Longitudinal follow-up of kinematic parameters in the high jump - A case study

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ABSTRACT

The aim of this study was to evaluate the high jump technique of a single subject by determining the influence of kinematic parameters, tracking the changes to the recorded values with changes to the height of the jump and comparing the recorded values with those of other elite high jumpers. The subject of the study was Blanka Vlasic, the Croatian women's record holder. Over a three-year period, her technique development was followed using data on 25 parameters acquired from jumps ranging from 1.80m to 2.00m. The values obtained for Vlasic are, for the most part, within the ranges documented for other world-class women high jumpers. Certain parameters for Vlasic changed with the height of the jump, influenced by improvements in her technique and important motor abilities. The authors found that systematic follow-up of the studied kinematic parameters enabled Vlasic to have a fast and rational technique learning process.

AUTHORS

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Introduction

Reviewing the literature on the kinematic parameters of the high jump, one will find analyses of jumps in the Olympic Games, World Championships and other major competitions by the world's top jumpers[1,2,3,4,5,6,7,8,9]. However, despite the relatively large number of studies that deal with this event, we were unable to find even one longitudinal follow-up study of high jump technique development from the beginning of an athlete's career through to the point of achieving the top results on the international level.

The aim of this study was to evaluate the high jump technique of a single subject by determining the influence of kinematic parameters, tracking the changes to the recorded values with the height of the jump and comparing the recorded values with those of other elite high jumpers.

Blanka Vlasic is the Croatian record holder for the women's high jump with personal bests of 2.05m indoors and 2.03m outdoors. She was twice World Junior Champion (2000 and 2002) and she took the silver medal at the 2006 IAAF World Indoor Athletics Championship in Moscow, where she cleared 2.00m. As a part of a research project entitled "Biomechanical optimisation of sports techniques", seven of her jumps from six training sessions and competitions over three years (2000 to 2003) were analysed. In this period, her personal best improved from 1.80m to 2.00m. Further information on the analysed jumps is given in Table 1.

Blanka Vlasic

Born:
8 November 1983
Split, Croatia

Height:
193cm

Weight:
72kg

Progression:

Season	Performance
2006	2.05m
2005	1.95m
2004	2.03m
2003	2.01m
2002	1.96m
2001	1.95m
2000	1.93m
1999	1.80m
1998	1.67m
1997	1.61m

Major Achievements

Competition	Rank	Performance	Date
11th IAAF World Indoor Championships	2	2.00m	12.3.2006
10th IAAF World Indoor Championships	3	1.97m	07.3.2004
9th IAAF World Championships	7	1.95m	31.8.2003
World Junior Championships	1	1.96m	20.7.2002
World Junior Championships	1	1.91m	20.10.2000

Table 1: Jumps analysed for the study

	Place	Date	Performance	Age
1	Zagreb (Croatia) – Indoor	19.02.2000	1.80m	16
2	Zagreb	09.06.2002	1.90m	18
3	Nova Gorica (Slovenia) – Indoor	21.12.2002	1.93m	19
4	Ljubljana (Slovenia) - Indoor	01.03.2003	1.95m	19
5	Zagreb	21.05.2003	1.95m	19
6	Zagreb	07.07.2003	1.95m	19
7	Zagreb	07.07.2003	2.00m	19

Methods

Acquisition of the video recordings necessary for kinematic analyses was made using two digital JVS DVL 9800 cameras, each with a frequency of 60Hz. The cameras were positioned 90° from each other and 10m away from the landing pit. Data analysis was performed according to the APAS (Ariel Performance Analysis System) protocol standards. By means of 3D kinematic analysis, data for the 25 parameters most frequently used in high jump technique studies were calculated (see Table 2). The parameters were related to the phases of the jump and compared with the values of reference data obtained on other elite high jumpers[7].

Results and discussion

The basic descriptive parameters and the overall results for the analysed jumps are given in Table 2.

Table 2: Basic descriptive parameters and overall results for the seven analysed jumps

PARAMETERS	MEAN	MIN	MAX	SD
HB – height of the bar (cm)	192.57	180.00	200.00	6.29
2nd LS – length of the penultimate stride (cm)	223.40	196.80	246.90	18.90
LS – length of the last stride (cm)	217.03	200.90	234.50	11.12
TB – toe to bar distance (cm)	85.57	74.20	102.00	11.78
CM-TD – distance from centre of mass (CM) to bar at touchdown (cm)	135.40	124.50	160.90	15.25
CTTO – take-off contact time (s)	0.18	0.18	0.20	0.01
Vx3 – horizontal velocity of CM at 3rd last stride (m/s)	6.87	6.14	7.54	0.52
Vx2 - horizontal velocity of CM at penultimate stride (m/s)	6.90	6.23	7.57	0.53
VxTD - horizontal velocity of CM at touchdown (m/s)	6.13	5.73	6.50	0.32
VxTO - horizontal velocity of CM at take-off (m/s)	4.57	4.12	5.02	0.29
VyTD - vertical velocity of CM at touchdown (m/s)	0.27	0.02	0.47	0.22
VyTO - vertical velocity of CM at take-off (m/s)	3.41	3.06	3.75	0.22
Vr – resultant velocity (m/s)	5.71	5.28	5.90	0.22
HCM3d last – height of CM at 3d last stride (cm)	103.53	97.70	109.70	4.13
HCM2nd last – height of CM at penultimate stride (cm)	99.07	94.50	104.80	3.38
HCMTD – height of CM at touchdown (cm)	97.63	94.90	100.50	1.82
HCMAM – height of CM at amortisation (cm)	108.01	100.70	114.80	5.75
HCMTO – take-off height of the CM – H1 (cm)	135.93	131.40	138.50	2.76
HCMMAX – maximum height of CM during the flight (cm)	197.79	190.50	203.90	4.95
H2 – height of flight of the CM (cm)	62.19	54.10	65.70	3.97
H3 – height of CM relative to the bar (cm)	5.57	1.00	11.00	3.87
HHIP- height of the hips above the bar (cm)	207.30	193.00	213.80	7.10
ANAM – knee angle at amortisation (degrees)	147.39	144.90	150.40	1.99
ANRU – approach angle (degrees)	33.64	31.00	38.00	2.50
ANTO – angle of take-off (degrees)	36.93	32.50	40.80	2.48

Length of the approach strides

The lengths of the approach strides are shown as *length of the penultimate stride* (2nd LS) and *length of the last stride* (LS). The individual results for these parameters for the seven analysed jumps are given in Table 3 and Figure 1.

Values for the lengths of the two last strides of the approach vary greatly and ideals cannot be stated. This is consistent with previous studies, in which individual variations in the length of these strides were shown. Some jumpers shorten the penultimate stride, while values for the last stride show significant individual variations[4].

In our subject's 1.80m and 1.90m jumps, her last stride was longer than the penultimate stride, while in the higher jumps the ratio of the lengths of these strides was reversed. When clearing higher heights, she had a longer penultimate than last stride, with the greatest difference being 21.1cm (in the 2.00m jump). According to these results, it can be concluded that the ratio of the lengths of her last and penultimate strides changes with the increase in the height of the jump. There is also a tendency to shorten the last stride in all of the higher jumps, and this is related to improvement in the execution of the approach technique.

Table 3: Lengths of the penultimate and last strides of the approach phase for the seven analysed jumps

HB (cm)	2nd LS (cm)	LS (cm)
180	210.5	234.5
190	196.8	208.0
193	246.9	226.1
195	206.2	200.9
195	231.5	215.2
195	231.4	215.1
200	240.5	219.4

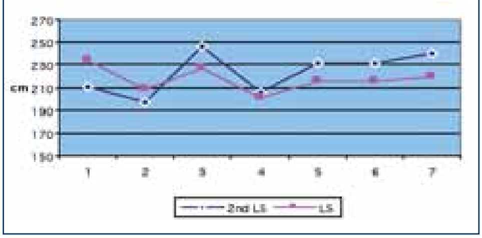

Figure 1. Lengths of the penultimate stride and last stride of approach phase for the seven analysed jumps

Horizontal velocity of the CM

The horizontal velocity in the approach and take-off phases are shown as the following

Table 4: Horizontal velocities in the approach and take-off phases for the seven analysed jumps and the range for elite jumpers

HB (cm)	Vx3 (m/s)	Vx2 (m/s)	VxTD (m/s)	VxTO (m/s)
180	6.44	6.23	5.73	5.02
190	6.14	6.42	5.87	4.12
193	7.07	6.94	6.41	4.50
195	6.43	6.48	5.79	4.57
195	7.23	7.34	6.32	4.73
195	7.21	7.32	6.30	4.73
200	7.54	7.57	6.50	4.33
Elite Jumpers	/	6.3-7.5	6.3-7.3	2.6 – 4.1

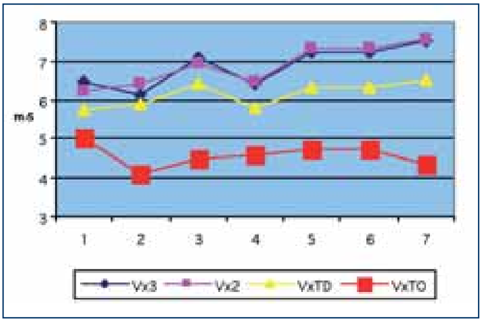

Figure 2: Horizontal velocities in the approach and take-off phases for the seven analysed jumps

kinematic parameters: *horizontal velocity of CM in the 3rd last stride* (Vx3), *horizontal velocity of CM in the penultimate stride* (Vx2), *horizontal velocity of CM at touch-down* (VxTD) and *horizontal velocity of CM at take-off* (VxTO). The individual results for these parameters for the seven analysed jumps are given in Table 4 and Figure 2.

Comparing the values of the horizontal velocity of the CM in the 1.80m and 2.00m jumps, it can be concluded that our subject increased the horizontal velocity of the CM in the 3rd last stride by 14.5%, in the penultimate stride by 17.7% and in the last stride by 11.8%. Conversely, horizontal velocity at take-off in the 2.00m jump decreased by 13.7% compared to the 1.80m jump.

Values for our subject's horizontal velocity of the CM in the penultimate stride are consistent with the values produced by other world-class women high jumpers[7]. Horizontal velocity in the last stride of the approach is usually reduced due to the lowering of the CM and preparation for the take-off. Despite the fact that in all the observed relevant parameters an increase in the horizontal velocity is observed, horizontal velocity in the last stride shows the biggest loss compared to other elite jumpers. It is possible to notice that the horizontal velocity at take-off (VxTO) is still higher than expected. One can assume that because of insufficient power in the lower limbs as well as technical weaknesses in take-off execution, a rational reduction of the horizontal velocity and transformation to vertical velocity does not happen.

Vertical velocities of the CM

The vertical velocities of the CM are shown as the following kinematic parameters: *vertical velocity of the CM at touchdown* (VyTD) and *vertical velocity of the CM at take-off* (VyTO). The individual results for these parameters for the seven analysed jumps are given in Table 5 and Figure 3.

Table 5: Vertical velocities of the CM at touchdown and take-off for the seven analysed jumps and the range for elite jumpers

HB (cm)	VyTD (m/s)	VyTO (m/s)
180	0.45	3.06
190	0.04	3.37
193	0.47	3.28
195	0.02	3.37
195	0.42	3.53
195	0.42	3.53
200	0.04	3.75
Elite Jumpers	-0.8 – 0.2	3.52 – 4.1

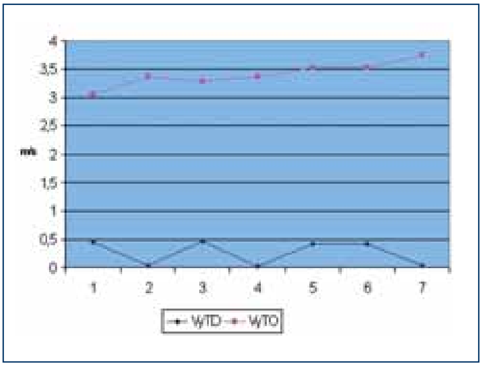

Figure 3: Vertical velocities of CM at touchdown and take-off for the seven analysed jumps

The vertical velocity of the CM at take-off increased in the highest analysed jump by

18.4% compared to the same parameter in the lowest jump. Values of the vertical velocity of the CM at touchdown in the 1.90m, 1.95m (one jump) and 2.00m jumps are consistent with other elite jumpers while values in her other jumps are higher when compared to reference data[7,5,4]. The vertical velocity of the CM at take-off, in two of her jumps (1.95m and 2.00m), are at the lower limit of values achieved by the other elite jumpers, while in her other jumps the vertical velocity is significantly lower.

Angles

The *angle of amortisation* (ANAM) represents the smallest knee angle of the take-off leg during take-off, and the acquired values fit within the range 144.9° - 150.4° (SD=1.99).

Table 6: Angles of amortisation, run up and take-off for the seven analysed jumps and the range for elite jumpers

HB (cm)	ANAM (º)	ANRU (°)	ANTO (°)
180	146.6	38.0	32.5
190	150.4	33.0	36.7
193	146.3	36.0	38.4
195	145.8	31.0	36.7
195	148.9	33.0	36.7
195	148.8	33.0	36.7
200	144.9	31.5	40.8
Elite Jumpers	140-160	25-40	42-52

Run up angle (ANRU) is the angle between the straight line of the bar and the tangent of the trajectory of CM at the moment of touchdown. In the analysed jumps, the values of this parameter range from 31° to 38° (SD=2.49).

Angle of take-off (ANTO) is determined by the horizontal and vertical component of the resultant velocity of take-off. Values acquired range from 32.5° to 40.8° (SD=2.48).

A lower knee angle of the take-off leg pertains to a greater flexion of the leg and a more pronounced lowering of the CM in the take-off phase. Observed values in all of our subject's jumps are consistent with those for other elite high jumpers[4]. The acquired results indicate that the amortisation angle in the knee joint is 1.15% lower in her highest analysed jump than the lowest.

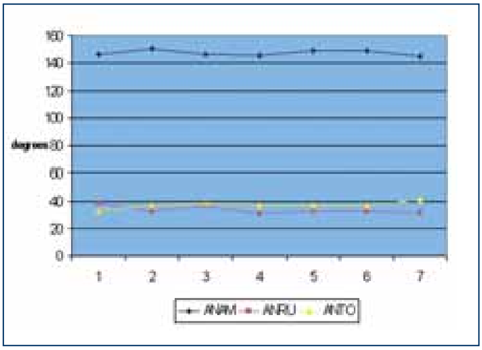

Figure 4: Angles of amortisation, run up and take-off for the seven analysed jumps

The run up angle in all of the observed jumps is within the range of other elite high jumpers. The angle in the 2.00m jump is reduced by 17.1% compared to the 1.80m jump, which is a consequence of accustoming the approach technique to the individual characteristics of our subject.

The take-off angle in all of the observed jumps is lower compared to other elite high jumpers. The value for this parameter increases with the increase in the height of the jump, and our subject increased the take-off angle in the highest jump by 20.3% compared to the value seen in the lowest jump. Given the fact that the take-off angle is completely determined by the horizontal and vertical components of resultant take-off velocity, it can be expected that changes in these parameters will yield a change in take-off angle.

Heights of the CM

The height of the CM in the last steps of the approach phase is determined by the anthropometrical characteristics of the jumper and is shown by the following kinematic parameters: *height of the CM in the 3rd last stride*

Table 7: Height of the CM in the 3rd last stride, height of the CM in the penultimate stride and take-off height of the CM or height of the CM in the last stride for the seven analysed jumps.

HB (cm)	HCM3d LAST (cm)	HCM2nd LAST (cm)	HCM TD (cm)
180	101.4	94.5	98.0
190	100.5	101.8	98.0
193	109.7	104.8	100.5
195	102.7	97.6	95.8
195	106.4	97.6	98.2
195	106.3	97.5	98.0
200	97.7	99.7	94.9

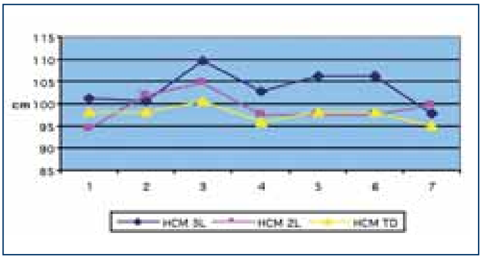

Figure 5: Height of the CM in the 3rd last stride, height of the CM in the penultimate stride and take-off height of the CM or height of the CM in the last stride for the seven analysed jumps.

(HCM3dLAST), *height of the CM in the penultimate stride of the approach* (HCM2dLAST) and *take-off height of the CM or height of the CM in the last stride* (TTPO).

The results point to the gradual lowering of the CM from the 3rd last to the last stride. This is, for the most part, a consequence of an inclination of the jumper's body towards the centre of the curve and, to a lesser degree, of stride extension or a decrease in knee angle.

Comparing the results of our subject's lowest and the highest analysed jumps, it is possible to notice that she lowered her CM at the beginning of take-off phase in the highest jump by 3.16% compared to the same value in the lowest jump.

Heights of the CM in the take-off phase are shown by the kinematic parameters: *height of the CM at amortisation* (HCMAM) and *height of the CM at take-off* (HCMTO).

Table 8: Height of the CM at amortisation and height of the CM at take-off for the seven analysed jumps and the range for elite jumpers

HB (cm)	HCMAM (cm)	HCMTO (cm)
180	103.0	136.9
190	108.9	132.7
193	110.6	138.5
195	103.4	131.4
195	114.8	136.9
195	114.7	136.8
200	100.7	138.3
Elite Jumpers	87-98	118-144

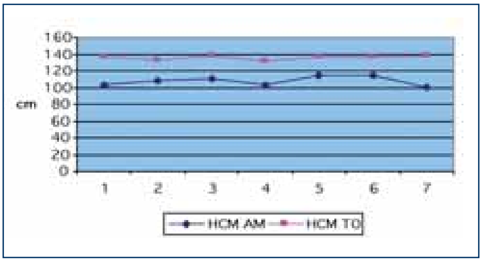

Figure 6: Height of the CM at amortisation and height of the CM at take-off for the seven analysed jumps.

The values of the height of CM at take-off and at amortisation in our subject are greater than the reference data. The height of the CM at take-off is within limits of the reference data. The heights of the CM in the approach and take-off phases are determined by the body height of an athlete. Elite jumpers, whose values were used as reference data, had lower body heights (169 to 184 cm) than our subject (193 cm).

If we consider the body height of the jumpers, it can be concluded that the acquired values of the analysed parameters of our subject fit within the range of values achieved by other elite jumpers.

Table 9: Maximum height of the CM during the flight, height of flight of the CM and height of the CM relative to the bar for the seven analysed jumps and the range for elite jumpers

HB (cm)	HCM MAX (cm)	H2 (cm)	H3 (cm)
180	191	54.1	11.0
190	194	61.3	4.0
193	204	65.5	11.0
195	196	64.4	1.0
195	199	62.1	4.0
195	199	62.2	4.0
200	204	65.7	4.0
Elite Jumpers	193 - 211	55 - 74	3 - 11

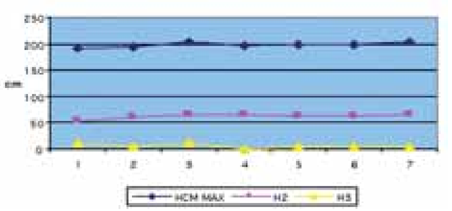

Figure 7: Maximum height of the CM during the flight, height of flight of the CM and height of the CM relative to the bar for the seven analysed jumps.

During amortisation in our subject's highest analysed jump, the height of the CM was 2.23% lower compared to her lowest analysed jump, while at take-off it was 1.01% higher than in the lowest jump.

The height of the CM at take-off is usually within the range of 68-73% of the athlete's body height. For our subject the value is 70.7%, which is consistent with the reference data[7]. Regardless of the increase in body mass, HCMTO in her 2.00m jump increased 1.01% compared to her 1.80m jump.

The heights of the CM in the flight phase are shown by kinematic parameters: *maximum height of the CM during the flight* (HCM-MAX), *height of flight of the CM* (H2) and *height of the CM relative to the bar* (H3), i.e. height above the bar.

H2 represents the difference between the maximum height of the CM and the height of the CM at take-off, and in our subject's analysed jumps this value ranges from 54.1-65.7cm (SD=3.96). These values are consistent with the reference data. The value for H2 increased with the increase in the height of the jump and in her 2.00m jump H2 height increased 17.6% compared to her 1.80m jump. The increase in H2 is a consequence of the increase in the maximum height of the CM (HCMMAX), given the fact that H1 is determined by the anthropometric characteristics of an athlete[10]. Height above the bar (H3) represents the difference between maximal height of CM at the moment of bar crossing (HCMMAX) and the height of the bar. In our subject this value ranges from 1-11 cm (SD=3.86) and her values are consistent with reference data. Our subject decreased her H3 height in the 2.00m jump by 63.6% compared to the 1.80m jump. In her higher jumps (1.95 and 2.00m), the values of this parameter are lower, which points to the good spinal flexibility and rotation around the sagital axis.

Height of the hips above the bar

The height of the hips above the bar (HHIP) in our subject's analysed jumps ranges from

193-213.8cm (SD=7.09cm), and the difference between the maximal height of CM and height of the hips ranges from 2-11.7cm (SD=3.36cm).

Table 10: Heights of the bar, hips and CM for the seven analysed jumps.

HB (cm)	HHIP (cm)	HCM MAX (cm)
180	193.0	191
190	204.5	194
193	213.8	204
195	206.3	196
195	210.7	199
195	210.6	199
200	212.2	204

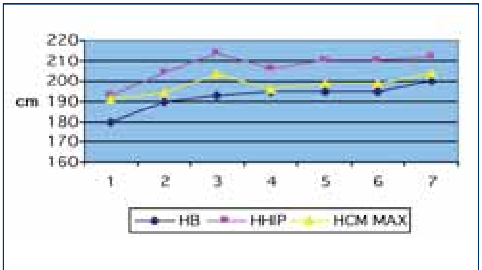

Figure 8: Heights of the bar, hips and CM for the seven analysed jumps.

Given the acquired values for this parameter, it can be concluded that for our subject the height of the hips above the bar increases with the height of the jump, with a standard deviation of 7.09cm. The difference between the height of the hips above the bar and the maximal height of the CM increases with the increase in the height of the jump, and our subject increased the difference in her highest analysed jump 75.6% compared to the lowest analysed jump.

Distance from centre of mass (CM) to bar at touchdown

The distance from CM to the bar at touchdown prior to take-off is shown by the kinematic parameters *toe to bar distance* (TB) and *distance from CM to bar at touchdown* (CMTD).

Table 11: Toe to bar distance and the distance from centre of mass to the bar at touch-down for the seven analysed jumps and the range for elite jumpers

HB (cm)	TB (cm)	CMTD (cm)
180	101.8	153
190	83.9	132
193	102.0	161
195	82.9	128
195	74.2	125
195	74.2	125
200	80.0	125
Elite Jumpers	53.0 - 108	/

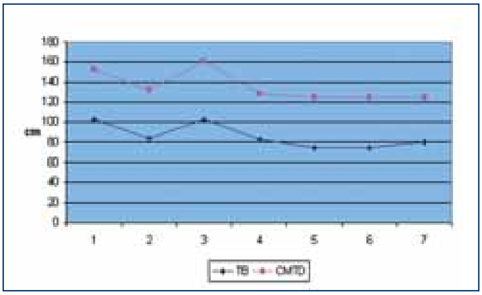

Figure 9: Toe to bar distance and the distance from the centre of mass to the bar at touch-down for the seven analysed jumps.

The values for our subject's toe to bar distance are within the limits of the reference data. In her higher jumps (1.95m and 2.00m), the TB is less than in the lower jumps. Our subject decreased this distance in her 2.00m jump 21.4% compared to her 1.80m jump.

Athletes with higher velocity in the last stride and higher horizontal velocity at take-off, begin the flight phase further away from the bar projection[7]. In our subject's 1.80m jump, the distance between the bar projection was higher than in her other jumps, and the reason for this is the higher horizontal velocity at take-off (5.02m/s).

The distance from the CM to the bar projection at touchdown decreases with an increase in the height of the jump. Our subject reduced the distance in the 2.00m jump 18.3% compared to the same parameter value in her 1.80m jump.

Given the fact that the toe to bar projection distance normally increases with the increase in the height of the jump, the results for our subject showing that the toe to bar projection distance decreases with the increase in the height of the jump indicate insufficient technical preparation and muscular weakness during the run-up and take-off phases in the lower jumps (1.80m to 1.93m). In these, she had difficulties transforming the vertical component of velocity and because of this her take-off was executed somewhat further away from the bar projection.

Table 12: Contact time for the seven analysed jumps and the range for elite jumpers

HB (cm)	CTTO (s)
180	0.20
190	0.18
193	0.18
195	0.18
195	0.18
195	0.18
200	0.18
Elite Jumpers	0.14 – 0.18

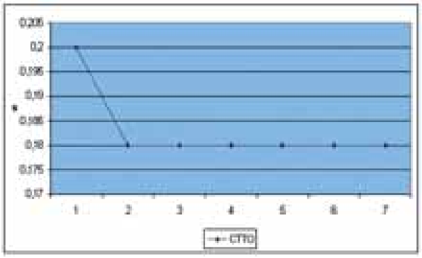

Figure 10: Contact time for the seven analysed jumps

Contact time

Contact time (CTTO) i.e. the time of contact between the take-off leg and the surface, is 0.18s in all of the observed jumps except for the 1.80m jump in which the value was 0.20s (SD=0.007).

The values of the contact time approach the upper limit of the range for other elite high jumpers.

The contact time in the 1.80m jump was 10% longer compared to the other observed jumps, which are, regardless of the height of the jump, constant. Given the fact that all of the jumps were recorded using 60Hz cameras, it is possible that this consistency is a consequence of insufficient sensitivity of the measuring instrument.

Conclusion

From our analysis of kinematic parameters of the approach, take-off and flight phases, as well as the comparison of data with other elite jumpers, it can be concluded that our subject, Blanka Vlasic, is for the most part within the range of the reference data values.

The development in the values recorded for certain parameters over the period of this study point to an improvement in technique and a higher level of fitness. The most noticeable are the increases in the approach velocity and vertical take-off velocity, which resulted in the significant increase in take-off angle. Consistent with this, the approach execution was adjusted, which eventually resulted in an optimal bar approach in the later jumps of the series. Maintaining the high position of the body during the preparation for take-off and the take-of itself is one of the important features of our subject's technique. The parameter that indicates consistency in maintaining the high position of the body is the knee angle of the take-off leg, which had a lowest amortisation value of 144°.

Over the period of this study, our subject's technique of bar crossing became more efficient (H3 value) and some of the jumps were executed with as little as 1cm difference between the height of the CM and the height of the bar.

With improvements in technique and better fitness levels, our subject can achieve further progress in her results. This raises optimism because she is very young, and her current PB of 2.05m gives hope for future world-class achievements.

Systematic follow-up of the studied kinematic parameters enabled our subject to have a fast and rational technique learning process. Kinematic analysis contributed to easier identification of the positive and negative characteristics of her technique. In this way, detected errors were systematically corrected during the training process. For certain technique elements, the coaches modified the existing exercises or developed completely new ones in the training process. The necessity for longitudinal follow-up of high jump technique in developing phases as well as in the phases of technique stabilisation is absolutely justified.

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