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

Zusammenfassung:


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)

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

Table 2. Body height and body mass

<table>
<thead>
<tr>
<th>HEIGHT OF THE JUMP (cm)</th>
<th>BODY HEIGHT (cm)</th>
<th>BODY MASS (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>180</td>
<td>188</td>
<td>62</td>
</tr>
<tr>
<td>190</td>
<td>193</td>
<td>73</td>
</tr>
<tr>
<td>193</td>
<td>193</td>
<td>72</td>
</tr>
<tr>
<td>195</td>
<td>193</td>
<td>72</td>
</tr>
<tr>
<td>200</td>
<td>193</td>
<td>72</td>
</tr>
</tbody>
</table>

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

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

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

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

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).

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; Slankma & Moravec, 1999; Dapena, 2000; Greig & Yeardon, 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 (DCGBLP; 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, HVLBP, 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, HVLBP) 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.
References


Submitted: February 10, 2006
Accepted: May 30, 2006

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LONGITUDINALNO ISTRAŽIVANJE VARIJABILITETA KINEMATIČKIH PARAMETARA SKOKA U VIS JEDNE HRVATSKE ATLETIČARKE

Sažetak

Uvod

Primjena kinematičkih mjernih sustava u atleti
ci nezaobilazna je metoda dijagnostike treniranosti
sportaša koja omogućuje dobivanje relevantnih
informacija o stanju sportaša i tehnici izvođenja sport-
skih gibanja. Istraživanjem linearnih i kutnih po-
maksa te brzina i ubrzanja može se dobiti detaljan
uduh tehnike gibanja, što može biti značajna kom-
ponenta praćenja, programiranja i kontrole procesa
treniranja 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
sobitni za efikasnost gibanja. U posljednjih nekolik
ko 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 longitudi-
nalnom 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 uku-
pu motoričku efikasnost skoka. Cilj ovog longitudi-
nalnog istraživanja bio je utvrditi varijabilitet kinemati-
tičkih parametra skoka u vis, kao i utjecaj promjena
osnovnih kinematičkih parametara na visinu skoka
koj bi se utvrdila varijabilitet kinematičkih parametara u
promatranom razdoblju.

Metode

Subjekt ovog istraživanja jedna je vrhunska hr-
vatska skakačica u vis. Za potrebe ovog istraživanja
analizirano je sedam skokova snimljenih u razdoblju
od 19. veljače 2000. godine do 7. ožujka 2003. go-
dine. Video zapisi, potrebni za kinematičku analizu,
prikupljeni su i zaprimljeni pomoću dvije digitalne vi-
dije kamere JVS DVL 9800, frekvencije 60 Hz, na
koj su prikupljeni analizirani skokovi, ispitanica
koj se najčešće koriste u istraživanjima tehnike skoka
u vis. Kinematički podaci su prikupljeni i izračunati
prema standardima procedure APAS (Ariel Perfor-
mance Analysis System). Podaci su obrađeni pro-
gramskim paketom Statistica za Windows 7.0.

Rezultati

U radu su prikazani osnovni deskriptivni para-
metri 25 kinematičkih parametara sedam analizi-
ranih skokova u vis, vrijednosti visine i mase tijela
pri svakom mjerenju, korelacije svih kinematičkih
parametara s visinom skoka te vrijednosti osno-
vnih kinematičkih parametara u svim analiziranim
skokovima.

Da bi se utvrdili osnovni kinematički parametri
skoka u vis, odnosno kinematički parametri koji ima-
ju najveću povezanost s visinom skoka, izračunate
su korelacije prošječnih vrijednosti kinematičkih pa-
rametara 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), horizontal-
alna brzina težišta tijela pretposljednjeg (drugog)
koraka zaleta (HV2RU).

Rasprava i zaključak

Dobiveni rezultati potvrđuju dosadašnje spozna-
je o povezanosti dobivenih osnovnih kinematičkih
parametara s visinom skoka te ukazuju na to kako
uspješnost skakača u vis nedvojbeno ovisi o brzi-
ni zaleta, izvođenju odraza te optimalnoj trajektori-
ji leta. Vrijednosti rezultata nekih kinematičkih pa-
rametara povećavaju se s povećanjem visine sko-
ka, dok se vrijednosti rezultata drugih kinematičkih
parametara smanjuju s povećanjem visine skoka.
Osnovni kinematički parametri koji se povećava-
ju s povećanjem visine skoka jesu: visina leta te-
ztišta tijela (H2), vertikalna brzina težišta tijela na
kraju odraza (VVETO), visina kukova iznad letvice
(HHIP), kut odraza (ANTO), maksimalna visina teži-
šta tijela u trenutku prelaska preko letvice (CGMAX)
horizontalna brzina težišta tijela pretposljednjeg
(drugog) koraka zaleta (HV2RU), dok se vrijedo-
ni kinematičkih parametara trajanje odraza (DTO)
koj i kut ulaska u odraz (ANETO) smanjuju s poveća-
njem visine skoka.

Analizom kinematičkih parametara svih skoko-
va utvrđeno je da vrijednosti rezultata svih kinema-
tičkih parametara variraju s povećanjem visine sko-
ka. Kinematički parametri koji imaju najveći varia-
bilitet rezultata s obzirom na visinu skoka jesu: duljina
drugog (pretposljednjeg) koraka zaleta (SD=18,90),
udažnost odraza tijela od ravnotežne letvice pri posta-
vljanju odrazne-note (SD=15,24), udaljenost odraza
tijela od ravnotežne letvice (SD=11,78) i dužina
posljednjeg koraka zaleta (SD=11,11). Najmanji va-
rijabilitet rezultata ima kinematički parametar traje-
anje 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
izvješća veliki broj iteracija skoka u vis u trenažnom
procesu, kao i velik broj skokova u natjecateljskim
uvjetima, što je zasigurno utjecalo na razvoj tehni-
ke skoka u vis. U tom razdoblju došlo je do promjene
tjelesne mase i visine tijela, što je vjerovatno utjecalo
na promjene ostalih antropoloških karakteristika.

Sažetak