3D Biomechanical Analysis of Galina-Samitova's Steeplechase Hurdling

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ABSTRACT

The purpose of this study was to investigate the kinematic parameters of the hurdling of women's steeplechase world record holder Gulnara Galkina-Samitova. Digital video cameras were used to record seven hurdle clearances during the women's 3000m steeplechase event at the Athens Grand Prix "Tsiklitiria" in July 2007. The kinematics of the last stride, the take-off, the clearance, the landing and the first stride after the hurdle were extracted using a 3D-DLT kinematic analysis. Descriptive statistics (mean value, standard deviation and coefficient of variation) were utilised in order to compare parameters of the hurdling technique from lap to lap. It was found that Galkina-Samitova executed her hurdling with greater speed and hurdle stride length than has been reported for women steeplechasers. Her approach stride length increased throughout the race, while a constant lowering of the peak height of the body centre of mass during the hurdle clearance was observed. Differences concerning the knee joint kinematics between the left and right leg were also found. The authors conclude that coaches must give greater emphasis to the bilateral execution of the hurdling technique. Furthermore, it is important to learn to execute hurdle clearances in fatiguing conditions.

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Introduction

The effectiveness of the training of women steeplechasers is built on improved technical development and the development of basic functional systems[1]. From a technical point of view, performance in the steeplechase depends on the hurdle clearance technique and its stability under the fatiguing conditions that occur during the race.

Unlike in other hurdling events, steeplechasers do not race in separate lanes[2]. Instead, they compete along with their rivals around the track and over 28 hurdles and seven water jumps over 3000m. As a consequence, a steeplechaser has to hurdle in a crowd, deciding at each barrier to take the lead or stay behind. The first option is most commonly utilised[3]. For these reasons, good coordination and spatial judgment are required[1].

To minimise the hurdle clearance time, hurdling without stepping on the barrier is the more the commonly used technique, despite the fact that the step-on technique has been found to be superior[4]. Steeplechase hurdling technique is often described as similar to 400m hurdling, with more relaxed clearance actions (less body lean, easy arm actions and the trail leg under the athlete) and a focus on returning to the running rhythm[3,5]. These factors result in a greater body centre of mass (BCM) height (preferably by 5-10cm[6]) over the hurdles than is seen in 400m hurdlers[7]. Taking into account the difference in running velocity, steeplechasers cover more distance in flight compared to the 400m hurdlers[7].

In order to prepare themselves for the take-off, athletes accelerate before the hurdle clearance[2,3,5,6,8,9]. High velocities during the clearance of the hurdle are correlated with fast push-off times for the take-off before the hurdle[10]. The take-off and landing distances are recommended to be approximately up to 1.5m and 1m respectively from the barrier, depending on the athlete's height, leg length and stride length[6,11].

No differences in technique have been found in how athletes clear one hurdle compared with another[12]. Moreover, no differences have been observed in the stride length around the four hurdles on the same lap[12]. However, it has been found that steeplechasers who lead with the same leg on every hurdle make larger adjustments in the last six strides, leading up to two strides from the hurdle[13].

Stride length before and after the hurdle depends on the running velocity of the steeplechaser. As velocity increases throughout the race, the approaching stride lengths gradually increase[10,12,14]. It has also been found that steeplechasers approach the second to last hurdle with greater speed than at all the other hurdles and have longer stride lengths before and after clearing the hurdle[14]. Although women have lower hurdles to clear, it seems they lose more speed over the barrier, compared to male steeplechasers[15].

As for the water jump, approach speed is also an important factor for negotiating it successfully[16]. It has been found that maintaining the race pace can be accomplished by accelerating during the approach to the water jump[16]. This acceleration, along with a relative long landing distance, are essential factors that predict success in water jump clearance by women[16,17]. The water jump has a greater effect on women's race pace compared to men, as they have lower approach velocity, shorter jump distance, smaller hip angle[18], slower exit velocity and greater push-off angle[17].

Most of the above mentioned studies used two-dimensional techniques to evaluate steeplechase hurdling[7,10,12,13,14,16,18]. There is a small number of studies available covering the three-dimensional biomechanics of steeplechasing[4,9,15,17]. This study provides a three-dimensional biomechanical analysis of the hurdle clearance technique and its modification during a women's 3000m steeplechase race by the 2008 Beijing Olympic Champion and world record holder Gulnara Galkina-Samitova.

Methods

Sample and Data Collection

Gulnara Galkina-Samitova was recorded when clearing the first hurdle in every lap during the women's 3000m steeplechase event at the Athens Grand Prix Meeting "Tsiklitiria 2007" (Athens Olympic Stadium, 2 July 2007). Two stationary digital JVC GR-DVL 9600EG (Victor Co., Japan) video cameras, placed on fixed tripods at a height of 1.2m and operating at a sampling frequency of 50 fields/sec, were used for the recording of the 1st, 6th, 11th, 16th, 21st, 26th and 31st barrier clearances (Figure 1). The first camera was placed on the photo-press stands behind the finish line and viewed the hurdle from the front-to-right side, approximately 135° to the plane of motion (Figure 2). The second camera was placed 8m outside the 9th lane and viewed the rear-to-right side of the hurdle, approximately 45° to the plane of motion. Both cameras recorded the last stride, the clearance and the first stride after the hurdle.

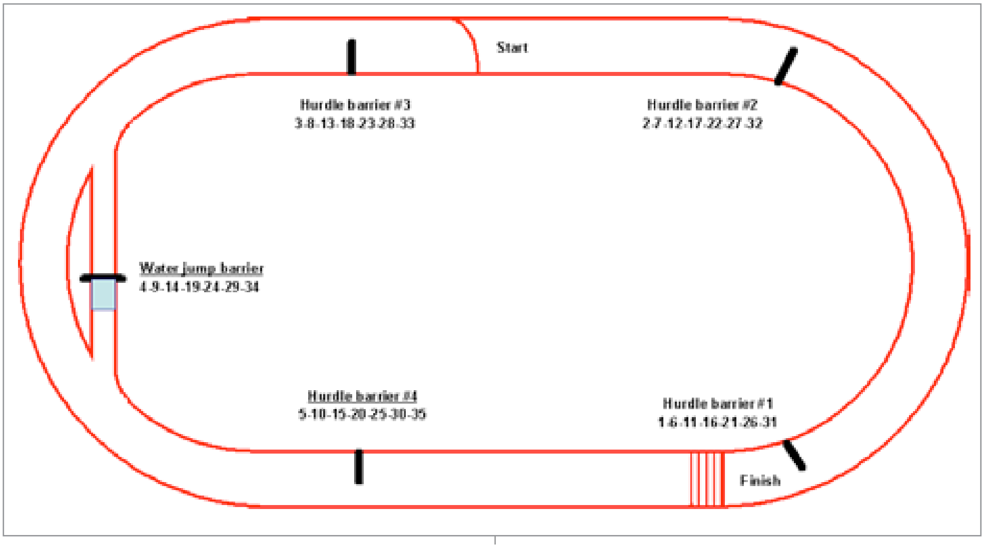

Figure 1: Barrier order for the 3000m steeplechase

Figure 2: Photosequence of Gulnara Galkina-Samitova's clearance of the examined hurdle in her 9:11.68 WL 3000m steeplechase at Athens Grand Prix "Tsiklitiria 2007" as recorded by camera #1

In order to produce three-dimensional coordinates with the use of a 3D-DLT technique[19], the area around the barrier and along the 1st lane was calibrated by placing 2.5m × 0.02m poles at predefined positions on the track. Y-axis was parallel to the long side of the hurdle and perpendicular to X-axis; the Z-axis was perpendicular and vertical to X- and Y-axis (Figure 3).

Data Analysis

Twenty-two anatomical points of the body (tip of the toe, 5th metatarsal, heel, ankle, knee, hip, shoulder, elbow, wrist, fingers on both sides of the body and the head) and selected points of the hurdle and the captured view were manually digitised in each field. The coordinates of the BCM were calculated for every field using a combination of segment parameters and anatomical data[21,22,23]. A 6Hz cut-off frequency, based on residual analysis[24], was selected for smoothing. This procedure allowed the calculation of the biomechanical parameters that illustrate the hurdling technique.

The instant of touchdown (TD) was defined as the first field where the foot clearly contacted the ground. The instant time of take-off (TO) was defined as the first field where the foot clearly left the ground. Thus, contact (T_c) and flight (T_f) time for each stride were recorded. The instant indicated as BARRIER refers to the instant when the BCM was exactly above the hurdle.

The following parameters were calculated based on the XYZ coordinates extracted from the digitised anatomical points:

Stride Length (SL): horizontal distance (S) between the touchdown points of the feet during two consecutive supports.

Horizontal Touchdown-Takeoff Distance (Dx): distance at X-axis from the toe of the support foot to the BCM projection.

Medio-lateral Touchdown to Take-off Distance (D_{TO}): distance at Y-axis from the toe of the support foot to the BCM projection.

Horizontal Velocity (Vx): BCM velocity at X-axis.

Medio-lateral Velocity (Vy): BCM velocity at Y-axis.

Vertical Velocity (Vz): BCM velocity at Z-axis.

Angle of Take-off in the Sagittal Plane (XZ) and **Frontal Plane** (YZ) (AngPr): Arc-tangent of vertical/horizontal BCM velocity and arc-tangement of medio-lateral/vertical velocity at the instant of the takeoff, respectively.

BCM Height (H): BCM height at Z-axis.

Knee Height (Hknee): difference at Z-axis between the hip and the knee of the trail leg at the highest point of the BCM flight trajectory during the clearance.

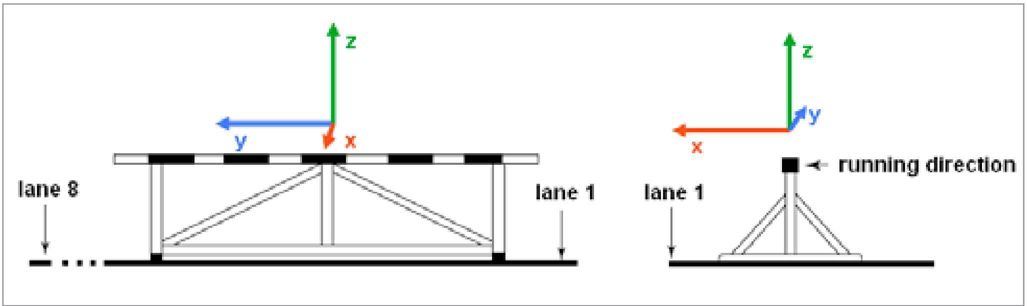

Figure 3: X-, Y- and Z-axis as defined in the present study (hurdle figures originally from the IAAF Competition Rules[20])

Knee Angle (θknee): angle formed in the XZ-plane by the thigh and the shank.

Angular Velocity of the Knee Joint (ωknee) and **Ankle Joint** (ωankle): the angular velocity of the rotation of the shank around the knee joint and the foot's rotation around the ankle joint, respectively.

Angle of Leg Placement in the Sagittal Plane (XZ) and **Frontal Plane** (YZ) (φleg): angle formed in the XZ-plane and the YZ-plane by the horizontal (X-axis) and the line connecting the BCM and the ankle joint, respectively.

Torso Inclination in the Sagittal Plane (XZ) and **Frontal Plane** (YZ) plane (φtorso): angle formed in the XZ-plane and the YZ-plane by the horizontal axis and the line connecting the hip and shoulder mid-axis, respectively.

Digitisation, smoothing and analyses were conducted using the A.P.A.S.-XP software (Ariel Dynamics Inc., Trabuco Canyon, CA). Descriptive statistics, i.e. mean value (x), standard deviation (SD) and coefficient of variance (CV, where CV=SD × 100/x), were utilised for the presentation of the results.

Results

Galkina-Samitova won the event with a performance of 9:11.68, achieving a world leading performance for the year up to that date. She ran the race at an almost even pace (Table 1). During the first kilometre of the race, two athletes were used as pacemakers, with Galkina-Samitova running just behind them. Galkina-Samitova used both legs as the take-off leg (left leg: 4 times, right leg: 3 times).

The results indicate that larger last strides were executed after the clearance of the 16th barrier (Table 2). This finding was combined with smaller sagittal support leg angle placements and shorter take-off distances from the hurdle. The lowest CV for the parameters of the last support before the hurdle was found for the BCM touchdown height. Low variance was found for the BCM height, the knee angle of the push-off leg and the torso inclination in both the sagittal and the frontal plane at the take-off for the clearance of the hurdle (Table 3). Conversely, high CVs were found for the take-off distance at Y-axis and the medio-lateral and vertical BCM take-off velocities.

Table 1: Race analysis of Gulnara Galkina-Samitova's 9:11.68 WL 3000m steeplechase at the Athens Grand Prix "Tsiklitiria 2007", 2 July 2nd 2007

Mark (m):	**228**	**624**	**1020**	**1416**	**1812**	**2208**	**2604**	**3000**	**x**	**SD**	**CV (%)**
Time (min:sec)	0:38	1:50	3:03	4:15	5:29	6:43	7:58	9:11			
Lap Time difference min:sec)	-	1:12	1:13	1:12	1:14	1:14	1:15	1:13	**1:14**	0:01	1.3
Average lap speed (m/sec)	6.00*	5.50	5.35	5.42	5.35	5.35	5.28	5.42	**5.38**	0.07	1.3
Rank 3rd	3rd	2nd	1st	1st	1st	1st	1st				
Barrier	**1st**	**6th**	**11th**	**16th**	**21st**	**26th**	**31st**	**Observations**			
Push-off eg for the clearance	Left	Right	Right	Left	Right	Left	Left	1. Pacemakers used in 1st km 2. Not leading in first 3 laps 3. Close takeoff for barrier #16			

** values are for the first half lap of the entire race*

Table 2: Touchdown parameters for the last support before the examined hurdles in Gulnara Galkina-Samitova's 9:11.68 WL 3000m steeplechase at the Athens Grand Prix "Tsiklitiria 2007", 2 July 2nd 2007

Barrier:	1st	6th	11th	16th	21st	26th	31st	x	SD	CV (%)
SL_{-1}(m)	1.64	1.69	1.75	1.61	1.87	1.90	1.94	**1.77**	0.13	7.5
Vx_{TD} (m/sec)	6.27	5.71	5.66	5.98	5.84	6.27	6.34	**6.01**	0.28	4.7
Vy_{TD}(m/sec)	0.04	0.33	0.61	0.53	0.56	0.65	0.73	**0.49**	0.24	47.7
Vz_{TD} (m/sec)	-0.12	-0.28	-0.36	-0.29	-0.49	-0.60	-0.34	**-0.35**	0.15	43.7
Dx_{TD}(m)	0.40	0.56	0.57	0.50	0.48	0.50	0.48	**0.50**	0.06	11.4
H_{TD}(m)	1.00	0.98	0.99	0.99	0.98	0.95	0.99	**0.98**	0.02	1.6
φleg_{TD}-XZ (°)	72	76	86	60	80	74	69	**74**	8	11.2
φleg_{TD}-YZ (°)	74	88	80	75	82	78	70	**78**	6	7.7

Table 3: Take-off parameters for the clearance of the examined hurdles Gulnara Galkina-Samitova's 9:11.68 WL 3000m steeplechase at the Athens Grand Prix "Tsiklitiria 2007", 2 July 2nd 2007

Barrier:	1st	6th	11th	16th	21st	26th	31st	x	SD	CV (%)
Vx_{TO} (m/sec)	5.70	5.20	5.41	5.75	5.47	5.22	5.71	**5.49**	0.23	4.2
Vy_{TO} (m/sec)	0.00	-0.61	-0.46	0.10	-0.35	-0.47	-0.21	**-0.29**	0.26	91.5
Vz_TO (m/sec)	1.98	2.28	2.56	2.36	2.01	2.23	2.17	**2.23**	0.20	9.0
Dx_{TO} (m)	0.20	0.29	0.27	0.29	0.40	0.36	0.30	**0.30**	0.06	21.3
Dy_{TO} (m)	-0.10	-0.03	0.02	-0.06	-0.01	0.03	-0.12	**-0.04**	0.06	149.3
H_{TO} (m)	1.17	1.20	1.21	1.21	1.20	1.18	1.18	**1.19**	0.02	1.3
φleg_{TO}-XZ (°)	70	71	62	86	64	70	74	**71**	8	11.0
φleg_{TO}-YZ (°)	77	86	81	72	85	81	73	**79**	5	6.8
$\varphi torso_{TO}$-XZ (°)	83	84	86	86	83	85	85	**85**	1	1.5
$\varphi torso_{TO}$-YZ (°)	86	80	87	86	80	82	88	**84**	4	4.2
$\theta knee_{TO}$-push-off (°)	153	165	165	161	160	167	161	**162**	5	2.9
$\theta knee_{TO}$ -swing (°)	76	63	71	74	73	80	71	**73**	5	7.2
$\omega knee_{MAX}$ -swing (rad/sec)	14.1	7.2	13.1	13.2	9.6	12.5	14.0	**12.0**	2.6	21.6
$\omega ankle_{MIN}$ -swing (rad/sec)	-6.5	-3.6	-7.6-	9.8	-4.9	-12.8	-14.4	**-8.5**	4.0	47.3
Push-off Time (sec)	0.14	0.16	0.16	0.14	0.16	0.16	0.14	**0.15**	0.01	7.1
S_{TO} from barrier (m)	1.61	1.45	1.51	1.22	1.36	1.32	1.28	**1.39**	0.14	9.9
AngPr - XZ (°)	19.2	23.7	25.3	22.3	20.2	23.1	20.8	**22.1**	2.1	9.7
AngPr - YZ (°)	0.0	11.7	8.9	1.7	7.6	9.6	4.7	**6.3**	4.3	68.4

The knee was more extended when the left leg was used as the lead leg (Table 4). The torso inclination in the frontal plane, when the athlete was exactly above the hurdle, was constantly increasing during the race. An upward movement of the BCM over the hurdle was observed after the 11th hurdle. Also, a constant lowering of peak BCM height during the hurdle stride was recorded after the 6th hurdle. Furthermore, a larger minimum knee angle for the trail leg was found during the last two laps.

Low CV values were recorded for the length of the hurdle stride, the BCM height over the hurdle, the maximum BCM height during the flight and the torso inclinations at both the sagittal and the frontal plane. However, a high variance was found for the distance of peak BCM height from the hurdle during the flight and the medio-lateral and vertical BCM velocity.

Table 4: Hurdle clearance parameters for the last support before the examined hurdles in Gulnara Galkina-Samitova's 9:11.68 WL 3000m steeplechase at the Athens Grand Prix "Tsiklitiria 2007", 2 July 2nd 2007

Barrier:	1st	6th	11th	16th	21st	26th	31st	x	SD	CV (%)
Flight Time (sec)	0.46	0.48	0.48	0.46	0.46	0.46	0.46	**0.47**	0.01	2.1
Hurdle stride (m)	3.01	2.89	2.92	2.88	2.88	2.98	2.86	**2.92**	0.06	1.9
Average clearance speed (m/sec)	6.54	6.02	6.08	6.26	6.26	6.48	6.22	**6.27**	0.19	3.0
Clearance Ratio (S_{TO}/S_{TD})	1.15	1.01	1.07	0.73	0.89	0.80	0.81	**0.92**	0.16	16.9
$H_{BARRIER}$ (m)	1.40	1.44	1.41	1.41	1.39	1.37	1.38	**1.40**	0.02	1.6
H_{MAX} (m)	1.41	1.45	1.44	1.42	1.41	1.40	1.40	**1.42**	0.02	1.4
S from barrier (m) when H_{MAX}	-0.16	-0.25	-0.33	0.15	-0.14	0.14	0.30	**-0.04**	0.24	571.8
$Vx_{BARRIER}$ (m/sec)	5.68	5.80	5.19	5.64	5.14	5.44	5.13	**5.43**	0.28	5.2
$Vy_{BARRIER}$ (m/sec)	-0.56	0.15	0.13	-0.48	0.42	0.25	0.57	**0.07**	0.43	628.5
$Vz_{BARRIER}$ (m/sec)	-0.32	-0.35	-0.67	0.47	0.09	0.31	0.33	**-0.02**	0.43	2145.7
$\theta knee_{MAX}$ -lead (°)	173	143	143	165	144	170	169	**158**	14	8.9
$\theta knee_{MIN}$ -trail (°)	42	29	31	28	32	62	62	**41**	15	37.1
$\omega knee_{MAX}$ -lead (rad/sec)	14.1	5.7	13.1	13.2	11.8	12.8	17.7	**12.6**	3.6	28.4
$\omega ankle_{MAX}$ -lead (rad/sec)	6.0	7.6	4.8	14.0	5.8	6.9	5.1	**7.2**	3.2	44.1
$\omega knee_{MIN}$ -trail (rad/sec)	-12.8	-13.0	-15.7	-13.4	-15.4	-12.4	-13.9	**-13.8**	1.3	9.3
$\omega ankle_{MIN}$ -trail (rad/sec)	-7.6	-7.7	-5.5	-4.7	-7.7	-5.0	-8.7	**-6.7**	1.6	23.6
$\varphi torso_{BARRIER}$ -XZ (°)	86	87	88	88	82	84	85	**86**	2	2.9
$\varphi torso_{BARRIER}$ -YZ (°)	83	85	87	87	88	88	90	**87**	2	2.5
Hknee-trail (m)	-0.35	-0.47	-0.45	-0.36	-0.48	-0.33	-0.37	**-0.40**	0.10	15.7

During the flight over the 31st barrier, Galkina-Samitova's horizontal and vertical BCM velocity seemed to be smoother than that over the 1st barrier (Figure 4). However, larger fluctuations were observed concerning the medio-lateral BCM velocity when hurdling over the 31st hurdle.

As for the sagittal BCM flight trajectory, a similar path up to the hurdle was observed between the 16th and the 31st barrier (Figure 5). The flight path was shorter and ended with a lower BCM touchdown height for the landing of 31st barrier clearance. As for the clearance of the 1st barrier, Galkina-Samitova performed it with a larger BCM flight path, which was evenly distributed before and after the hurdle.

Concerning the landing after the hurdle, the left leg landed with a larger placement angle than the right leg (Table 5). After the pacemakers withdrew, Galkina-Samitova took the lead and landed closer to the inside of the lane.

A constant decrease of vertical BCM touchdown velocity was observed after the 16th hurdle. In the last two clearances of the examined hurdle, the knee angle of the trail leg was larger. Low CV values were observed for the BCM touchdown height, the knee ankle of the support leg and the torso inclination at the frontal plane. On the opposite, the highest variance was recorded for the medio-lateral BCM touchdown velocity.

Finally, lower knee joint angular velocities were observed when the right leg was the swing leg during the support after the hurdle (Table 6). Furthermore, the ankle joint of the lead leg changed its function from extension to flexion after the clearance of the 16th hurdle. As for the take-off for the first stride after the hurdle, high variability was found for the medio-lateral BCM velocity and the ankle joint angular velocity of the lead leg. Small CVs were recorded for the time of take-off, the BCM take-off height and the knee angle of the take-off leg.

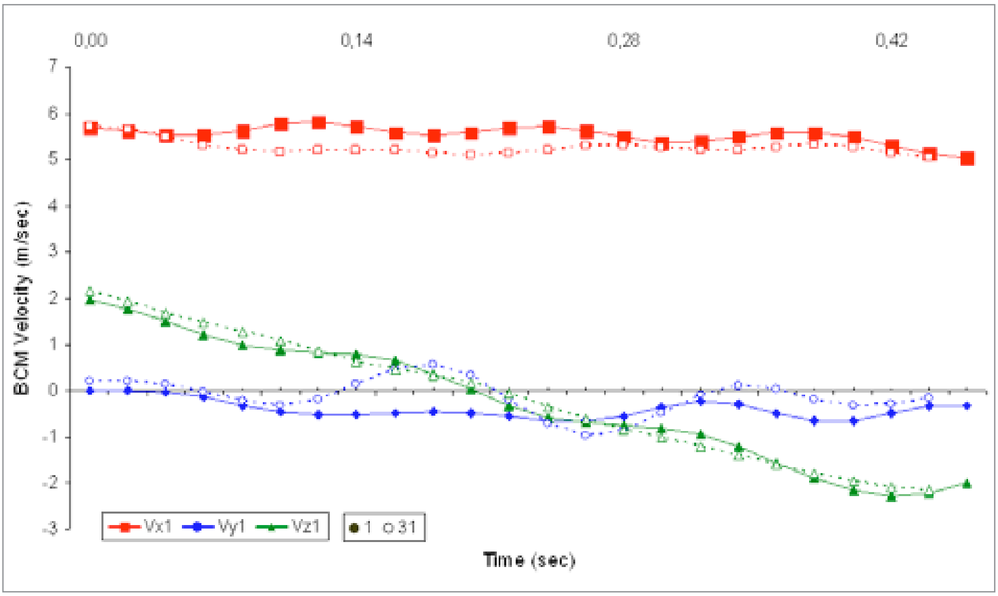

Figure 4: The horizontal (Vx: □), saggital (Vy: O) and vertical (Vz: Δ) velocity of the Body Center of Mass (BCM) from the takeoff (time=0.00sec) to the touchdown after the hurdle for the clearance of the 1st (filled data points) and 31st barrier (empty data points) in Gulnara Galkina-Samitova's 9:11.68 WL 3000m steeplechase at the Athens Grand Prix "Tsiklitiria 2007", 2 July 2nd 2007

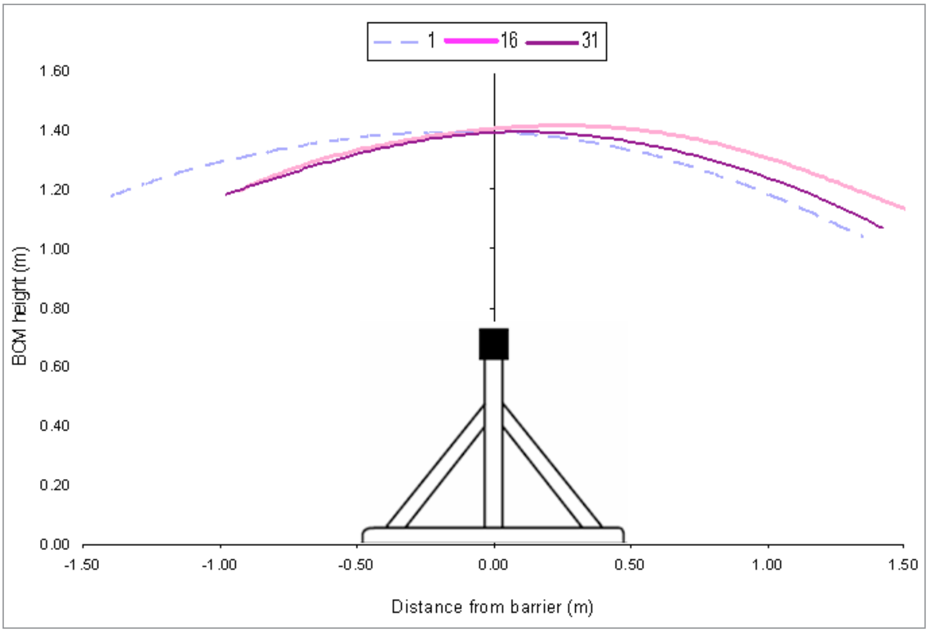

Figure 5: Saggital view of the Body Center of Mass (BCM) trajectory during the clearance of the 1st, the 16th and the 31st barrier in Gulnara Galkina-Samitova's 9:11.68 WL 3000m steeplechase at the Athens Grand Prix "Tsiklitiria 2007", 2 July 2nd 2007

Table 5: Landing parameters after the clearance of the examined hurdle in Gulnara Galkina-Samitova's 9:11.68 WL 3000m steeplechase at the Athens Grand Prix "Tsiklitiria 2007", 2 July 2nd 2007

Barrier	1st	6th	11th	16th	21st	26th	31st	x	SD	CV (%)
S_{TD} from barrier (m)	1.39	1.25	1.40	1.54	1.50	1.47	1.60	**1.45**	0.12	7.9
Dx_{TD} (m)	0.05	0.21	0.21	0.11	0.14	0.19	0.17	**0.15**	0.06	38.1
Dy_{TD} (m)	-0.02	-0.12	-0.05	-0.04	-0.09	0.00	-0.08	**-0.06**	0.04	73.4
H_{TD} (m)	1.03	1.07	1.07	1.12	1.03	1.07	1.07	**1.07**	0.03	2.9
Vx_{TD} (m/sec)	5.04	4.47	4.93	5.11	4.90	4.82	5.01	**4.90**	0.21	4.3
Vy_{TD} (m/sec)	-0.34	0.23	-0.15	-0.42	-0.33	0.02	-0.07	**-0.15**	0.23	152.8
Vz_{TD} (m/sec)	-1.99	-2.33	-2.45	-2.67	-2.16	-2.22	-2.14	**-2.28**	0.23	9.9
$\theta knee_{TD}$ -support (°)	162	163	159	166	164	167	160	**163**	3	1.8
$\theta knee_{TD}$-swing (°)	109	161	111	90	116	90	78	**108**	27	25.2
φleg_{TD}-XZ (°)	84	73	77	85	75	81	87	**80**	5	6.6
φleg_{TD}-YZ (°)	88	82	83	77	86	84	83	**83**	4	4.2
$\theta knee_{MIN}$ -support (°)	152	138	146	151	149	150	150	**148**	5	3.2

Table 6: Take-off parameters for the first stride between the hurdles in Gulnara Galkina-Samitova's 9:11.68 WL 3000m steeplechase at the Athens Grand Prix "Tsiklitiria 2007", 2 July 2nd 2007

Barrier	**1st**	**6th**	**11th**	**16th**	**21st**	**26th**	**31st**	**x**	**SD**	**CV (%)**
Vx_{TO} (m/sec)	5.48	5.06	5.15	5.74	5.12	5.41	5.82	**5.40**	0.30	5.6
Vy_{TO} (m/sec)	-0.15	-0.11	0.21	-0.82	-0.46	0.79	0.14	**-0.06**	0.51	899.0
Vz_{TO} (m/sec)	-0.67	-0.02	-0.15	-1.01	-0.34	-0.40	-0.27	**-0.41**	0.33	81.9
Dx_{TO} (m)	0.48	0.43	0.50	0.57	0.50	0.48	0.52	**0.50**	0.04	8.6
H_{TO} (m)	0.95	0.94	0.92	0.97	0.89	0.92	0.94	**0.93**	0.03	2.75
AngPr - XZ (°)	-7.0	-0.3	-4.8	-10.8	-4.6	-4.2	-3.2	**-5.0**	3.3	65.4
Support Time (sec)	0.14	0.14	0.14	0.14	0.14	0.14	0.14	**0.14**	0	0
$\theta knee_{TO}$ -push-off (°)	144	143	152	147	145	153	151	**148**	4	2.8
$\theta knee_{TO}$ -swing (°)	158	153	156	160	158	173	168	**161**	7	4.4
$\omega knee_{MAX}$ -swing (rad/sec)	10.8	10.2	10.3	15.4	11.1	17.1	15.8	**13.0**	3.0	23.2
$\omega ankle_{MAX}$ -swing (rad/sec)	3.8	5.6	3.6	3.3	-9.4	-6.1	-6.4	**-0.8**	6.2	776.8
$\varphi torso_{TO}$-XZ (°)	80	82	80	89	80	83	87	**83**	4	4.3
$\varphi torso_{TO}$-YZ (°)	89	90	87	87	89	87	83	**87**	2	2.7
SL_{+1} (m)	1.26	1.04	1.09	1.27	1.13	1.20	1.19	**1.17**	0.09	7.4
ΔVx (%)	-12.6	-11.4	-9.0	-4.0	-12.3	-13.7	-8.2	**-10.2**	3.4	33.0
Stride ratio (SL_{-1}/SL_{+1})	0.77	0.62	0,62	0.79	0.60	0.63	0.61	**0.66**	0.08	11.9

Discussion

Galkina-Samitova's result in the 3000m steeplechase at the Athens Grand Prix "Tsiklitiria 2007" was at a high standard, as it was the 17th fastest time ever for the event at the end of the 2009 season[25]. The comparison of the intermediate times presented in Table 1 with those reported for the final of the 2009 IAAF World Championships in Athletic, where she clocked a similar result (9:11.09)[26], indicate that she actually ran faster during the first 2.6km in the 2007 race in Athens.

Although it has been found that stride lengths gradually increase as running velocity increases throughout the race[10,12,14], Galkina-Samitova increased her approach stride length throughout the race without changing pace. The average distance from the take-off point of the last stride to the landing point of the first stride after the hurdle was larger than has been previously reported[12]. As mentioned elsewhere[9], her velocity was higher than the Athens 2007 race pace during the last stride before the barrier. The average percent of horizontal velocity loss after the clearance of the barrier was 10.2%, which was in accordance with the relationship between velocity loss and clearance height found by INGEBRETSEN ET AL[15]. It is worth noting that this percentage was lower than those measured for women steeplechasers[7].

The average take-off distance from the hurdle was 1.39m, within the range proposed[6,11], but lower than found for women steeplechasers[7]. The average landing distance was 1.45m. This finding, along with the hurdle stride length (average: 2.92m), was larger than those reported in the above mentioned studies. The suggestion that slower running pace results in a slightly shorter hurdle stride[2] was not supported, since the results of the present study revealed that the stride after the barrier was shorter[2].

The average angles of sagittal leg placement for the take-off and the touchdown at the hurdles found in the present study were similar to those reported by BOLLSCHWEILER[7]. Contrary to the findings of that study, Galkina-Samitova during the Athens 2007 race had her torso in a more upright position and had a larger vertical difference between the hip and the knee of the trail leg at the highest point of the BCM flight trajectory during the clearance.

The small variance observed for the clearance height is commonly observed for women steeplechasers[15]. In the present study, the small variance for the height of the BCM in every phase of the hurdle clearance was associated to the athlete's anthropometric factors and the stability of the movements (technique) for acquiring the take-off and touchdown body positioning. This is supported by the fact that low CV were found for the knee joint angle of the support leg at take-off and touchdown, the torso inclination in both sagittal and frontal planes and the duration of the support and flight phases of the hurdle clearance.

The need for energy conservation over the 3000m race might be the cause of the constant decrease in the peak height of the BCM during the clearance of the barrier. This lowering of the BCM flight path started after the 6th barrier. This fact, associated with the decreased vertical BCM touchdown velocity after the 16th barrier, revealed a more economic hurdling technique during the late stages of the race. Specifically, during the last two laps, the need for a quicker first stride after the hurdle, with a lower metabolic cost, was evident, since a faster knee extension and a larger knee angle of the swing leg at the instant of take-off was observed.

Galkina-Samitova increased the length of the approach stride and decreased the take-off distance from the hurdle throughout the race. During the race, the peak height of the BCM constantly decreased. However, the torso inclination during the clearance was constantly increased. Furthermore, a trend for altering the movement patterns during the race was revealed. For instance, from the fourth lap on, the BCM was moving upwards instead of downwards when it was exactly above the hurdle. Also, the knee of the lead leg extended with approximately twice the angular velocity of the flexion of the ankle until the 21st hurdle. From that point on, the angular extension/flexion velocities of both joints were equal. This might be a result of stepping closer to the hurdle with a higher approach speed. Finally, the ankle joint of the lead leg was extending during the take-off for the first stride after the hurdle from the first lap of the race until the 16th hurdle. After that point of the race, the ankle joint was flexed at the same instant. All these changes are fatigue related[27,28].

The high CV observed mainly for the parameters associated with the medio-lateral (Y) axis was due to the differentiations caused by using either leg as the push-off leg, since Galkina-Samitova cleared the examined hurdle using both the right and the left leg for the push-off. Specifically, lower leg placement angles in both the sagittal and frontal planes were observed when she used the left leg for the push-off. On this occasion, a smaller vertical knee-hip distance occurred by the trail leg. This caused smaller touchdown and larger take-off knee angles during the first support after the hurdle. All the above factors resulted in a shorter length of the first stride between the hurdles. On the other hand, when the left leg was used as the lead leg, the knee angle extended more than the right leg and it was more flexed during the landing. This larger amortisation action of the left leg indicates that larger amounts of energy were consumed in order to terminate the support phase in the given time. In general, it is a distinct advantage for steeplechasers to hurdle with either foot and to master the hurdling techniques (leading and trailing functions) in either leg, in order to sustain rhythm during the race[2,8,29]. This is important, because steeplechasers who lead with the same leg at every barrier jump are either over or under striding in the approach, resulting in either decreased approach horizontal velocity or an increased metabolic cost[13].

Conclusion

Galkina-Samitova executed the steeplechase barrier hurdling with greater velocity and hurdle stride length than previously reported for women steeplechasers. The least variable technique elements detected in the present study were:

i) the BCM height in all the phases of the barrier hurdling
ii) the knee joint angle of the support leg at take-off and touchdown
iii) the torso inclination in both sagittal and frontal planes, and
iv) the duration of the support and the flight over the hurdle.

Her approach stride length increased throughout the race, while a constant lowering of the peak height of the BCM during the clearance of the hurdle was observed. Differences concerning the knee joint kinematics between the left and right leg were also found. Greater emphasis must be given to the bilateral execution of the steeplechase hurdling technique and to execute hurdle clearances under fatiguing conditions.

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