IAAF World Championships
LONDON 2017

BIOMECHANICAL REPORT

FOR THE

IAAF World Championships
LONDON 2017

Triple Jump Women's

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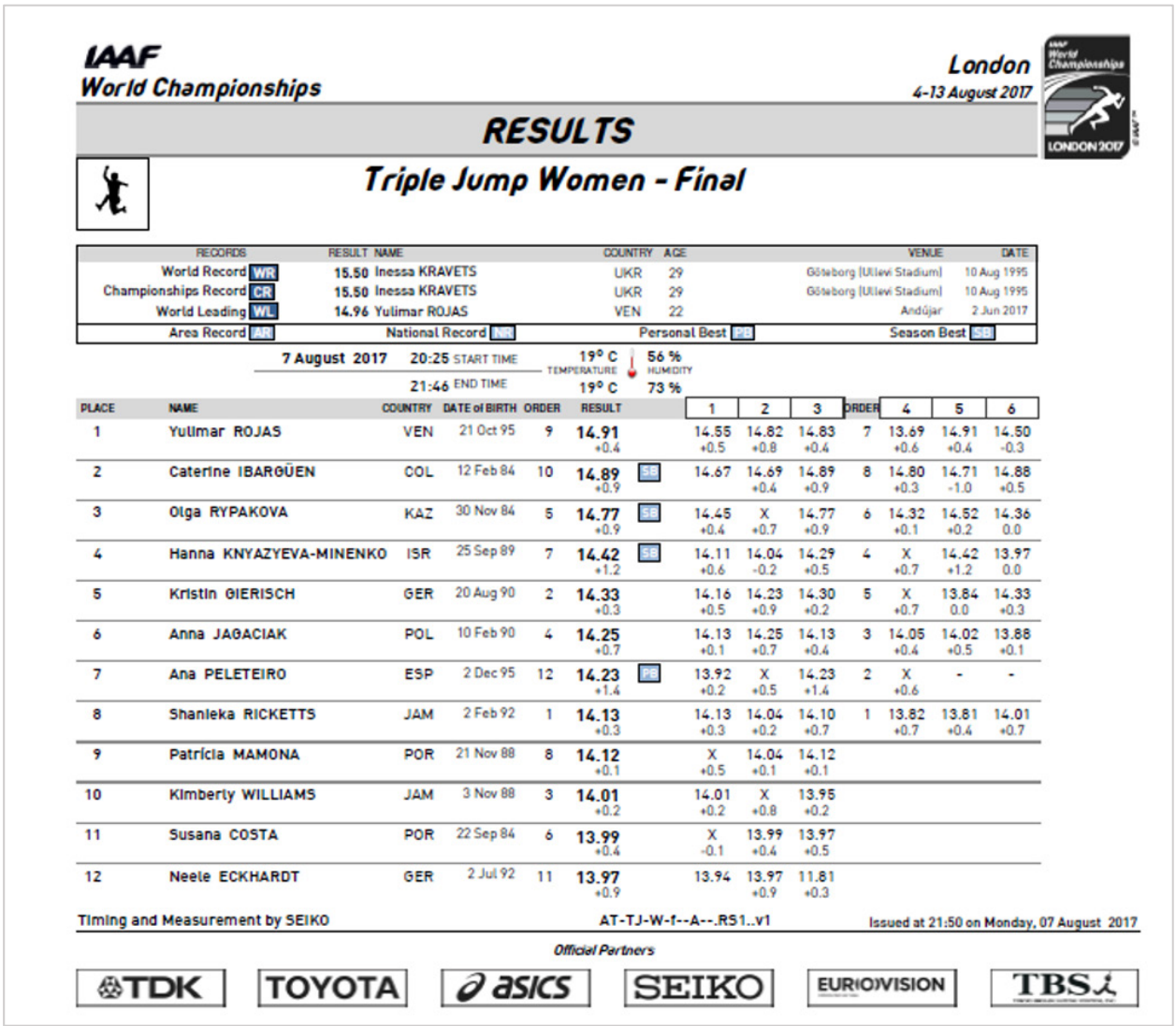
INTRODUCTION

The women's triple jump finals took place on the night of August 7th in warm and still weather conditions. Coming into the event, it was predicted to be a battle between Yulimar Rojas of Venezuela and Caterine Ibargüen from Colombia. It ended up being a close battle between the two South Americans. However, it was a fifth round jump of 14.91 metres that clinched the gold medal for Rojas ahead of Ibargüen who had led from the third round with 14.89 metres. She was unable to better Rojas in her final round and so had to settle for silver. Olga Rypakova of Kazakhstan claimed the bronze medal with her third round jump of 14.77 metres.



IAAF World Championships — London 4-13 August 2017

RESULTS

Triple Jump Women - Final

RECORDS	RESULT	NAME	COUNTRY	AGE	VENUE	DATE
World Record WR	15.50	Inessa KRAVETS	UKR	29	Göteborg (Ullevi Stadium)	10 Aug 1995
Championships Record CR	15.50	Inessa KRAVETS	UKR	29	Göteborg (Ullevi Stadium)	10 Aug 1995
World Leading WL	14.96	Yulimar ROJAS	VEN	22	Andújar	2 Jun 2017

Area Record AR · National Record NR · Personal Best PB · Season Best SB

7 August 2017 — 20:25 START TIME — 19° C TEMPERATURE — 56 % HUMIDITY
21:46 END TIME — 19° C — 73 %

PLACE	NAME	COUNTRY	DATE of BIRTH	ORDER	RESULT		1	2	3	ORDER	4	5	6
1	Yulimar ROJAS	VEN	21 Oct 95	9	14.91 +0.4		14.55 +0.5	14.82 +0.8	14.83 +0.4	7	13.69 +0.6	14.91 +0.4	14.50 -0.3
2	Caterine IBARGÜEN	COL	12 Feb 84	10	14.89 +0.9	SB	14.67	14.69 +0.4	14.89 +0.9	8	14.80 +0.3	14.71 -1.0	14.88 +0.5
3	Olga RYPAKOVA	KAZ	30 Nov 84	5	14.77 +0.9	SB	14.45 +0.4	X +0.7	14.77 +0.9	6	14.32 +0.1	14.52 +0.2	14.36 0.0
4	Hanna KNYAZYEVA-MINENKO	ISR	25 Sep 89	7	14.42 +1.2	SB	14.11 +0.6	14.04 -0.2	14.29 +0.5	4	X +0.7	14.42 +1.2	13.97 0.0
5	Kristin GIERISCH	GER	20 Aug 90	2	14.33 +0.3		14.16 +0.5	14.23 +0.9	14.30 +0.2	5	X +0.7	13.84 0.0	14.33 +0.3
6	Anna JAGACIAK	POL	10 Feb 90	4	14.25 +0.7		14.13 +0.1	14.25 +0.7	14.13 +0.4	3	14.05 +0.4	14.02 +0.5	13.88 +0.1
7	Ana PELETEIRO	ESP	2 Dec 95	12	14.23 +1.4	PB	13.92 +0.2	X +0.5	14.23 +1.4	2	X +0.6	-	-
8	Shanieka RICKETTS	JAM	2 Feb 92	1	14.13 +0.3		14.13 +0.3	14.04 +0.2	14.10 +0.7	1	13.82 +0.7	13.81 +0.4	14.01 +0.7
9	Patrícia MAMONA	POR	21 Nov 88	8	14.12 +0.1		X +0.5	14.04 +0.1	14.12 +0.1				
10	Kimberly WILLIAMS	JAM	3 Nov 88	3	14.01 +0.2		14.01 +0.2	X +0.8	13.95 +0.2				
11	Susana COSTA	POR	22 Sep 84	6	13.99 +0.4		X -0.1	13.99 +0.4	13.97 +0.5				
12	Neele ECKHARDT	GER	2 Jul 92	11	13.97 +0.9		13.94	13.97 +0.9	11.81 +0.3				

Timing and Measurement by SEIKO — AT-TJ-W-f--A--.RS1..v1 — Issued at 21:50 on Monday, 07 August 2017

Official Partners

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METHODS

Seven vantage locations for camera placement were identified and secured. These locations were situated in the stand along the back straight in line with the runway. A calibration procedure was conducted before and after each competition. A rigid cuboid calibration frame was positioned on the run up area multiple times over discrete predefined areas along the runway to ensure an accurate definition of a volume within which athletes were achieving running their last two steps before the take-off board and their hop, step and jump.

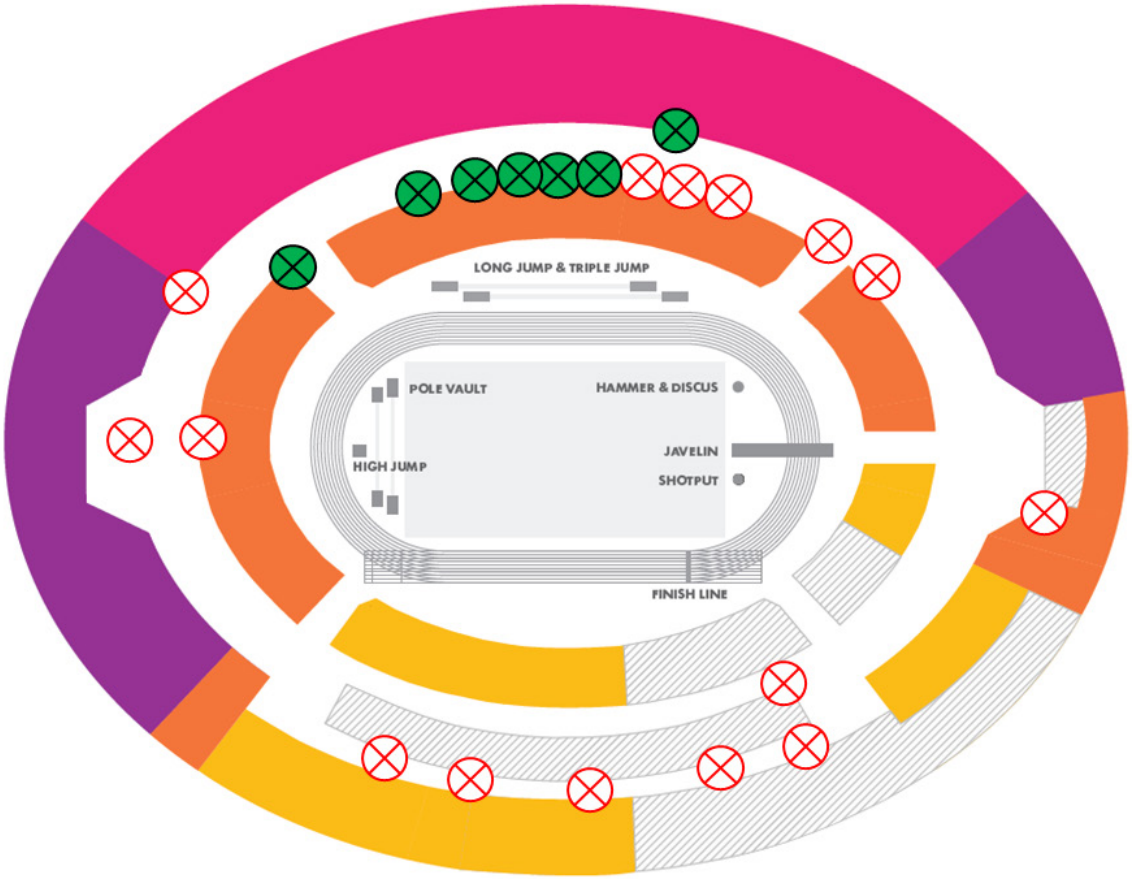


Figure 1. Camera locations within the stadium for the women's triple jump final (shown in green).

Nine cameras were used to record the action during the triple jump final. Three Sony PXW-FS5 cameras operating at 200 Hz (shutter speed: 1/1750; ISO: 2500; FHD: 1920x1080 px) were used to capture the motion of athletes as they were moving through the calibrated area of the run-up to the take-off board. Six Canon EOS 700D cameras operating at 60 Hz (shutter speed: 1/1000; ISO: 1600; SHD: 1280x720 px) were positioned in line with the runway to capture the kinematics of the hop, step and jump sections of the triple jump including landing. These cameras operated in pairs to capture these zones of movement for the athletes.

The video files were imported into SIMI Motion (SIMI Motion version 9.2.2, Simi Reality Motion Systems GmbH, Germany) and were manually digitised by a single experienced operator to

obtain kinematic data. An event synchronisation technique (synchronisation of four critical instants) was applied through SIMI Motion to synchronise the two-dimensional coordinates from each camera involved in the recording. Digitising started 15 frames before the beginning of the step and completed 15 frames after to provide padding during filtering. Each file was first digitised frame by frame and upon completion adjustments were made as necessary using the points over frame method, where each point (e.g. right knee joint) was tracked through the entire sequence. The Direct Linear Transformation (DLT) algorithm was used to reconstruct the three-dimensional (3D) coordinates from individual camera's x and y image coordinates. Reliability of the digitising process was estimated by repeated digitising of one jump with an intervening period of 48 hours. The results showed minimal systematic and random errors and therefore confirmed the high reliability of the digitising process. De Leva's (1996) body segment parameter models were used to obtain data for the whole body centre of mass (CM). A recursive second-order, low-pass Butterworth digital filter (zero phase-lag) was employed to filter the raw coordinate data. The cut-off frequencies were calculated using residual analysis.

Figure 2. The calibration frame was constructed and filmed before and after the competition.

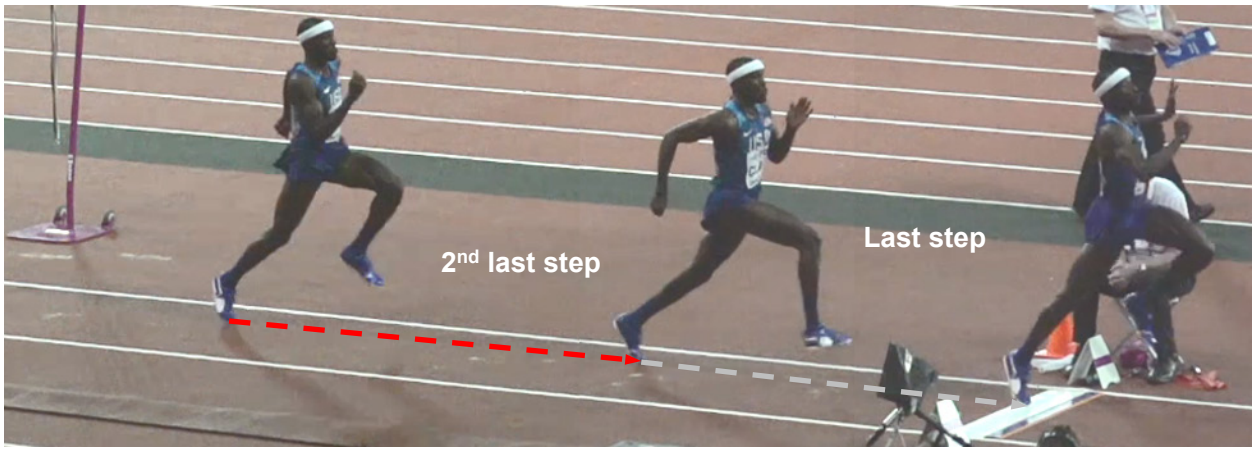


Figure 3. The last two steps before the take-off board in the triple jump.

Table 1. Definition of variables analysed in the triple jump final.

Variable	Definition
Official distance	The official distance published in the results.
Effective distance	The distance from the foot tip at take-off to the mark in the sand that is closest to the take-off board.
Take-off loss	The distance from the foot tip (take-off foot) to the front edge of the take-off board.
Step length (2nd last and last step before take-off board)	The length of the second-last and last approach steps before the take-off board measured from the foot tip in each step to the next foot tip.
Step length (hop, step and jump)	The length of the hop, step and jump as measured from the foot tip in each step to the next foot tip.
Relative step length (hop, step and jump)	The percentage length of the hop, step and jump relative to the effective distance.
Velocity (2nd last and last step before take-off, hop, step and jump)	The mean horizontal (anteroposterior) centre of mass (CM) velocity of the athlete measured during the last two steps before the take-off board as well as the hop step and jump. The horizontal velocity was also measured at the instant of take-off of the hop, step and jump.
Vertical velocity (hop, step and jump)	The athlete's vertical CM velocity at the instant of take-off of the hop, step and jump.
Change in horizontal velocity (hop, step and jump)	The difference between the horizontal velocity at take-off for the hop, step and jump, relative to the value at toe-off of the preceding step.
Contact time (hop, step and jump)	The time spent in contact during the support phase of the hop, step and jump.
Trunk angle	The angle of the trunk relative to the horizontal and considered to be 90° in the upright position measured at touchdown (TD) and take-off (TO) of the hop, step and jump contact

	phases. This was also measured at instant of landing.
Take-off angle	The angle of the athlete's CM at take-off relative to the horizontal of the hop, step and jump.
Knee angle	The angle between the thigh and lower leg and considered to be 180° in the anatomical standing position. This was measured when it reached its minimum during contact of the hop, step and jump. It was also measured at the instant of landing.
Thigh angle of swing leg	The angle of the thigh of the swinging leg measured from the horizontal at take-off of the hop, step and jump.
Thigh angular velocity of swing leg	The mean angular velocity of the thigh of the swinging leg from initial contact to take-off of the hop, step and jump.
CM lowering (hop, step and jump)	The reduction in CM height from take-off of the last step to the minimum CM height during the contact phases of the hop, step and jump.
Hip angle	The angle between the trunk and thigh and considered to be 180° in the anatomical standing position. This was measured at the instant of landing.
Landing distance	The distance from the athlete's heel to the centre of mass at the first contact in the pit.
Landing loss	The distance between the first contact point in the sand and the point to which the measurement was made. A value of zero indicates no landing loss.

Note: *CM = centre of mass.*

RESULTS

Overall analysis

Table 2 below provides the official recorded distance of each athlete along with its comparison with their personal and season best. Peleteiro was the only athlete to jump a personal best, improving on her previous best by a centimetre. Three other athletes jumped season's bests including the silver and bronze medallists.

Table 2. Competition results in comparison with athletes' personal bests (PB) and season's bests (SB) for 2017 (before World Championships).

Athlete	Rank	Official distance (m)	SB (2017) (m)	Comparison with SB (m)	PB (m)	Comparison with PB (m)
ROJAS	1	14.91	14.96	−0.05	15.02	−0.11
IBARGÜEN	2	14.89	14.86	0.03	15.31	−0.42
RYPAKOVA	3	14.77	14.64	0.13	15.25	−0.48
KNYAZYEVA-MINENKO	4	14.42	14.17	0.25	14.78	−0.36
GIERISCH	5	14.33	14.40	−0.07	14.46	−0.13
JAGACIAK	6	14.25	14.29	−0.04	14.33	−0.08
PELETEIRO	7	14.23	14.22	0.01	14.22	0.01
RICKETTS	8	14.13	14.38	−0.25	14.57	−0.44
MAMONA	9	14.12	14.42	−0.30	14.65	−0.53
WILLIAMS	10	14.01	14.54	−0.53	14.62	−0.61
COSTA	11	13.99	14.38	−0.39	14.57	−0.58
ECKHARDT	12	13.97	14.35	−0.38	14.35	−0.38

Note: *Negative values represent a shorter jump in the World Championship final compared with the PB and SB.*

Table 3 provides some distance characteristics of each athlete's best jumps in relation to their effective distance and distance lost at the take-off board. The lowest loss at the take-off board was by Costa with a 1 centimetre loss and the highest loss was by Mamona with a loss of 20 centimetres. The mean loss was 7 centimetres. Table 4 below shows the step lengths of each finalist for the last two steps before the take-off board, the hop, step and jump.

Table 3. Distance characteristics of the individual best jumps.

Athlete	Analysed attempt	Official distance (m)	Effective distance (m)	Take-off loss (m)
ROJAS	5	14.91	15.02	0.11
IBARGÜEN	3	14.89	14.92	0.03
RYPAKOVA	3	14.77	14.86	0.09
KNYAZYEVA-MINENKO	5	14.42	14.45	0.03
GIERISCH	6	14.33	14.43	0.10
JAGACIAK	2	14.25	14.32	0.07
PELETEIRO	3	14.23	14.25	0.02
RICKETTS	1	14.13	14.17	0.04
MAMONA	3	14.12	14.32	0.20
WILLIAMS	1	14.01	14.07	0.06
COSTA	2	13.99	14.00	0.01
ECKHARDT	2	13.97	14.03	0.06

Table 4. Step length data for the two steps before the take-off board and the hop, step and jump.

Athlete	2nd last (m)	Last (m)	Hop (m)	Step (m)	Jump (m)
ROJAS	2.48	2.27	5.21	3.95	5.86
IBARGÜEN	2.35	2.15	5.49	4.02	5.41
RYPAKOVA	2.17	2.45	5.26	4.35	5.25
KNYAZYEVA-MINENKO	2.38	2.35	5.24	3.89	5.32
GIERISCH	2.17	2.26	5.06	4.20	5.17
JAGACIAK	2.07	2.05	5.40	3.96	4.96
PELETEIRO	2.06	2.13	5.37	3.61	5.27
RICKETTS	2.32	2.06	5.02	3.98	5.17
MAMONA	2.32	2.13	5.11	4.38	4.83
WILLIAMS	2.03	1.90	5.54	3.78	4.75
COSTA	2.36	2.14	5.15	3.97	4.88
ECKHARDT	1.86	2.02	4.75	4.15	5.13

Note: *The hop, step and jump distances were provided by deltatre.*

Table 5 and Figure 4 illustrate the contribution of the hop, step and jump (relative percentage) to the effective distance. Table 4 also shows the technique used by each athlete (classified as either hop- or jump-dominated if the difference in relative percentage of the hop and jump was greater than 2%).

Table 5. Relative percentage of the hop, step and jump to overall effective distance and the technique employed.

Athlete	Hop (%)	Step (%)	Jump (%)	Technique
ROJAS	34.7	26.3	39.0	Jump-dominated
IBARGÜEN	36.8	26.9	36.3	Balanced
RYPAKOVA	35.4	29.3	35.3	Balanced
KNYAZYEVA-MINENKO	36.3	26.9	36.8	Balanced
GIERISCH	35.1	29.1	35.8	Balanced
JAGACIAK	37.7	27.7	34.6	Hop-dominated
PELETEIRO	37.7	25.3	37.0	Balanced
RICKETTS	35.4	28.1	36.5	Balanced
MAMONA	35.7	30.6	33.7	Balanced
WILLIAMS	39.4	26.9	33.8	Hop-dominated
COSTA	36.8	28.4	34.9	Balanced
ECKHARDT	33.9	29.6	36.6	Jump-dominated

Note: *Percentages might not add up to 100% because of rounding.*

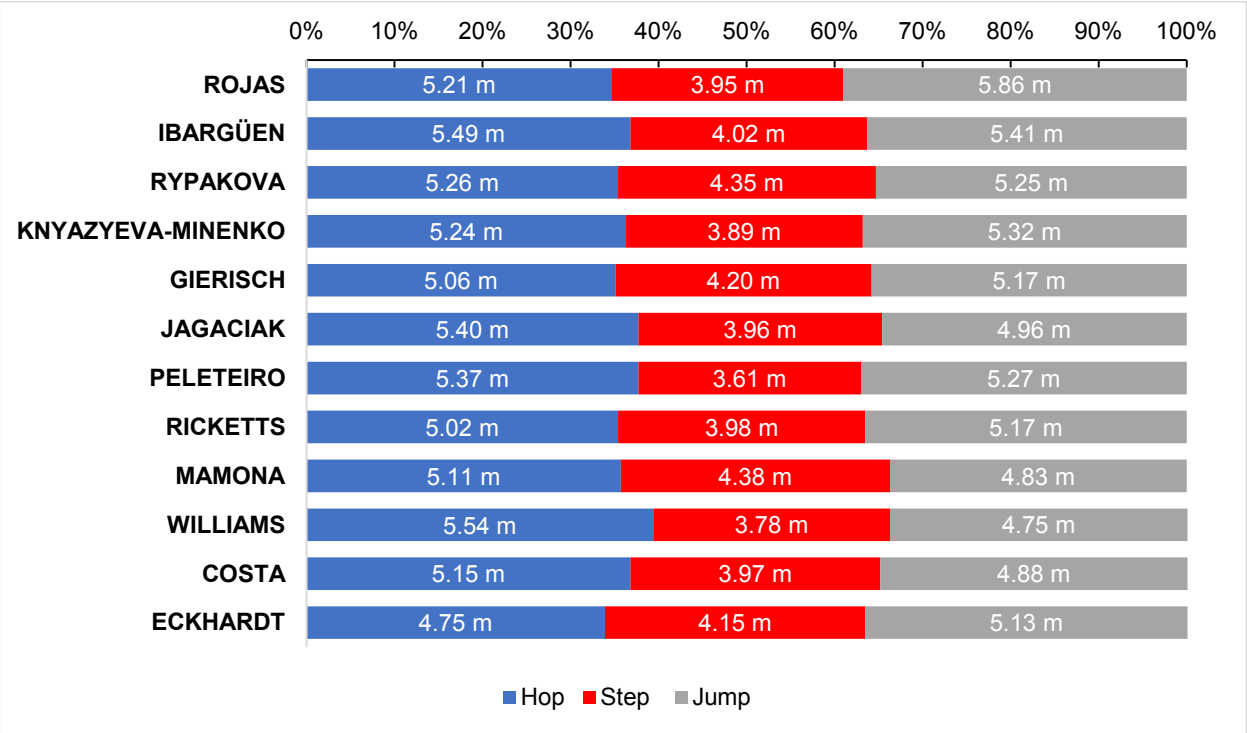
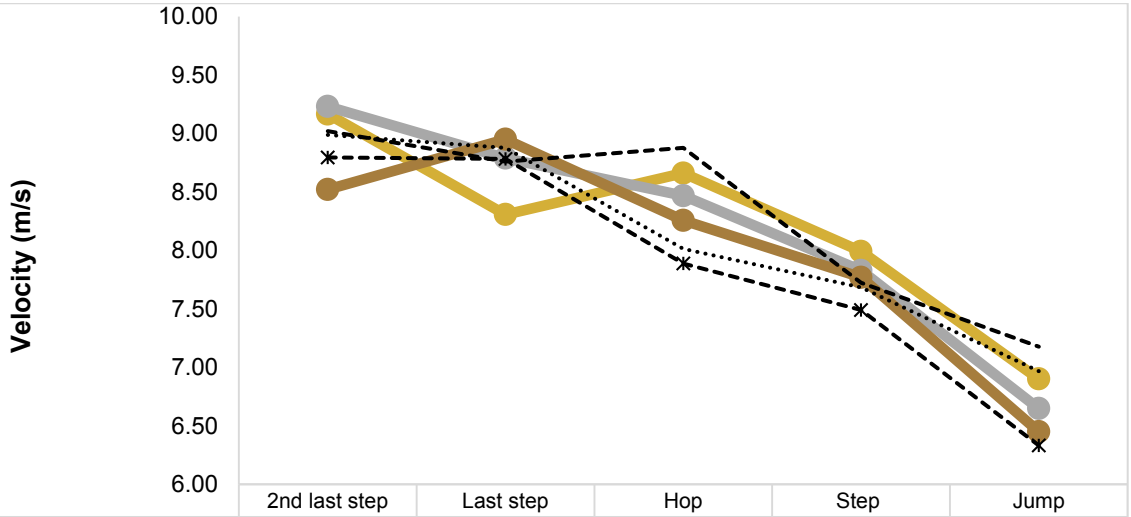


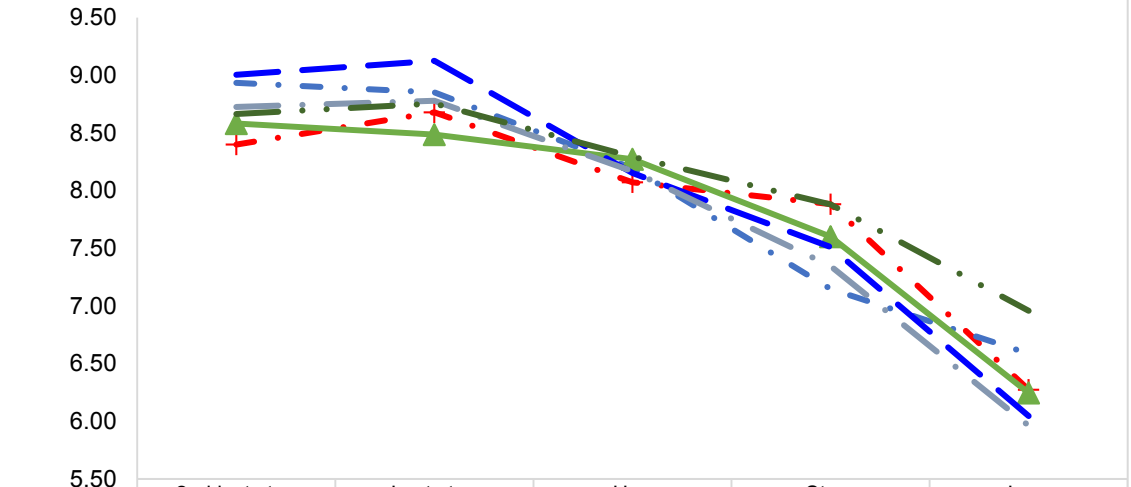
Figure 4. Relative percentage of hop, step and jump lengths (relative to effective distance) along with step length in metres.

Figures 5 and 6 show the change in velocities across the two steps before the take-off board, the hop, the step and jump. The mean horizontal velocity for the second-last step before the take-off board was 8.84 m/s and the last step before the take-off board was 8.76 m/s. The mean horizontal velocity for the hop was 8.28 m/s, the step was 7.65 m/s and the jump was 6.55 m/s.



	2nd last step	Last step	Hop	Step	Jump
ROJAS	9.17	8.31	8.66	7.99	6.90
IBARGÜEN	9.23	8.79	8.47	7.83	6.65
RYPAKOVA	8.52	8.95	8.26	7.77	6.45
KNYAZYEVA-MINENKO	8.99	8.88	8.01	7.68	6.97
GIERISCH	9.02	8.76	8.88	7.72	7.18
JAGACIAK	8.80	8.78	7.89	7.49	6.33

Figure 5. Change in horizontal velocity of the two steps before the take-off board and the hop, step and jump for the top 6 finishers.



	2nd last step	Last step	Hop	Step	Jump
PELETEIRO	8.40	8.68	8.07	7.88	6.27
RICKETTS	8.93	8.85	8.19	7.15	6.59
MAMONA	8.58	8.49	8.27	7.60	6.25
WILLIAMS	9.00	9.13	8.15	7.51	6.05
COSTA	8.73	8.78	8.17	7.35	5.96
ECKHARDT	8.67	8.76	8.29	7.88	6.96

Figure 6. Change in horizontal velocity of the two steps before the take-off board and the hop, step and jump for the bottom 6 finishers.

***Note**: The velocities in Figures 5 and 6 include contact and flight of each phase.*

Figures 7, 8 and 9 show the contact and flight times for hop, step and jump, respectively. The medallists are highlighted in their respective medal colours. Table 6 on the next page shows the step times for the two steps before the take-off board, the hop, step and jump.

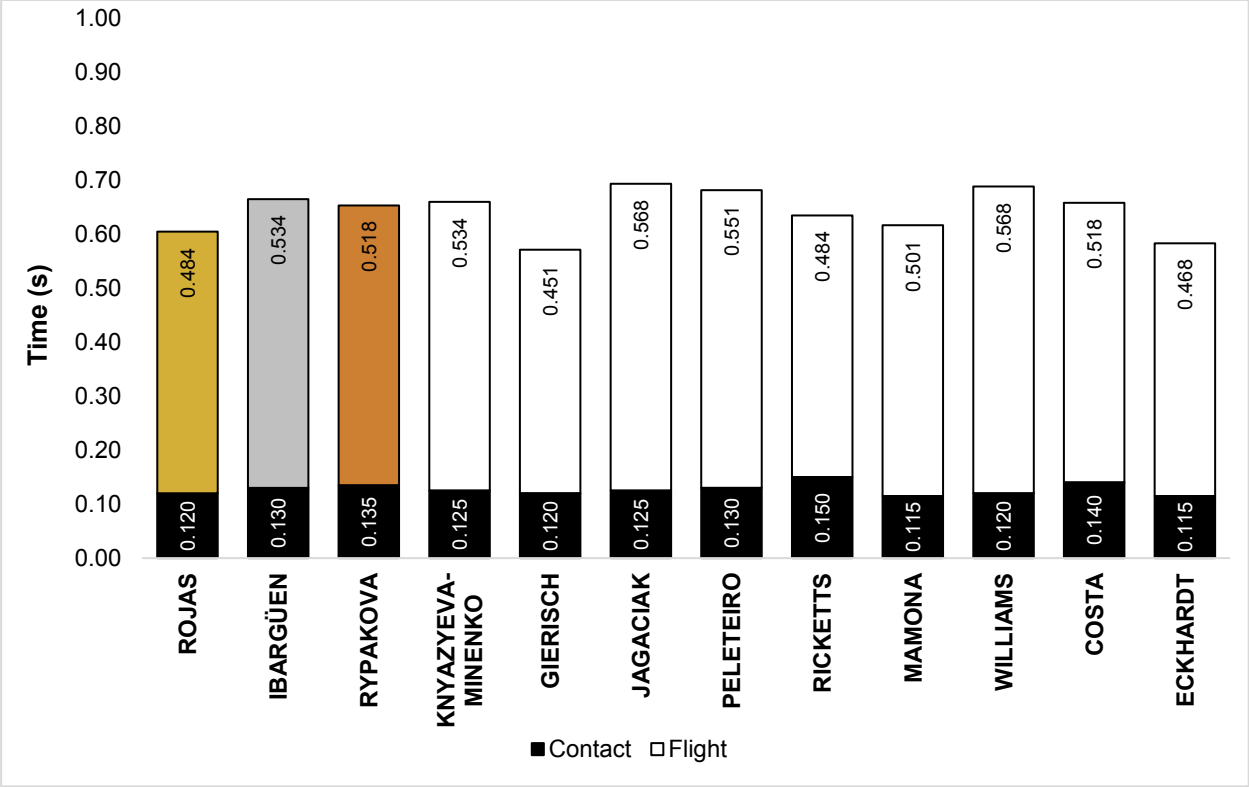


Figure 7. Contact and flight times for the hop phase of the triple jump for all finalists.

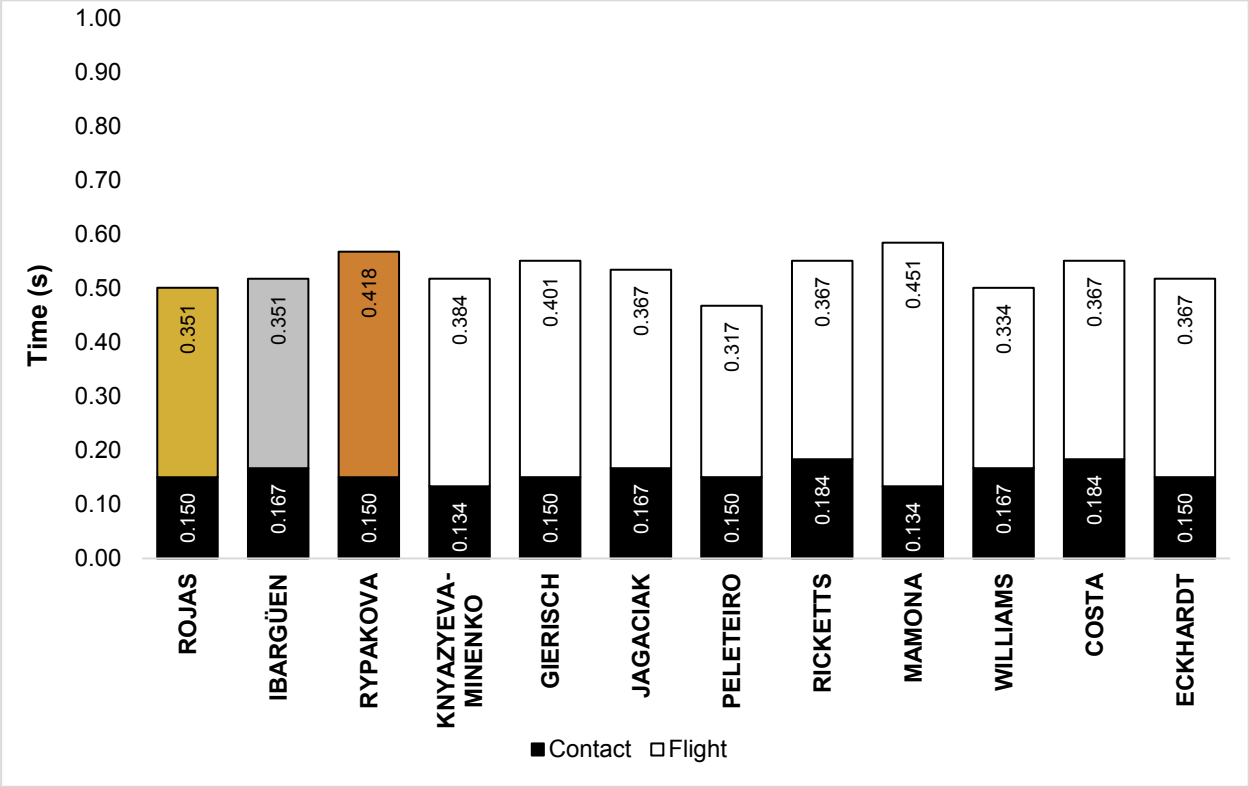


Figure 8. Contact and flight times for the step phase of the triple jump for all finalists.

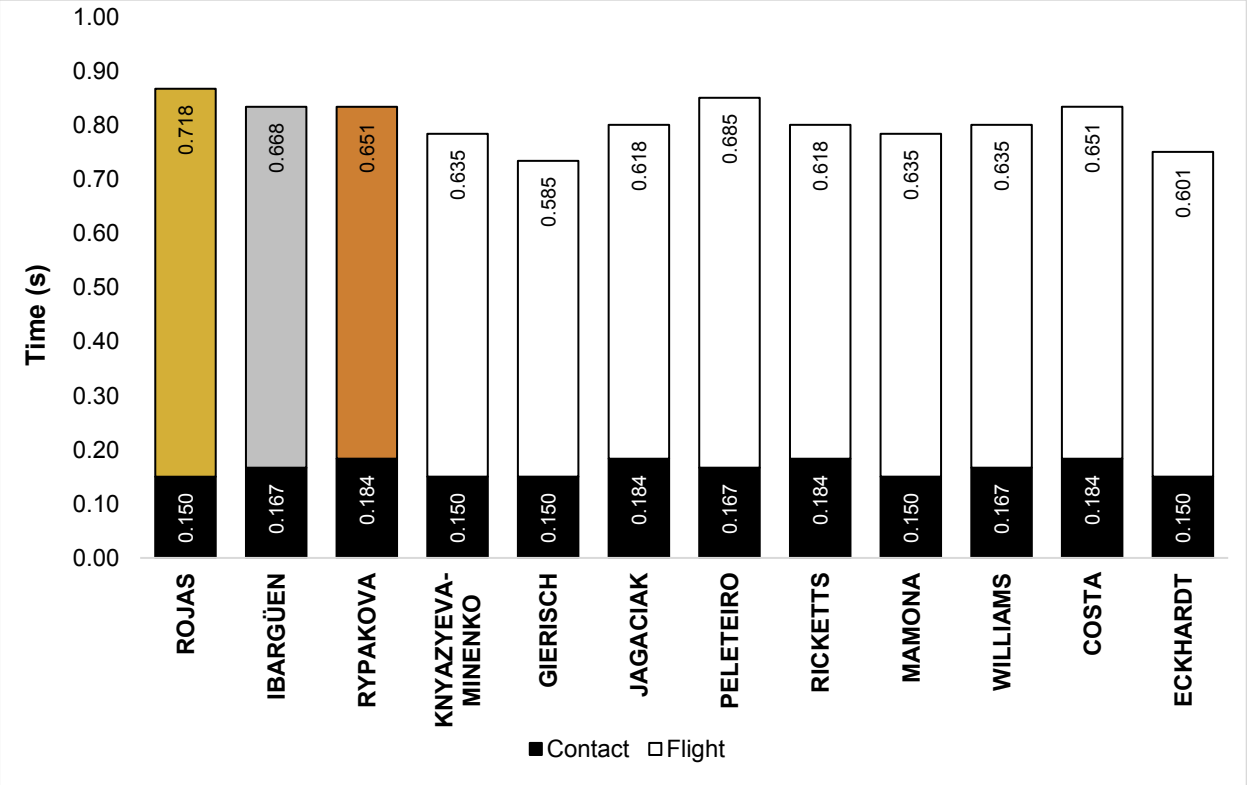


Figure 9. Contact and flight times for the jump phase of the triple jump for all finalists.

Table 6. Step times for the two steps before the take-off board and the hop, step and jump.

Athlete	2nd last (s)	Last (s)	Hop (s)	Step (s)	Jump (s)
ROJAS	0.265	0.205	0.604	0.501	0.868
IBARGÜEN	0.250	0.205	0.664	0.518	0.835
RYPAKOVA	0.245	0.245	0.653	0.568	0.835
KNYAZYEVA-MINENKO	0.270	0.230	0.659	0.518	0.785
GIERISCH	0.230	0.220	0.571	0.551	0.735
JAGACIAK	0.230	0.200	0.693	0.534	0.802
PELETEIRO	0.225	0.200	0.681	0.467	0.852
RICKETTS	0.250	0.215	0.634	0.551	0.802
MAMONA	0.260	0.215	0.616	0.585	0.785
WILLIAMS	0.225	0.175	0.688	0.501	0.802
COSTA	0.255	0.225	0.658	0.551	0.835
ECKHARDT	0.210	0.195	0.583	0.517	0.751

Hop, step and jump analysis

Table 7 shows the horizontal and vertical velocities of the take-off for the hop, step and jump phases. Table 8 shows the change in CM height for the hop, step and jump.

Table 7. Horizontal and vertical velocities at take-off of the hop, step and jump.

	Hop		Step		Jump	
Athlete	Horizontal velocity (m/s)	Vertical velocity (m/s)	Horizontal velocity (m/s)	Vertical velocity (m/s)	Horizontal velocity (m/s)	Vertical velocity (m/s)
ROJAS	8.01	2.39	8.01	1.66	6.28	3.15
IBARGÜEN	8.70	2.69	7.73	1.82	6.47	3.00
RYPAKOVA	8.03	2.53	7.60	2.01	6.25	2.62
KNYAZYEVA-MINENKO	7.40	2.85	7.33	2.13	6.59	2.80
GIERISCH	8.58	2.46	7.58	2.22	6.56	2.40
JAGACIAK	8.33	3.01	7.35	1.98	6.19	2.51
PELETEIRO	8.79	2.82	7.74	1.70	6.13	2.71
RICKETTS	8.13	2.40	7.39	1.76	5.81	2.61
MAMONA	7.65	2.70	7.46	2.30	6.13	2.66
WILLIAMS	7.62	3.00	7.40	1.81	6.46	2.61
COSTA	8.20	2.61	7.15	2.20	5.85	2.73
ECKHARDT	8.22	2.46	7.63	2.09	6.89	2.32

***Note**: These instantaneous velocities for the phases have been captured at different frame rates. This should be considered when examining these velocities along with those in Figures 5 and 6.*

Table 8. CM height lowering during the hop, step and jump.

Athlete	Hop (cm)	Step (cm)	Jump (cm)
ROJAS	5	18	13
IBARGÜEN	4	23	15
RYPAKOVA	4	22	12
KNYAZYEVA-MINENKO	4	20	9
GIERISCH	4	18	9
JAGACIAK	6	20	13
PELETEIRO	6	22	13
RICKETTS	3	19	17
MAMONA	3	19	18
WILLIAMS	3	17	13
COSTA	5	23	10
ECKHARDT	4	21	11

The change in horizontal velocity between these phases is shown in Figure 10 below. The mean change in horizontal velocity between the hop and the previous step was −1.00 m/s, between the hop and step was −0.61 m/s and between the step and jump was −1.23 m/s.

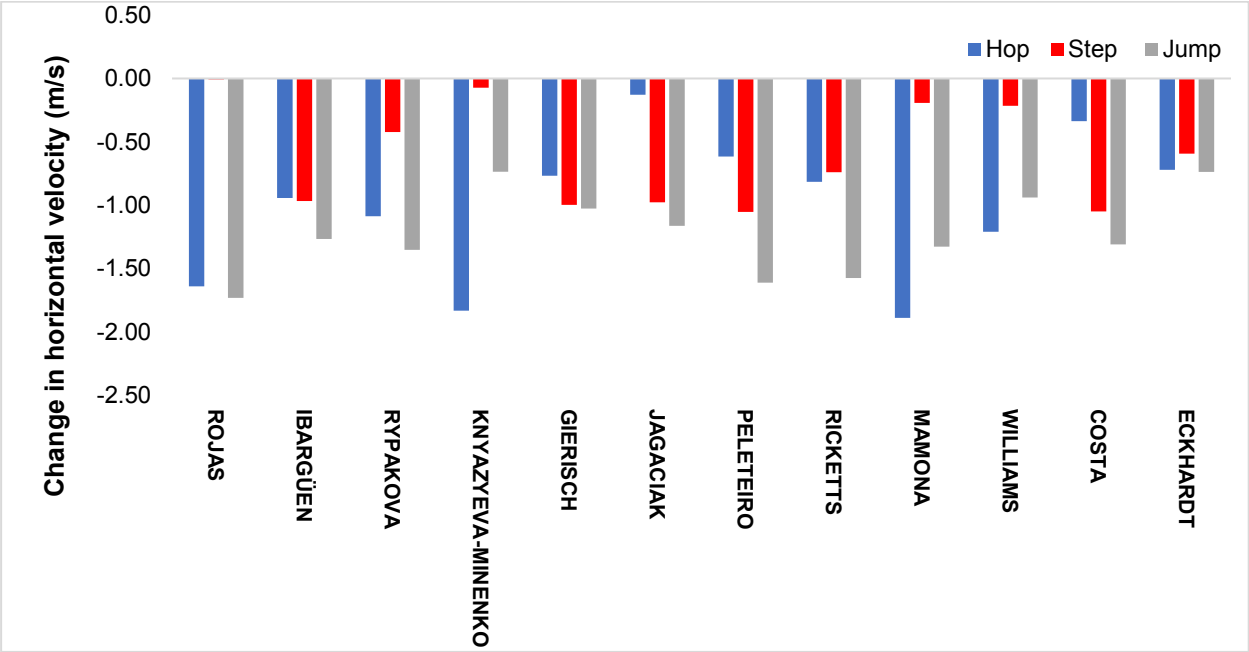
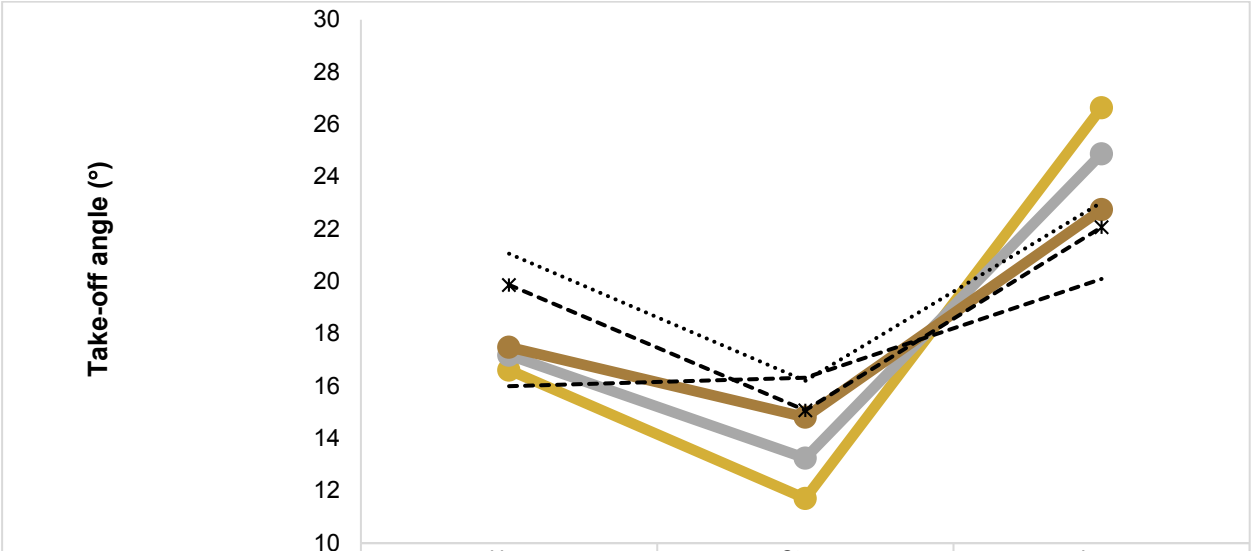


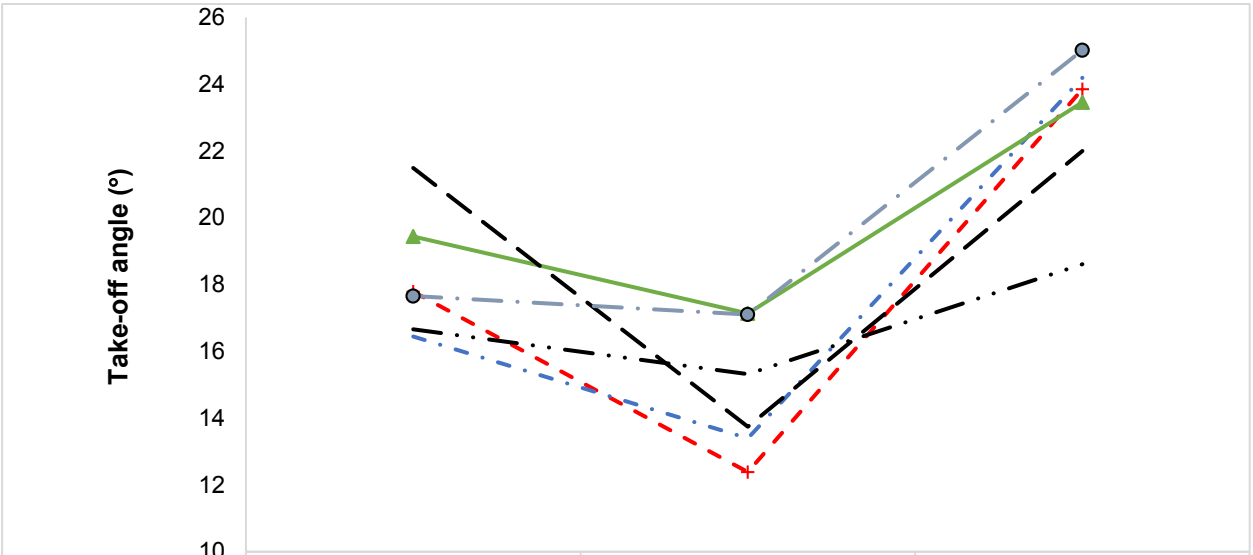
Figure 10. The change in horizontal velocity for the hop, step and jump for each finalist.

Figures 11 and 12 below show the change in take-off angle of the hop, step and jump take-off phases. The mean take-off angle for the hop was 18.2°, for the step was 14.7° and for the jump was 23.0°.



	Hop	Step	Jump
ROJAS	16.6	11.7	26.6
IBARGÜEN	17.2	13.2	24.9
RYPAKOVA	17.5	14.8	22.7
KNYAZYEVA-MINENKO	21.1	16.2	23.0
GIERISCH	16.0	16.3	20.1
JAGACIAK	19.9	15.1	22.1

Figure 11. Take-off angle in the hop, step and jump for the top 6 finalists.



	Hop	Step	Jump
PELETEIRO	17.8	12.4	23.8
RICKETTS	16.4	13.4	24.2
MAMONA	19.4	17.1	23.5
WILLIAMS	21.5	13.7	22.0
COSTA	17.7	17.1	25.0
ECKHARDT	16.7	15.3	18.6

Figure 12. Take-off angle in the hop, step and jump for the bottom 6 finalists.

Table 9 below presents the minimum knee angle during the contact phases of the hop, step and jump. Table 10 shows the change in trunk angle from touchdown to take-off of the hop, step and jump.

Table 9. Minimum knee angle during the contact phases of hop, step and jump.

Athlete	Hop (°)	Step (°)	Jump (°)
ROJAS	147.2	140.8	145.1
IBARGÜEN	155.3	140.8	141.4
RYPAKOVA	152.1	140.4	136.5
KNYAZYEVA-MINENKO	145.2	149.9	143.3
GIERISCH	140.9	141.3	135.1
JAGACIAK	157.7	133.2	134.0
PELETEIRO	130.6	139.6	130.0
RICKETTS	130.9	135.4	122.2
MAMONA	132.7	137.0	142.5
WILLIAMS	130.8	130.9	131.0
COSTA	123.1	125.1	137.5
ECKHARDT	155.0	137.6	141.1

Table 10. Changes in trunk angle during touchdown (TD) and take-off (TO) of the hop, step and jump.

	Hop		Step		Jump	
Athlete	TD (°)	TO (°)	TD (°)	TO (°)	TD (°)	TO (°)
ROJAS	85.3	81.4	85.4	83.2	91.4	84.3
IBARGÜEN	87.6	91.2	89.7	78.3	82.1	80.6
RYPAKOVA	87.8	86.0	89.1	75.8	88.3	77.6
KNYAZYEVA-MINENKO	93.0	88.8	89.9	80.8	90.8	80.5
GIERISCH	95.1	85.6	96.1	89.9	90.8	86.4
JAGACIAK	90.2	89.2	85.7	82.1	83.4	79.9
PELETEIRO	91.9	87.3	94.0	86.4	88.5	88.5
RICKETTS	89.8	85.9	89.2	78.1	79.2	82.7
MAMONA	85.7	84.9	89.6	79.2	85.4	78.5
WILLIAMS	88.4	88.4	93.1	75.8	77.3	75.2
COSTA	84.8	77.0	87.0	79.3	86.3	85.6
ECKHARDT	83.4	87.0	92.2	79.2	83.7	77.3

Table 11 shows the thigh angle (relative to the horizontal plane) at take-off along with the thigh angular velocity of the swing leg during the contact phase of the hop, step and jump. The mean thigh angle for the hop, step and jump was −19.6°, −27.5° and −24.1°, respectively. The mean thigh angular velocity of the swing leg for the hop, step and jump was 555 °/s, 345 °/s and 343 °/s, respectively.

Table 11. Thigh angle at take-off and mean thigh angular velocity of the swing leg (during the contact phase) for the hop, step and jump.

	Hop		Step		Jump	
Athlete	Thigh angle (°)	Mean thigh angular velocity (°/s)	Thigh angle (°)	Mean thigh angular velocity (°/s)	Thigh angle (°)	Mean thigh angular velocity (°/s)
ROJAS	−35.7	456	−27.2	363	−29.4	297
IBARGÜEN	−20.9	569	−22.2	364	−29.7	320
RYPAKOVA	−14.8	549	−30.0	357	−18.3	381
KNYAZYEVA-MINENKO	−7.2	623	−30.7	359	−8.6	445
GIERISCH	−30.2	536	−37.3	269	−27.7	336
JAGACIAK	−18.4	546	−25.7	366	−27.3	366
PELETEIRO	−14.1	629	−25.6	339	−19.7	338
RICKETTS	−21.0	489	−27.1	325	−19.7	297
MAMONA	−22.5	597	−35.3	316	−39.3	292
WILLIAMS	−19.6	550	−17.5	326	−21.0	292
COSTA	−10.5	537	−19.6	380	−23.2	347
ECKHARDT	−20.0	574	−32.3	379	−24.8	404

Note: *A negative lead thigh angle means the thigh is below the horizontal.*

Landing analysis

Table 12 shows the angles of the trunk, hip and knee on landing with the sand. The loss in landing is also shown. The only athlete to record a loss on landing was Knyazyeva-Minenko with a loss of 12 centimetres. The mean hip angle at landing was 82.9°. The mean knee angle was 122.2°, while the mean trunk angle was 71.2°. Figure 13 shows the landing distance by each athlete. The mean landing distance was 0.41 metres.

Table 12. Landing characteristics in the women's triple jump final.

Athlete	Hip angle (°)	Knee angle (°)	Trunk angle (°)	Landing loss (m)
ROJAS	79.3	144.9	61.4	0.00
IBARGÜEN	70.3	94.7	71.8	0.00
RYPAKOVA	71.2	119.4	58.3	0.00
KNYAZYEVA-MINENKO	93.5	133.5	85.4	0.12
GIERISCH	72.5	127.2	75.2	0.00
JAGACIAK	103.1	152.4	65.7	0.00
PELETEIRO	75.2	110.2	81.4	0.00
RICKETTS	87.3	102.1	73.7	0.00
MAMONA	88.3	129.8	77.1	0.00
WILLIAMS	94.0	138.7	72.8	0.00
COSTA	113.2	108.3	89.3	0.00
ECKHARDT	46.3	105.0	42.2	0.00

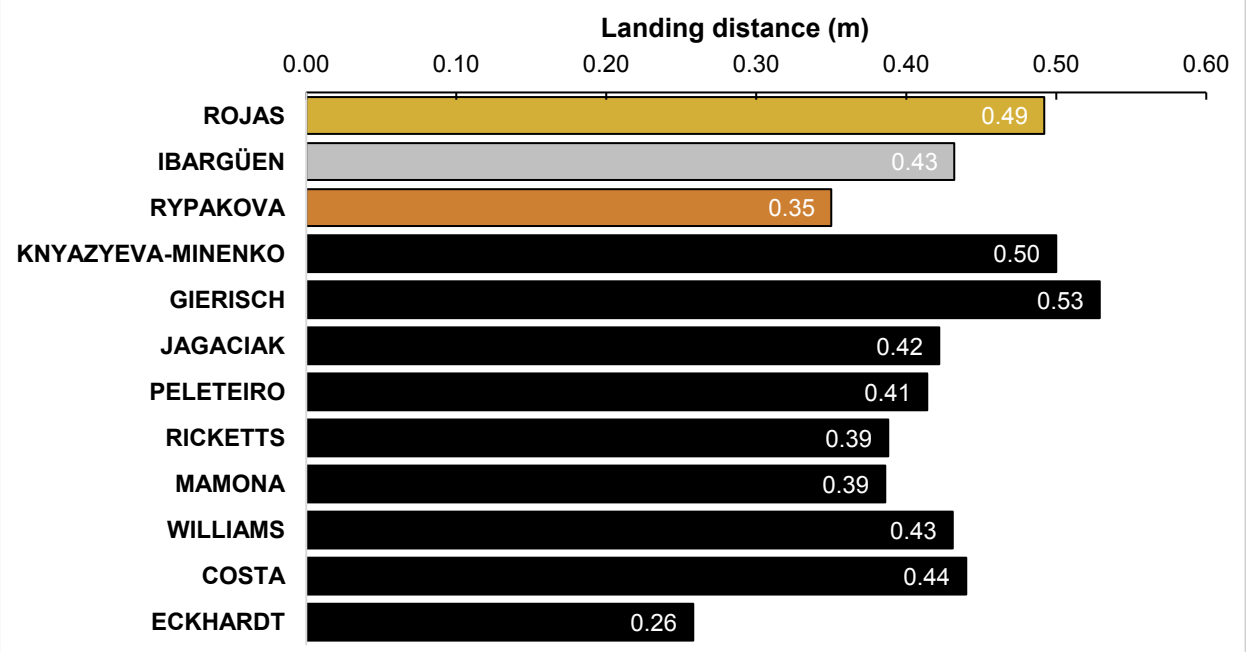


Figure 13. The landing distances for each finalist in the women's triple jump.

COACH'S COMMENTARY

The triple jump is an event that demands a series of efforts rather than one maximal effort as in other events. It is important that triple jumpers build speed and maintain it as much as possible while building vertical velocity in the hop, step and jump phases.

The distribution of effort during the hop, step and jump phases is always interesting. In the women's final, two thirds of the athletes showed a "balanced technique" whereas there were two (Jagaciak and Williams) with a "hop-dominated" and two with a "jump-dominated" (Rojas and Eckhardt) technique which was similar to the men's final. Despite having a relatively small step (3.95 metres), the gold medallist (Rojas) had a far superior jump compared with the rest of the athletes (5.86 metres).

The ability to create speed and maintain it through the phases of the triple jump is crucial to successful jumping. Rojas was the best athlete at doing this in the final. She had the lowest mean loss in velocity (−0.47 m/s) across the last step, hop, step and jump phases (Figures 5 and 6). Even though she lost horizontal velocity (loss of 1.73 m/s) between the step and jump take-off, this was offset by a gain in vertical velocity of 1.49 m/s by take-off for the jump (Figure 10) thereby highlighting that increasing vertical velocity is important to offset inevitable losses in horizontal velocity. Rojas had the highest take-off velocity at 26.6° further highlighting this change in approach.

The contact phases during the hop, step and jump are crucial to prevent excessive losses of horizontal velocity. Control of upper-body rotation while the foot acts as a pivot during contact is important. The women's finalists did not show a clear relationship between trunk angle changes and their change in velocities as the men did. Interestingly, Rojas had the smallest change in trunk angle (change of 2.2°) during the step contact phase and a relatively low take-off angle (11.7°) from the step and the lowest vertical velocity (1.66 m/s). Given her relatively poor step length of 3.95 metres for this phase, this could potentially mean that to improve her step phase that she tries to increase her vertical velocity and thereby increase her take-off angle at this point. Three of the top four finishers had the largest trunk rotation (Rypakova 10.7°, Knyazyeva-Minenko 10.3°, Rojas 7.1°) during the contact phase of the jump. There was a similar trend evident in the men's final. Having increased trunk extension on touchdown of the support phases is important to prevent over rotation through contact and potential losses in horizontal and vertical velocity thereby ensuring jump distance is not compromised. Having a high vertical velocity is important for jump distance – there was a correlation between vertical velocity and jump distance (r = 0.64).

As any triple or long jumper knows, the ability to control the landing in the pit is crucial. What the analysis shows is that only one of the finalists, Knyazyeva-Minenko, had a loss / fall-back on

landing with her number bib making a mark in the sand and it appears that is quite costly (12 centimetres). Luckily, it wasn't a loss that affected her ability to win a medal. In general, when looking at the men's and women's finals, the women appear to be more effective at maintaining and maximising their landing distance.

We had a very deserving winner in Rojas. Throughout all analysed phases she demonstrated excellent technique and it was her ability to maintain her velocity along with good conversion to the vertical that meant she had an excellent jump phase and performance overall. As highlighted previously, if her step phase can be improved further she will continue to be a hard act to beat.

CONTRIBUTORS

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Toni Minichiello is a coach for British Athletics. He has worked with a number of elite and senior athletes, most notably Olympic gold medallist and triple World Champion Jessica Ennis-Hill, whom he coached from the age of 15 years old. In 2012, Toni won the BBC Sports Personality of the Year Coach Award. Toni has also been awarded the accolade of UK Sports Coach of the Year and was inducted into the Fellowship of Elite Coaches in 2014.