (HHIP) ranged from 193 to 213.8 cm (SD = 7.09), and given the acquired values of the analyzed parameter it can be concluded that the *height of the hips above the bar* (HHIP) increased with the increase in the height of the jump, while standard deviation value was 7.09.

The angle of the take-off (ANTO) was determined by the horizontal and vertical component of the resultant velocity of the take-off. Values of the mentioned parameter ranged from 32.5° to 40.8° (SD = 2.48). Values increased with the increase in the height of the jump, and the subject increased the angle of take-off in her highest jump by 20.3% compared to the same value in her lowest jump. Given the fact that the *angle of the take-off* (ANTO) is completely determined by the horizontal and vertical component of the resultant velocity of the take-off, it can be expected that the change in the mentioned parameters will yield an increase in the angle of the take-off.

The values of *maximum height of CG at the moment of crossing the bar* (CG-

Table 4. The values of basic kinematic parameters in all of the observed jumps

HEIGHT OF THE JUMP (cm)	H2 (cm)	VVETO (m/s)	HHIP (cm)	ANTO (°)	DTO (ms)	ANETO (°)	CGMAX (cm)	HV2RU (m/s)
180	54.1	3.06	193.0	32.5	0.20	38.0	191	6.23
190	61.3	3.37	204.5	36.7	0.18	33.0	194	6.42
193	65.5	3.28	213.8	38.4	0.18	36.0	204	6.94
195	64.4	3.37	206.3	36.7	0.18	31.0	196	6.48
195	62.1	3.53	210.7	36.7	0.18	33.0	199	7.34
195	62.2	3.53	210.6	36.7	0.18	33.0	199	7.32
200	65.7	3.75	212.2	40.8	0.18	31.5	204	7.57
DIFFERENCE (200 cm-180 cm)	11.6	0.69	19.2	8.3	-0.02	-6.5	13	1.34

MAX) ranged from 191 to 204 cm. The values increased with the increase in the height of the jump, and the subject increased the *maximum height of CG at the moment of crossing the bar* (CGMAX) by 6.4% compared to the lowest jump (Figures 1, 2 and 3).

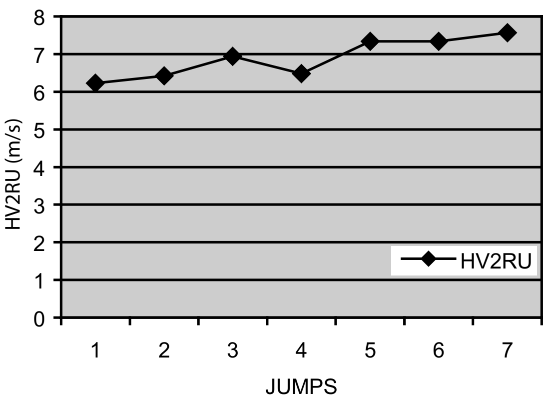

Figure 1. Horizontal velocity in the second stride of the run-up phase (HV2RU).

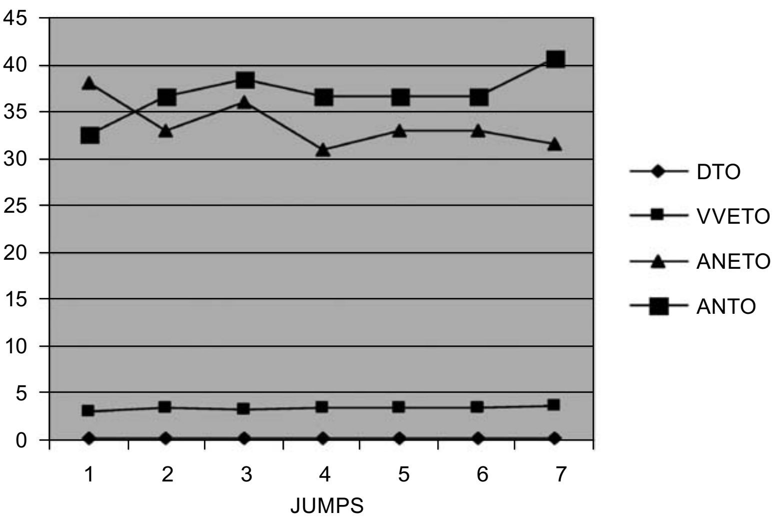

Figure 2. The duration of the take-off (DTO), vertical velocity at the end of the take-off (VVETO), angle at the moment of entering the take-off (ANETO) and angle of the take-off (ANTO).

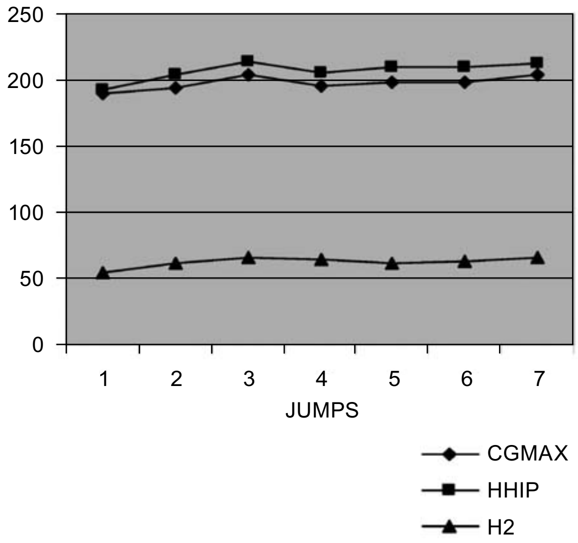

Figure 3. H2 height of CG (H2), height of the hips (HHIP) and the maximal height of CG (CGMAX).

Discussion and conclusion

Analysis of basic kinematic parameters

According to the acquired results pertaining to the correlation between kinematic parameters and the height of the jump, it can be concluded that the following basic kinematic parameters have the highest correlation:

1.) H2 - *height of CG*, that is height of the flight of CG (r=0.91),
2.) VVETO - vertical *velocity of CG at the end of the take-off* (r=0.90),
3.) HHIP - *height of the hips above the bar* (r=0.90),
4.) ANTO - *angle of the take-off* (r=0.90),
5.) DTO - *duration of the take-off* (r=-0.89),

6.) ANETO - *angle at the moment of entering the take-off* (r=-0.82),
7.) CGMAX - *maximum height of CG at the moment of bar crossing* (r=0.80),
8.) HV2RU - *horizontal velocity of CG in the second stride during the run-up* (r=0.79).

Many authors who performed high jump analysis point out that the biggest influence on the height of the jump can be contributed to *vertical velocity of CG at the end of the take-off* (Krazhev et al., 1989; Conrad & Ritzdorf, 1990; Brüggemann & Loch, 1992; Čoh, 1992; Slamka & Moravec, 1999; Dapena, 2000; Greig & Yeadon, 2000; Wilson et al., 2004), while *the run-up velocity, height of CG in the moment of the take-off leg positioning, vertical velocity of CG at the end of the take-off, maximum height of CG at the moment of bar crossing* and *height of the hips above the bar* are the parameters that discriminate between the jumpers the most (Čoh, Ćuk, & Borštnik, 1993). Basic kinematic parameters acquired in this research are confirming the findings of previous research dealing with the high jump technique, according to which significant influence on the height of the jump can be contributed to *vertical velocity of CG at the end of the take-off* (VVETO). Parameter that is, according to the results of this research, the most correlated with the height of the jump is *height of CG*, that is *height of the flight of CG* (H2), which pertains to the difference between *maximal height of CG* (CGMAX) and the *height of CG at the end of the take-off* (CGETO).

Out of the total number of basic kinematic parameters, during the run-up phase the significant correlation with the height of the jump is observed with *horizontal velocity of CG in the second stride during the run-up* (HV2RU). In the take-off phase, a significant correlation with the height of the jump is produced by *vertical velocity of CG at the end of the take-off* (VVETO), *angle of the take-off* (ANTO), *duration of the take-off* (DTO) and *angle at the moment of entering the take-off* (ANETO), while in the flight phase a significant correlation is observed between the height of the jump and *height of CG,* that is *height of the flight of CG* (H2), *height of the hips above the bar* (HHIP) and *maximum height of CG at the moment of bar crossing* (CGMAX).

Acquired results confirm the current findings on relationship between previously mentioned kinematic parameters with the height of the jump and point out that, undoubtedly, performance of high jumpers depends on the run-up velocity, take-off action as well as optimal flight trajectory.

Changes of basic kinematic parameters

The values of *vertical velocity of CG at the end of the take-off* (VVETO) fit into the interval 3.06 - 3.75 m/s (SD=0.21), while *vertical velocity of CG at the end of the take-off* (VVETO) in the highest jump increased by 18.4% compared to the same value in the lowest jump. *Vertical velocity at the end of the take-off* (VVETO) increases with the increase of the height of the jump (Conrad & Ritzdorf, 1990), while increase in *vertical velocity at the end of the take-off* (VVETO), given the longitudinal character of this research, is probably the consequence of increase of the horizontal velocity in entering the take-off, better, execution of the take-off as well as the improvement in motor abilities.

The *duration of the take-off* (DTO) that is, the duration contact between the take-off leg and the surface in all of the analyzed jumps reads 0.18 s, except for the 180-cm jump in which the value read 0.20 s (SD=0.007). According to the results it can be concluded that the values of *the take-off duration* (DTO) in all of the observed jumps remain constant, except for the 180-cm jump. The *duration of the take-off* (DTO) in 180-cm jump is 10% less compared to the rest of the jumps that are, regardless of the height of the jump, constant. Given the stability of the analyzed kinematic parameter in the similar research (Čoh, 1987), it can be concluded that the duration of the take-off (DTO) in the analyzed jumps is the most stable parameter given the increase in the height of the jump (SD=0.007). Because all the jumps were recorded using the 60 Hz camera, it can be assumed that the duration of the take-off is not a constant parameter, but a consequence of insufficient sensitivity of the measurement instrument.

Angle at the moment of entering the take-off (ANETO) represents the ratio between the length of movement trajectory of CG and the radius of the take-off point. The values of the analyzed jumps ranged from 31° to 38° (SD=2.49). The analyzed parameter decreases with the increase in the height of the jump. Angle at the moment of entering the take-off in the 200-cm jump decreased by 17.1 % compared to the same values in the 180-cm jump. Given the time period of this research, decreased values of the analyzed parameter can be explained by the changes in technique. The way the run-up phase is executed (number of strides, length of the strides, and the beginning of the run-up) probably changed with regard to motor learning process. A large number of iterations as well as the changes in anthropological traits surely contributed to the execution of the run-up phase, and therefore influenced the changes in the observed parameter.

Horizontal velocities of CG in the second stride of the run-up (HV2SRU) ranged from 6.14 to 7.23 m/s (SD=0.52). Comparing the results of the analyzed parameter in the 180-cm and 200-cm jumps it can be concluded that the *horizontal velocity of CG in the second stride of the run-up* (HV2SRU) increased in the 200-cm jump by 17.7% compared to the 180-cm jump. The acquired values of the *horizontal velocity in the second stride of the take-off* confirm the findings according to which the horizontal velocity of the run-up increases with the increase in bar height (Čoh, 1987). Given the longitudinal research, the increase in horizontal velocity is probably the consequence of improvement in motor abilities as well as possible changes in the length and execution of the run-up.

Variability in kinematic parameters

By analysis of kinematic parameters in the run-up, take-off and flight it was determined that the values of all of the observed parameters vary in relation to height of the jump (standard deviation values or SD).

Kinematic parameters that have the biggest variability in results with regard to the height of the jump are: *length of the penultimate stride during the run-up* (L2SRU; SD=18.90), *distance between CG and the bar projection at the moment of the take-off leg positioning* (DCGBPLP; SD=15.24), *distance between take-off point and bar projection* (DTPBP; SD=11.78) and *length of the last stride during the run-up* (L1SRU; SD=11.11).

The variability of results of kinematic parameters *height of CG during the run-up, take-off and flight* (CG3S, CG2S, CGLP, CGAMORT, CGETO, CGMAX), as well as the *height of the hips above the bar* (HHIP) ranged from 7.09 (HHIP) to 1.81 (CGLP) standard deviations.

In *angle of amortization* (ANAMORT), *angle at the moment of entering the take-off* (ANETO) and *take-off angle* (ANTO) the variability ranges from 2.49 (ANETO) to 1.99 (ANAMORT) standard deviations.

The variability of horizontal velocities of CG in the run-up and take-off (HV3RU, HV2RU, HVLP, HVTO), *vertical velocity of CG in the moment of the take-off leg positioning* (VBLP) and *at the end of the take-off* (VVETO) as well as *resultant velocity* (RESV) ranged from 0.52 (HV3RU, HVLP) to 0.21 (VBLP) standard deviations.

The *duration of the take-off* (DTO), that is the *duration of contact between the take-off leg* and the surface, is the parameter with the smallest variability among the observed parameters (SD=0.007).

Analyzing the parameters of all of the observed jumps it was determined that the values of kinematic parameters vary with the increase in the height of the jump. Values of some parameters in all of the observed jumps increase with the increase in the height of the jump, while values of other kinematic parameters decrease with the increase in the height of the jump. Given the longitudinal research, it is essential to consider the changes in motor abilities and the influence of motor learning process on forming the motor programs essential for correct execution of movement. In time period in which the data was collected, the subject performed a large number of iterations of high jump during the training process, as well as a large number of high jumps in competition, which surely influenced the development of technique of high jump. In the time span of this research inevitable changes in the body mass and body height have occurred which probably had an impact on the changes in other anthropologic features.

Values of certain parameters point to the improvement in technique and higher level of fitness. The most noticeable is the increase in the approach run-up velocity, vertical take-off velocity that resulted in the significant increase in take-off angle. In concordance with that, approach execution was adjusted, which eventually resulted in optimal bar approach in later phases of development. Maintaining the high position of the body during the preparation for the take-off and the take-off itself is one of the important features of the subject's high jump technique. The parameter which indicates the constancy in maintaining the high position of the body is knee angle of the take-off leg that had the lowest amortization value of 144 degrees.

The technique of bar clearing became more efficient (H3 value) and some of the jumps were executed with 4 cm or just 1 cm difference between the center of mass (CM) and the height of the bar.

With improvements in technique and with better fitness level, especially with plyometric training this, Croatian female high jumper can achieve progression of her high jump results.

With regard to performance, the research could be repeated using the larger sample of subjects and a larger number of jumps on various heights.

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LONGITUDINALNO ISTRAŽIVANJE VARIJABILITETA KINEMATIČKIH PARAMETARA SKOKA U VIS JEDNE HRVATSKE ATLETIČARKE

Sažetak

Uvod

Primjena kinematičkih mjernih sustava u atletici nezaobilazna je metoda dijagnostike treniranosti sportaša koja omogućuje dobivanje relevantnih informacija o stanju sportaša i tehnici izvođenja sportskih gibanja. Izračunavanjem linearnih i kutnih pomaka te brzina i ubrzanja moguće je dobiti detaljan uvid u tehniku gibanja, što može biti značajna komponenta praćenja, programiranja i kontrole procesa treninga u različitim atletskim disciplinama.

Skok u vis može se strukturalno podijeliti na fazu zaleta, odraza, leta i doskoka, a u okviru tih faza analiziraju se kinematičke veličine i parametri koji su bitni za efikasnost gibanja. U posljednjih nekoliko godina jedna vrhunska hrvatska skakačica u vis postigla je zapažene rezultate na svjetskoj razini, a kako bi se istražila pozadina postignuća uspješnih rezultata sustavno je promatrano sedam skokova na različitim visinama skoka u vis u razdoblju od tri godine. Stoga se ovo istraživanje temelji na longitudinalnom praćenju kinematičkih parametara i njihovih promjena u analiziranim skokovima, pri čemu se nisu uzele u obzir promjene antropoloških obilježja (osim tjelesne visine i mase tijela) ni ostali aspekti trenažnog procesa koji, zasigurno, utječu na ukupnu motoričku efikasnost skoka. Cilj ovog longitudinalnog istraživanja bio je utvrditi osnovne kinematičke parametre skoka u vis, kao i utjecaj promjena osnovnih kinematičkih parametara na visinu skoka te utvrditi varijabilitet kinematičkih parametara u promatranom razdoblju.

Metode

Subjekt ovog istraživanja jedna je vrhunska hrvatska skakačica u vis. Za potrebe ovog istraživanja analizirano je sedam skokova snimljenih u razdoblju od 19. veljače 2000. godine do 7. ožujka 2003. godine. Video zapisi, potrebni za kinematičke analize, prikupljeni su i zaprimljeni pomoću dvije digitalne video kamere JVS DVL 9800, frekvencije 60 Hz, na šest natjecanja i trening natjecanja. Istraživanje je obuhvatilo analizu 25 kinematičkih parametara koji se najčešće koriste u istraživanjima tehnike skoka u vis. Kinematički podaci su prikupljeni i izračunati prema standardima procedure APAS (Ariel Performance Analysis System). Podaci su obrađeni programskim paketom Statistica for Windows 7.0.

Rezultati

U radu su prikazani osnovni deskriptivni parametri 25 kinematičkih parametara sedam analiziranih skokova u vis, vrijednosti visine i mase tijela pri svakom mjerenju, korelacije svih kinematičkih parametara s visinom skoka te vrijednosti osnovnih kinematičkih parametara u svim analiziranim skokovima.

Da bi se utvrdili osnovni kinematički parametri skoka u vis, odnosno kinematički parametri koji imaju najveću povezanost s visinom skoka, izračunate su korelacije prosječnih vrijednosti kinematičkih parametara iz svih mjerenja s visinom skoka. Osnovni kinematički parametri jesu: *visina leta težišta tijela* (H2), *vertikalna brzina težišta tijela na kraju odraza* (VVETO), *visina kukova iznad letvice* (HHIP), *kut odraza* (ANTO), *trajanje odraza* (DTO), *kut ulaska u odraz* (ANETO), *maksimalna visina težišta tijela u trenutku prelaska preko letvice* (CGMAX), *horizontalna brzina težišta tijela pretposljednjeg (drugog) koraka zaleta* (HV2RU).

Rasprava i zaključak

Dobiveni rezultati potvrđuju dosadašnje spoznaje o povezanosti dobivenih osnovnih kinematičkih parametara s visinom skoka te ukazuju na to kako uspješnost skakača u vis nedvojbeno ovisi o brzini zaleta, izvođenju odraza te optimalnoj trajektoriji leta. Vrijednosti rezultata nekih kinematičkih parametara povećavaju se s povećanjem visine skoka, dok se vrijednosti rezultata drugih kinematičkih parametara smanjuju s povećanjem visine skoka. Osnovni kinematički parametri koji se povećavaju s povećanjem visine skoka jesu: *visina leta težišta tijela* (H2), *vertikalna brzina težišta tijela na kraju odraza* (VVETO), *visina kukova iznad letvice* (HHIP), *kut odraza* (ANTO), *maksimalna visina težišta tijela u trenutku prelaska preko letvice* (CGMAX) i *horizontalna brzina težišta tijela pretposljednjeg (drugog) koraka zaleta* (HV2RU), dok se vrijednosti kinematičkih parametara *trajanje odraza* (DTO) i *kut ulaska u odraz* (ANETO) smanjuju s povećanjem visine skoka.

Analizom kinematičkih parametara svih skokova utvrđeno je da vrijednosti rezultata svih kinematičkih parametara variraju s povećanjem visine skoka. Kinematički parametri koji imaju najveći varijabilitet rezultata s obzirom na visinu skoka jesu: *duljina drugog (pretposljednjeg) koraka zaleta* (SD=18,90), *udaljenost težišta tijela od ravnine letvice pri postavljanju odrazne noge* (SD=15,24), *udaljenost odraza (prstiju) od ravnine letvice* (SD=11,78) i *dužina posljednjeg koraka zaleta* (SD=11,11). Najmanji varijabilitet rezultata ima kinematički parametar *trajanje odraza*, odnosno vrijeme kontakta odrazne noge s podlogom, na što ukazuje vrijednost standardne devijacije koja iznosi tek 0,007. U razdoblju tijekom kojega su prikupljeni analizirani skokovi, ispitanica je izvela veliki broj iteracija skoka u vis u trenažnom procesu, kao i velik broj skokova u natjecateljskim uvjetima, što je zasigurno utjecalo na razvoj tehnike skoka u vis. U tom razdoblju došlo je do promjene tjelesne mase i visine tijela, što je vjerojatno utjecalo i na promjene ostalih antropoloških karakteristika.

S obzirom na dobivene rezultate, istraživanje bi bilo dobro ponoviti na većem uzorku ispitanika i većem broju skokova na različitim visinama.