



BIOMECHANICAL REPORT

FOR THE

IAAF™

WORLD INDOOR CHAMPIONSHIPS 2018

Triple Jump Women

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INTRODUCTION

The women's triple jump took place on the morning of Saturday 3rd March. This was a thrilling final during which the medal positions were keenly contested and personal bests were produced by three of the top four athletes. At the halfway point the lead was held by Kimberly Williams of Jamaica with a third round effort and personal best of 14.48 metres. Spain's Ana Peleteiro produced a personal best of 14.40 metres with her fourth round jump which placed her in the bronze medal position. However, it was the current outdoor world champion, Yulimar Rojas of Venezuela, who produced a jump that would not be beaten in the fifth round. Her effort of 14.63 metres – a world leading jump – was enough to clinch the gold medal.

IAAF		World Indoor Championships				Birmingham (GBR)		1-4 March 2018					
RESULTS													
Triple Jump Women - Final													
													
RECORDS	RESULT	NAME	COUNTRY	AGE	VENUE	DATE							
World Indoor Record WIR	15.36	Tatyana LEBEDEVA	RUS	28	Budapest (Sportaréna)	6 Mar 2004							
Championship Record CR	15.36	Tatyana LEBEDEVA	RUS	28	Budapest (Sportaréna)	6 Mar 2004							
World Leading WL	14.63	Yulimar ROJAS	VEN	23	Birmingham	3 Mar 2018							
Area Indoor Record AIR		National Indoor Record NIR			Personal Best PB		Season Best SB						
3 March 2018 11:00 START TIME													
12:26 END TIME													
PLACE	NAME	COUNTRY	DATE of BIRTH	ORDER	RESULT		1	2	3	ORDER	4	5	6
1	Yulimar ROJAS	VEN	21 Oct 96	1	14.63 WL		14.24	14.07	14.27	7	14.36	14.63	X
2	Kimberly WILLIAMS	JAM	3 Nov 88	16	14.48 PB		14.37	14.41	14.48	8	14.31	X	14.32
3	Ana PELETEIRO	ESP	2 Dec 96	17	14.40 PB		13.18	13.82	14.18	6	14.40	X	X
4	Andreea PANTUROIU	ROU	24 Feb 96	8	14.33 PB		14.05	X	14.16	5	14.33	X	X
5	Keturah ORJI	USA	6 Mar 96	13	14.31		14.13	X	14.07	4	14.28	14.31	
6	Paraskevi PAPACHRISTOU	GRE	17 Apr 89	2	14.05		14.05	11.73	14.01	3	13.36	X	
7	Viktoriya PROKOPENKO	ANA	17 Apr 91	7	14.05		13.76	13.87	14.05	2	13.72	13.92	
8	Tori FRANKLIN	USA	7 Oct 92	4	14.03		14.03	13.52	13.70	1	11.34	13.94	
9	Nubia SOARES	BRA	26 Mar 96	5	14.00 SB		X	13.97	14.00				
10	Shanieka RICKETTS	JAM	2 Feb 92	12	13.93		13.93	13.36	13.68				
11	Gabriela PETROVA	BUL	29 Jun 92	6	13.91 SB		X	X	13.91				
12	Dovilė DZINDZALEITAITĖ	LTU	14 Jul 96	9	13.90		13.90	13.74	13.64				
13	Neele ECKHARDT	GER	2 Jul 92	15	13.87		13.24	13.87	13.70				
14	Iryna VASKOUSKAYA	BLR	2 Apr 91	10	13.81		X	13.81	13.37				
15	Anna KRYLOVA	ANA	3 Oct 86	11	13.75		13.75	13.66	13.49				
16	Kristiina MÄKELÄ	FIN	20 Nov 92	3	13.73		X	13.73	13.57				
17	Thea LAFOND	DMA	6 Apr 94	14	13.68		X	13.63	13.68				
Timing and Measurement by SEIKO						AT-TJ-W-f--A--.RS1..v1			Issued at 12:27 on Saturday, 03 March 2018				
Official Partners													
													

METHODS

Five vantage locations for camera placement were identified and secured. These locations were situated in the stand along the home 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 completing their last two steps before the take-off board and their hop, step and jump.

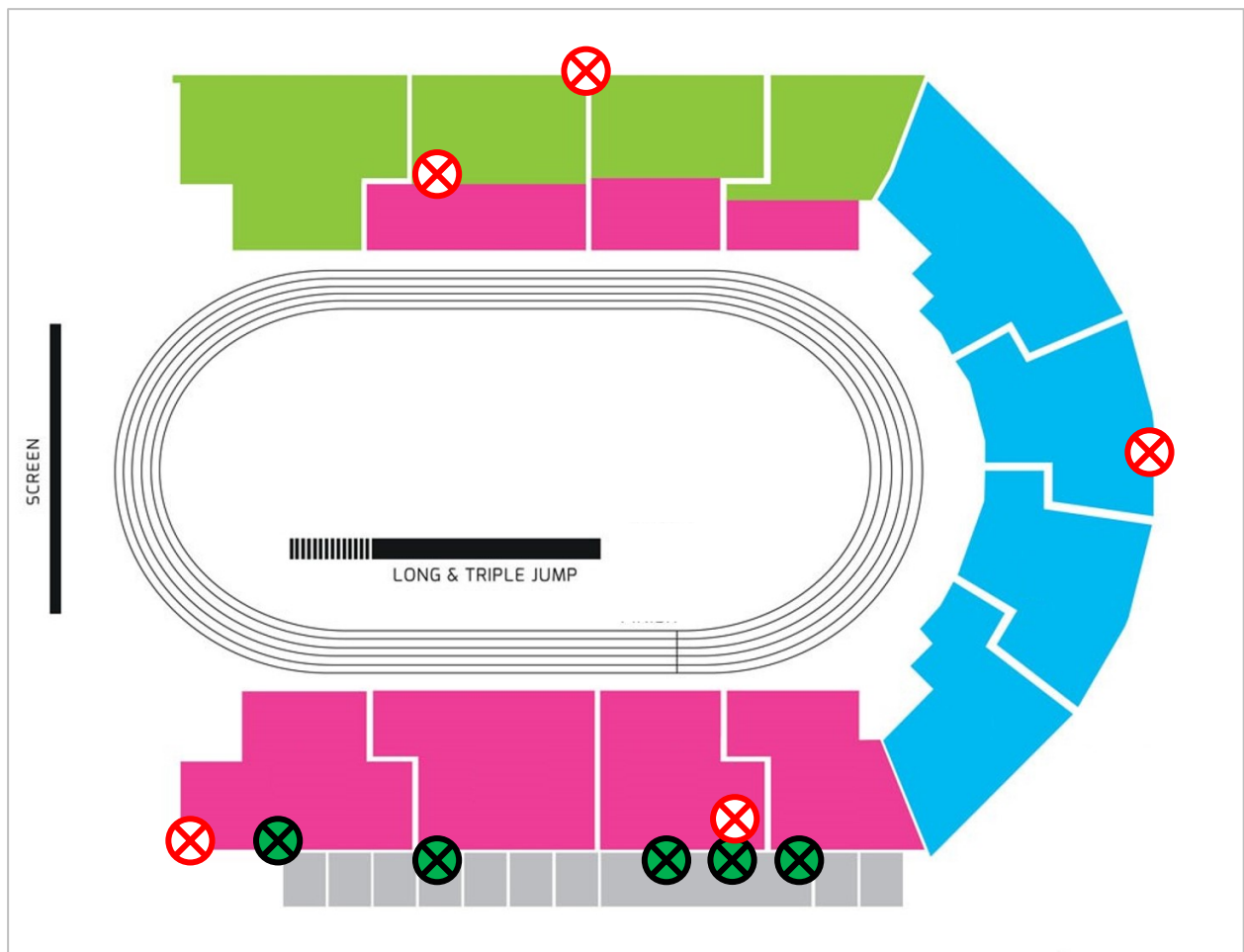


Figure 1. Camera layout for the women's triple jump indicated by green-filled circles.

Seven 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: 2000-4000; 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. Four Sony RX10 M3 cameras operating at 100 Hz (shutter speed: 1/1000; ISO: 2000-3600; FHD: 1920x1080 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.

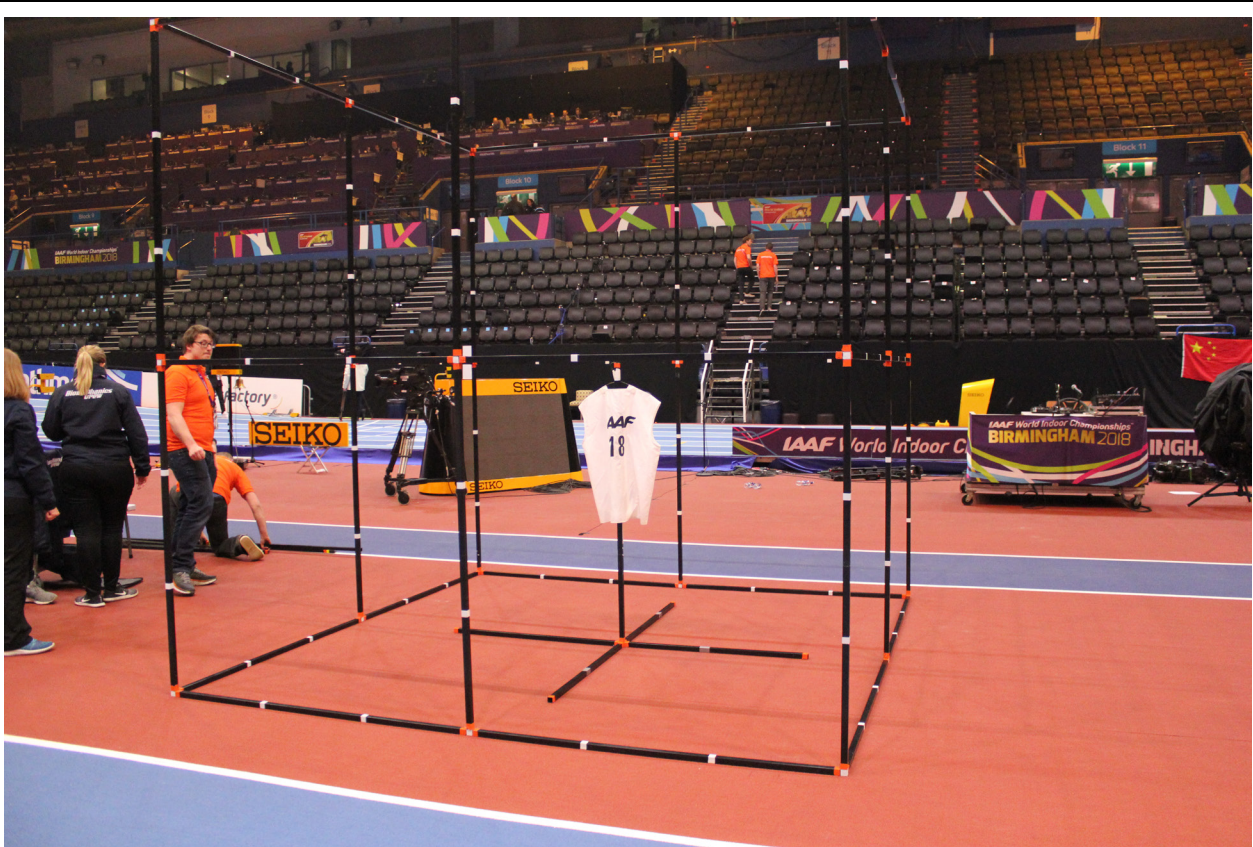


Figure 2. The calibration frame was constructed and filmed before and after the competition.

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.

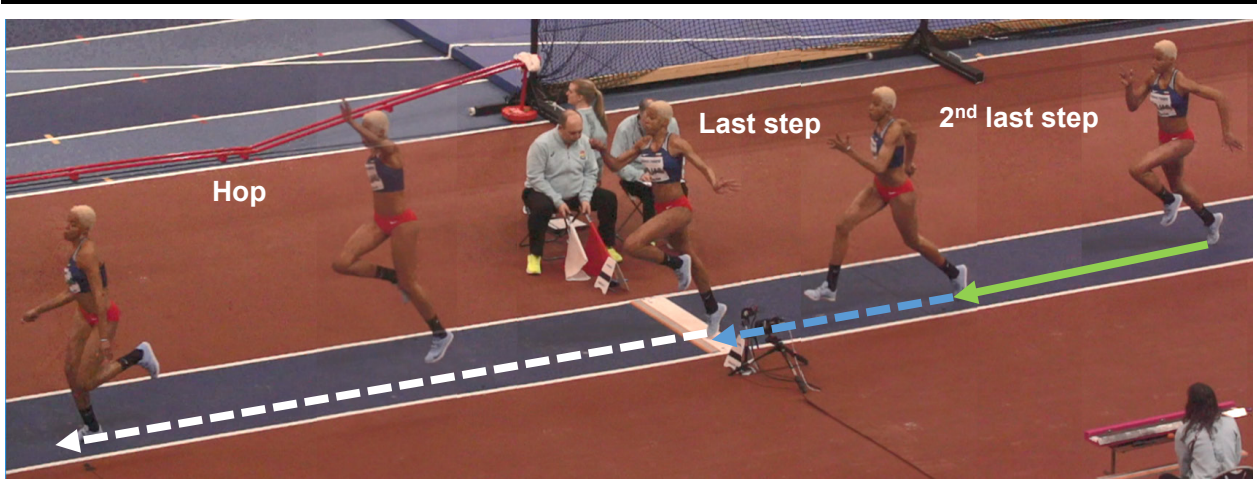


Figure 3. The last two steps before the take-off board and the hop phase in the triple jump.

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 measured from the tip of the foot at take-off to the take-off board plus the official distance.
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.
Horizontal velocity at take-off (hop, step and jump)	The athlete's horizontal (anteroposterior direction) CM velocity at the instant of take-off of the hop, step and jump.
Vertical velocity at take-off (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.
Flight time (hop, step and jump)	The time spent in the air during the flight phase of the hop, step and jump.
Trunk lean angle	The angle of the trunk relative to the horizontal at the instant of touchdown and take-off and considered to be 0° in the upright position. A negative value indicates they are behind the upright position and a positive value indicates they are in front of the upright position. This was 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.
Body inclination angle	The angle of a line between the athlete's CM and contact foot relative to the vertical at the instant of touchdown (TD) and take-off (TO) of the hop, step and jump contact phases.
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.
Knee angle	The angle between the thigh and lower leg and considered to be 180° in the anatomical standing position. This was measured at TD on the board and when it reached its minimum on the take-off board.
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. There were three athletes who improved their personal bests with five athletes in total achieving a season's best.

Table 2. Competition results in comparison with athletes' personal bests (PB) and season's bests (SB) for 2018 (before World Championships).

Athlete	Rank	Official distance (m)	SB (2018) (m)	Comparison with SB (m)	PB (m)	Comparison with PB (m)
ROJAS	1	14.63	-	-	14.79	-0.16
WILLIAMS	2	14.48	14.25	0.23	14.47	0.01
PELETEIRO	3	14.40	13.86	0.54	14.20	0.20
PANTUROIU	4	14.33	14.15	0.18	14.15	0.18
ORJI	5	14.31	13.97	0.34	14.56	-0.25
PAPACHRISTOU	6	14.05	13.90	0.15	14.55	-0.50
PROKOPENKO	7	14.05	14.44	-0.39	14.44	-0.39
FRANKLIN	8	14.03	14.22	-0.19	14.33	-0.30
SOARES	9	14.00	14.13	-0.13	14.13	-0.13
RICKETTS	10	13.93	14.30	-0.37	14.30	-0.37
PETROVA	11	13.91	14.02	-0.11	14.39	-0.48
DZINDZALEITAITÉ	12	13.90	14.49	-0.59	14.08	-0.18
ECKHARDT	13	13.87	14.53	-0.66	14.53	-0.66
VASKOUSKAYA	14	13.81	14.08	-0.27	14.08	-0.27
KRYLOVA	15	13.75	14.13	-0.38	14.13	-0.38
MÄKELÄ	16	13.73	14.16	-0.43	14.39	-0.66
LAFOND	17	13.68	14.22	-0.54	14.22	-0.54

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 smallest loss at the take-off board was by Vaskouskaya with a loss of 0.001 metres, and the largest loss was by Ricketts with a loss of 0.410 metres. The mean loss was 0.08 metres. Table 4 on the next page 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	14.63	14.704	0.074
WILLIAMS	3	14.48	14.529	0.049
PELETEIRO	4	14.40	14.440	0.040
PANTUROIU	4	14.33	14.343	0.013
ORJI	5	14.31	14.418	0.108
PAPACHRISTOU	1	14.05	14.208	0.158
PROKOPENKO	3	14.05	14.091	0.041
FRANKLIN	1	14.03	14.161	0.131
SOARES	3	14.00	14.080	0.080
RICKETTS	1	13.93	14.340	0.410
PETROVA	3	13.91	14.003	0.093
DZINDZALETAITÉ	1	13.90	14.089	0.189
ECKHARDT	2	13.87	14.056	0.186
VASKOUSKAYA	2	13.81	13.811	0.001
KRYLOVA	1	13.75	13.776	0.026
MÄKELÄ	2	13.73	13.799	0.069
LAFOND	3	13.68	13.842	0.162

Note: The take-off distances were provided by deltatire.

Table 4. Step length data for the last 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	2.57	2.16	5.224	4.14	5.34
WILLIAMS	2.15	2.11	5.409	4.07	5.05
PELETEIRO	2.24	2.15	5.050	4.85	4.54
PANTUROIU	2.08	2.16	4.933	4.52	4.89
ORJI	1.97	2.14	5.568	4.03	4.82
PAPACHRISTOU	2.04	1.98	5.188	4.14	4.88
PROKOPENKO	2.21	2.07	5.151	4.20	4.74
FRANKLIN	2.17	2.41	-	-	-
SOARES	2.10	2.23	5.080	4.34	4.66
RICKETTS	2.30	2.31	5.180	3.95	5.21
PETROVA	2.14	2.23	5.133	4.15	4.72
DZINDZALETAITÉ	2.12	2.16	5.229	4.41	4.45
ECKHARDT	1.97	2.02	4.956	4.20	4.90
VASKOUSKAYA	2.10	2.20	4.891	3.91	5.01
KRYLOVA	2.23	2.12	4.676	4.38	4.72
MÄKELÄ	2.33	2.18	4.909	3.92	4.97
LAFOND	2.36	2.18	5.072	4.32	4.45

Note: The hop, step and jump distances were provided by deltatre and there was no value recorded for Franklin.

Hop, step and jump analysis

Table 5 and Figure 4 illustrate the contribution of the hop, step and jump (relative percentage) to the effective distance. Table 5 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	35.5	28.2	36.3	Balanced
WILLIAMS	37.2	28.0	34.8	Hop-dominated
PELETEIRO	35.0	33.6	31.4	Hop-dominated
PANTUROIU	34.4	31.5	34.1	Balanced
ORJI	38.6	28.0	33.4	Hop-dominated
PAPACHRISTOU	36.5	29.1	34.3	Hop-dominated
PROKOPENKO	36.6	29.8	33.6	Hop-dominated
FRANKLIN	-	-	-	-
SOARES	36.1	30.8	33.1	Hop-dominated
RICKETTS	36.1	27.5	36.3	Balanced
PETROVA	36.7	29.6	33.7	Hop-dominated
DZINDZALEITAITÉ	37.1	31.3	31.6	Hop-dominated
ECKHARDT	35.3	29.9	34.9	Balanced
VASKOUSKAYA	35.4	28.3	36.3	Balanced
KRYLOVA	33.9	31.8	34.3	Balanced
MÄKELÄ	35.6	28.4	36.0	Balanced
LAFOND	36.6	31.2	32.1	Hop-dominated

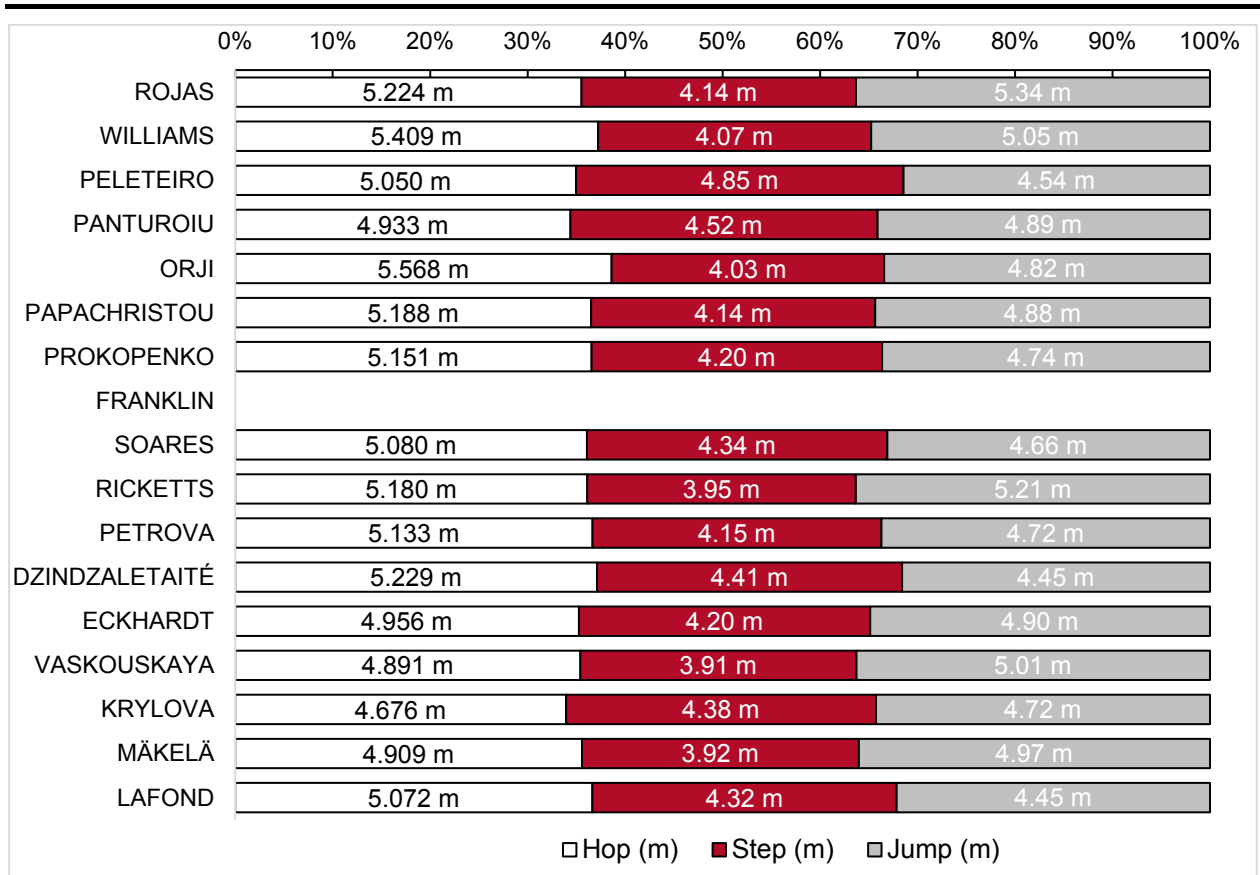


Figure 4. Relative percentage of hop, step and jump lengths (relative to effective distance) along with step length in metres.

Figures 5, 6 and 7 show the contact and flight times for hop, step and jump, respectively. Table 6 on the next page shows the step times for the two steps before the take-off board, the hop, step and jump.

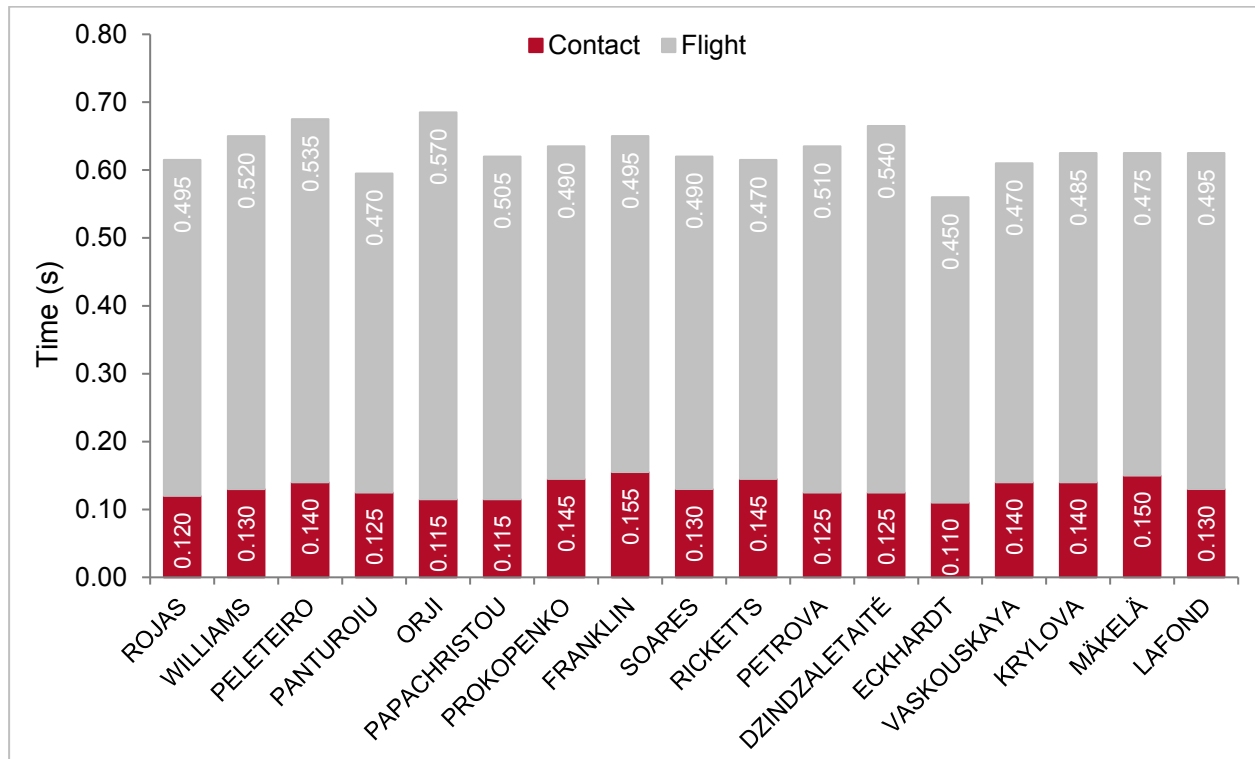


Figure 5. Contact and flight times for the hop phase of the triple jump for all finalists.

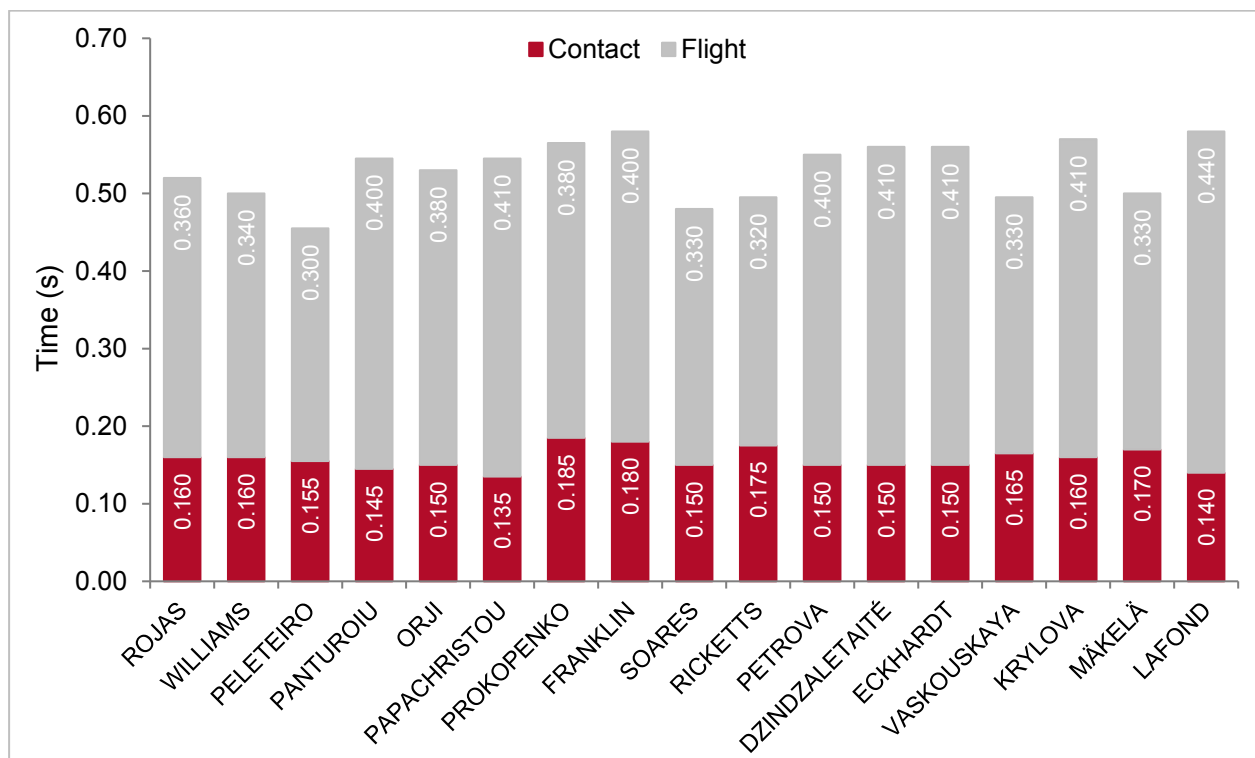


Figure 6. Contact and flight times for the step phase of the triple jump for all finalists.

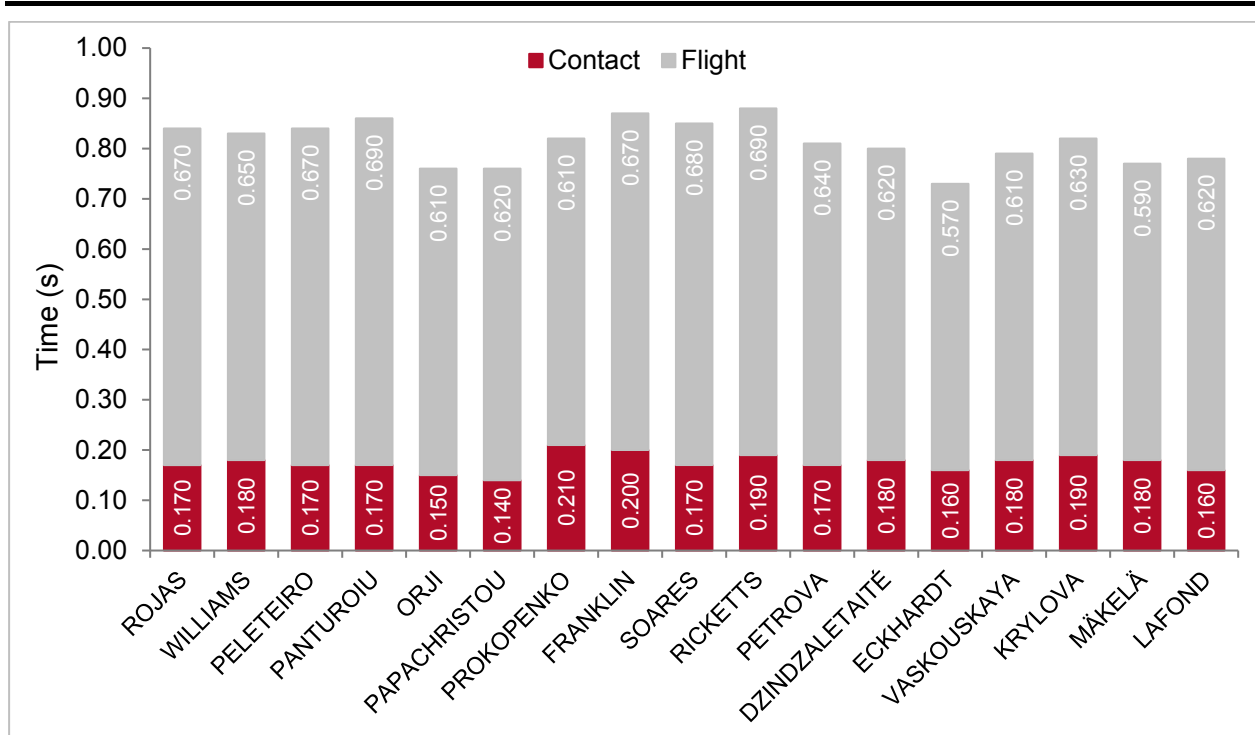


Figure 7. Contact and flight times for the jump phase of the triple jump for all finalists.

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

Athlete	2 nd last (s)	Last (s)	Hop (s)	Step (s)	Jump (s)
ROJAS	0.265	0.225	0.615	0.520	0.840
WILLIAMS	0.235	0.190	0.650	0.500	0.830
PELETEIRO	0.230	0.205	0.675	0.455	0.840
PANTUROIU	0.245	0.200	0.595	0.545	0.860
ORJI	0.210	0.200	0.685	0.530	0.760
PAPACHRISTOU	0.230	0.185	0.620	0.545	0.760
PROKOPENKO	0.250	0.210	0.635	0.565	0.820
FRANKLIN	0.240	0.235	0.650	0.580	0.870
SOARES	0.230	0.215	0.620	0.480	0.850
RICKETTS	0.260	0.230	0.615	0.495	0.880
PETROVA	0.240	0.225	0.635	0.550	0.810
DZINDZALEITĚ	0.240	0.205	0.665	0.560	0.800
ECKHARDT	0.210	0.210	0.560	0.560	0.730
VASKOUSKAYA	0.235	0.220	0.610	0.495	0.790
KRYLOVA	0.245	0.220	0.625	0.570	0.820
MÄKELÄ	0.265	0.220	0.625	0.500	0.770
LAFOND	0.265	0.220	0.625	0.580	0.780

Table 7 shows the horizontal and vertical velocities of the take-off for the hop, step and jump phases. The mean horizontal velocity at take-off for the hop, step and jump was 8.16 m/s, 7.37 m/s and 6.18 m/s, respectively. The mean vertical velocity at take-off for the hop, step and jump was 2.52 m/s, 2.06 m/s and 2.69 m/s, respectively.

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

Athlete	Hop		Step		Jump	
	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	8.28	2.47	7.47	1.94	6.21	2.84
WILLIAMS	8.53	2.66	7.89	1.74	5.57	2.98
PELETEIRO	8.04	2.67	7.62	1.52	6.07	2.88
PANTUROIU	8.21	2.29	7.34	2.21	5.87	3.09
ORJI	7.99	2.86	7.42	2.15	6.31	2.44
PAPACHRISTOU	7.95	2.48	7.40	2.29	6.22	2.80
PROKOPENKO	8.16	2.55	7.09	2.02	6.25	2.46
FRANKLIN	8.13	2.54	7.00	1.96	5.55	2.51
SOARES	8.31	2.44	7.67	1.91	6.69	2.77
RICKETTS	8.24	2.23	7.61	1.70	5.99	2.88
PETROVA	8.03	2.66	7.03	2.20	6.47	2.60
DZINDZALETAITÉ	8.04	2.84	7.22	2.39	5.92	2.64
ECKHARDT	8.57	2.24	7.67	2.28	6.69	2.38
VASKOUSKAYA	8.16	2.53	7.67	1.77	6.69	2.57
KRYLOVA	7.77	2.54	6.77	2.32	5.87	2.82
MÄKELÄ	7.97	2.41	7.29	2.11	6.78	2.40
LAFOND	8.35	2.46	7.20	2.49	5.92	2.59

Table 8 on the next page shows the change in CM height for the hop, step and jump. The mean CM height lowering for the hop, step and jump was 5 cm, 22 cm and 13 cm, respectively.

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

Athlete	Hop (cm)	Step (cm)	Jump (cm)
ROJAS	3	20	13
WILLIAMS	3	21	16
PELETEIRO	4	19	11
PANTUROIU	7	18	14
ORJI	6	21	9
PAPACHRISTOU	4	22	13
PROKOPENKO	5	28	17
FRANKLIN	8	25	16
SOARES	7	17	12
RICKETTS	5	22	11
PETROVA	6	25	11
DZINDZALEITAITÉ	7	26	13
ECKHARDT	4	19	15
VASKOUSKAYA	6	23	13
KRYLOVA	5	22	17
MÄKELÄ	5	24	14
LAFOND	6	17	13

The change in horizontal velocity between these phases is shown in Figure 8 below. The mean change in horizontal velocity between the hop and the previous step was -0.76 m/s, between the hop and step was -0.79 m/s and between the step and jump was -1.19 m/s.

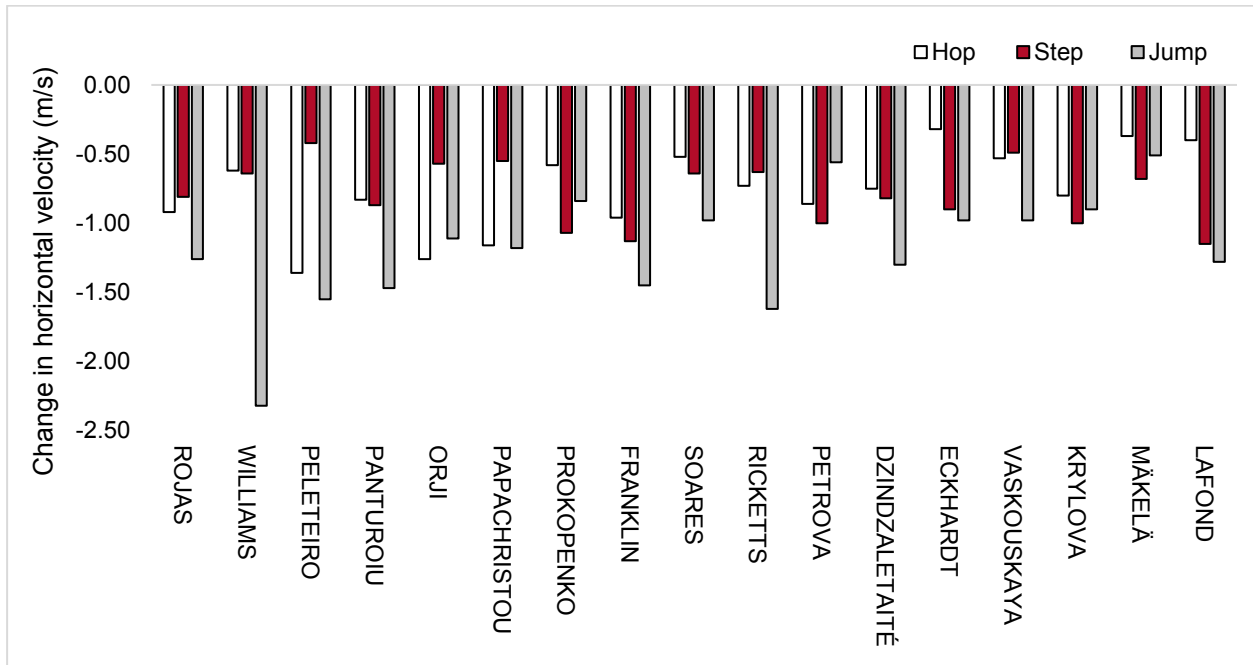


Figure 8. The change in horizontal velocity for the hop, step and jump for each finalist.

Figures 9, 10 and 11 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 17.2°, for the step was 15.7° and for the jump was 23.7°.

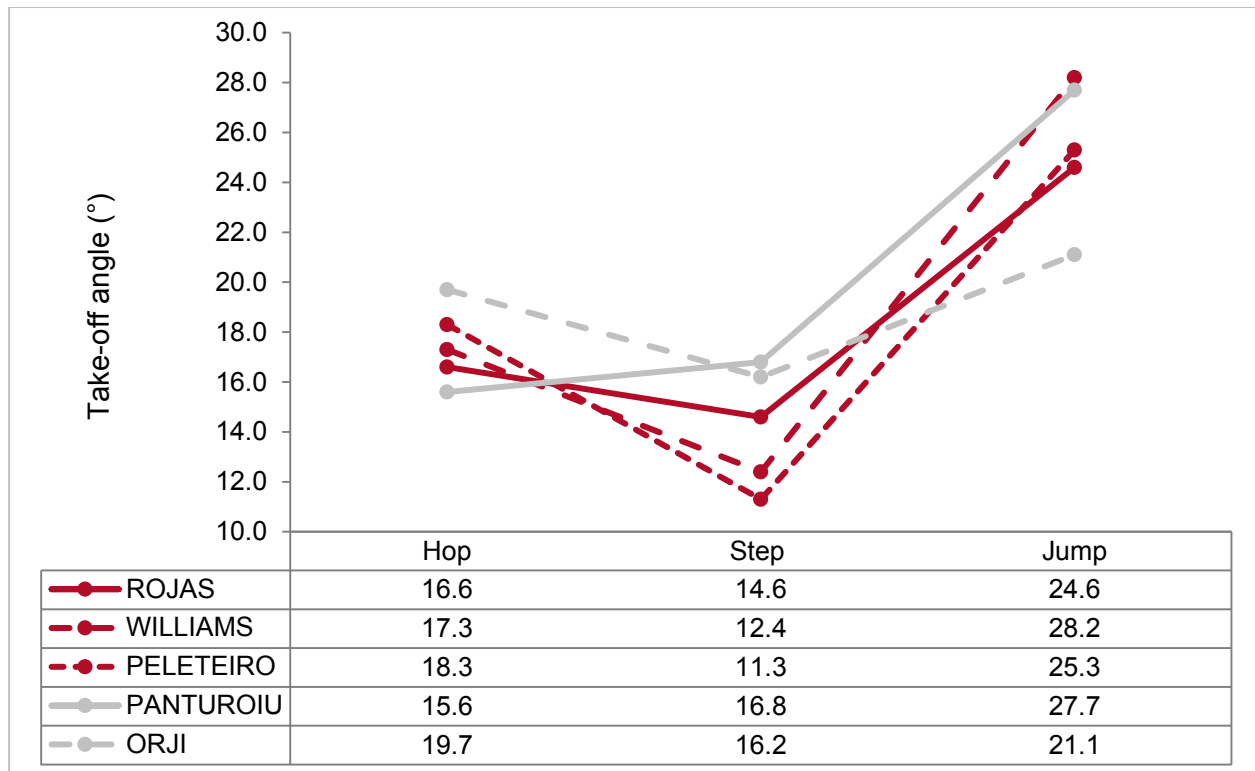


Figure 9. Take-off angle in the hop, step and jump for the top 5 finalists.

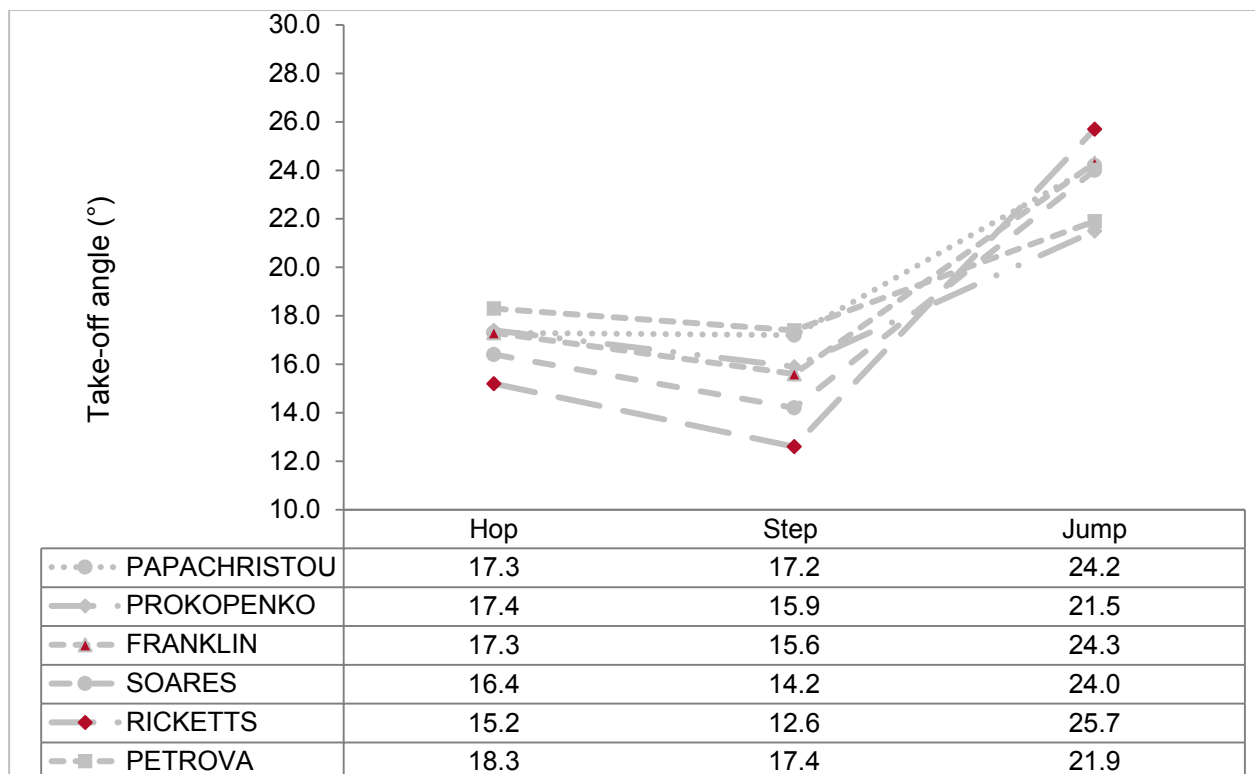


Figure 10. Take-off angle in the hop, step and jump for the middle 6 finalists.

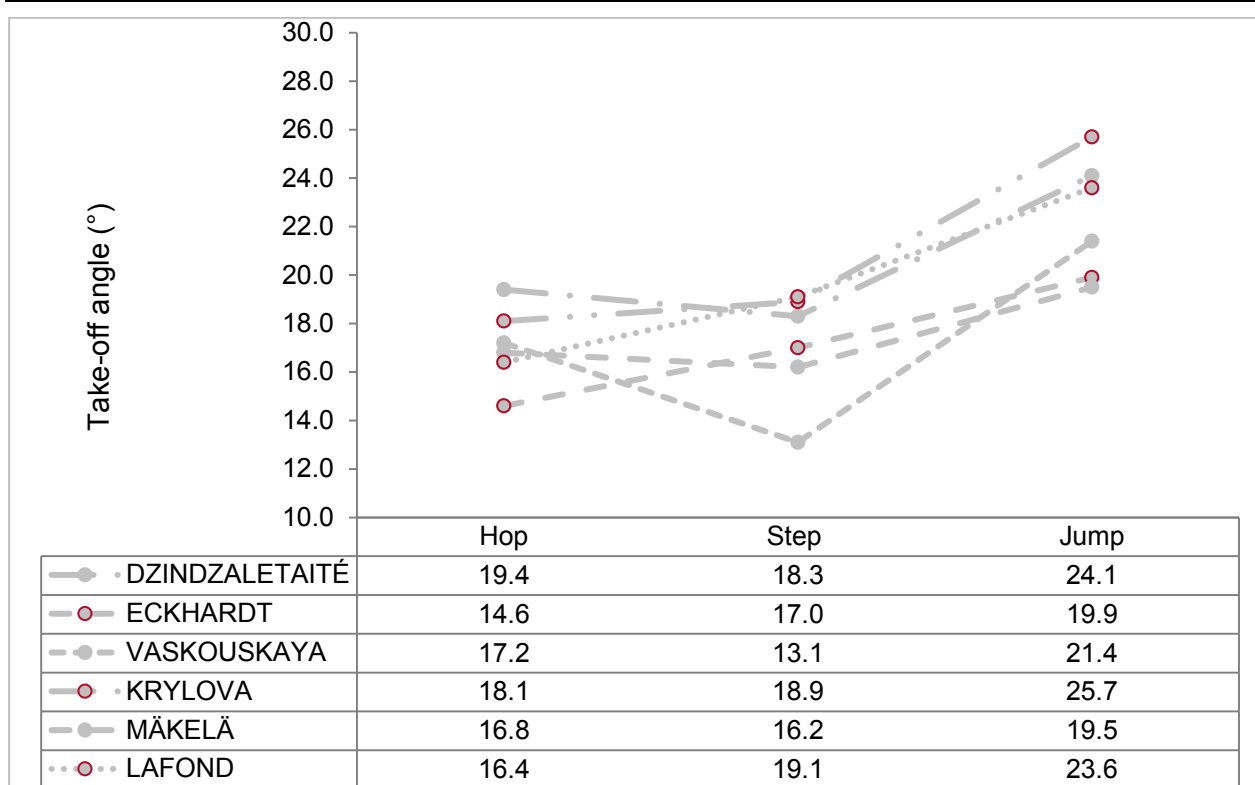


Figure 11. Take-off angle in the hop, step and jump for the bottom 6 finalists.

Table 9 below presents the changes in knee angle of the contact leg during the contact phases of the hop, step and jump. The mean knee range of motion (ROM) for the hop, step and jump was 23.5°, 30.4° and 26.6°, respectively.

Table 9. Characteristics of the knee of the contact leg during the contact phases of the hop, step and jump on the take-off board.

Athlete	Hop			Step			Jump		
	TD angle (°)	Min angle (°)	ROM (°)	TD Angle (°)	Min angle (°)	ROM (°)	TD Angle (°)	Min angle (°)	ROM (°)
ROJAS	156.2	133.1	23.1	166.0	126.9	39.1	165.8	138.8	27.0
WILLIAMS	152.3	137.4	14.9	156.5	133.2	23.3	155.1	120.7	34.4
PELETEIRO	153.9	128.2	25.7	160.5	131.0	29.5	151.1	129.3	21.8
PANTUROIU	153.5	131.5	22.0	160.1	126.4	33.7	160.9	125.5	35.4
ORJI	164.4	137.8	26.6	161.2	133.2	28.0	161.4	146.6	14.8
PAPACHRISTOU	161.6	146.5	15.1	165.1	134.2	30.9	153.3	148.1	5.2
PROKOPENKO	151.5	136.0	15.5	168.8	123.4	45.4	149.5	114.8	34.7
FRANKLIN	161.2	132.0	29.2	159.1	131.0	28.1	160.6	126.2	34.4
SOARES	162.6	134.0	28.6	163.6	121.1	42.5	162.4	139.6	22.8
RICKETTS	161.3	128.6	32.7	159.6	121.6	38.0	169.6	127.9	41.7
PETROVA	168.5	140.7	27.8	162.8	131.9	30.9	173.5	137.2	36.3
DZINDZALEITAITÉ	165.7	135.9	29.8	157.7	133.2	24.5	156.4	144.7	11.7
ECKHARDT	160.0	143.8	16.2	155.3	131.6	23.7	173.5	140.7	32.8
VASKOUSKAYA	156.5	142.0	14.5	165.5	138.5	27.0	162.2	122.3	39.9
KRYLOVA	155.0	133.4	21.6	162.7	124.2	38.5	164.5	138.4	26.1
MÄKELÄ	171.1	139.2	31.9	156.1	134.4	21.7	158.4	136.6	21.8
LAFOND	161.8	137.2	24.6	158.0	145.2	12.8	163.0	151.1	11.9

Note: TD = touchdown, Min = minimum, ROM = range of motion.

Table 10 shows the change in trunk angle from touchdown to take-off of the hop, step and jump. The mean trunk range of motion from touchdown (TD) to take-off (TO) for the hop, step and jump was -3.4° , -9.1° and -4.0° , respectively.

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

Athlete	Hop		Step		Jump	
	TD ($^\circ$)	TO ($^\circ$)	TD ($^\circ$)	TO ($^\circ$)	TD ($^\circ$)	TO ($^\circ$)
ROJAS	4.2	6.4	1.7	15.1	1.5	1.3
WILLIAMS	6.4	10.2	3.8	7.0	5.3	12.5
PELETEIRO	-5.1	1.2	-3.1	6.4	-1.2	0.5
PANTUROIU	-1.6	2.5	-5.2	9.8	-0.3	8.2
ORJI	1.7	10.1	-0.1	12.9	7.4	6.3
PAPACHRISTOU	-3.5	3.6	-2.1	13.8	10.5	14.9
PROKOPENKO	2.5	6.1	-1.3	8.5	5.5	3.1
FRANKLIN	-0.4	0.8	0.8	9.5	5.2	7.0
SOARES	0.3	-1.8	-6.1	3.9	7.0	9.2
RICKETTS	5.5	10.5	4.4	8.4	3.6	4.6
PETROVA	-1.7	2.9	-3.7	6.6	-0.4	11.1
DZINDZALEITAITÉ	-0.7	2.0	8.9	14.7	10.9	15.8
ECKHARDT	4.4	4.5	3.0	6.1	-1.4	15.4
VASKOUSKAYA	3.2	8.7	-3.5	6.8	6.3	9.8
KRYLOVA	5.2	11.6	-0.4	13.4	6.6	10.3
MÄKELÄ	3.3	5.7	5.0	8.3	6.6	6.2
LAFOND	10.2	7.1	3.1	8.6	1.5	6.5

Note: A negative trunk angle indicates that trunk is extended beyond the upright position while a positive trunk angle indicates the trunk angle is flexed beyond the upright position.

Table 11 shows the change in body inclination angle from touchdown to take-off of the hop, step and jump. The mean change in body inclination range of motion from touchdown (TD) to take-off (TO) for the hop, step and jump was 55.0°, 57.7° and 54.3°, respectively.

Table 11. Changes in body inclination angle during touchdown (TD) and take-off (TO) of the hop, step and jump.

Athlete	Hop		Step		Jump	
	TD (°)	TO (°)	TD (°)	TO (°)	TD (°)	TO (°)
ROJAS	-25.2	21.9	-24.4	29.3	-28.7	22.9
WILLIAMS	-30.3	25.4	-27.8	34.3	-34.0	22.6
PELETEIRO	-34.6	22.5	-23.2	32.1	-35.6	20.6
PANTUROIU	-28.0	25.5	-28.4	28.9	-32.1	23.8
ORJI	-28.8	21.6	-23.2	29.5	-25.4	22.9
PAPACHRISTOU	-28.8	23.4	-26.7	27.0	-25.8	25.2
PROKOPENKO	-31.1	26.2	-26.7	32.6	-30.0	29.9
FRANKLIN	-33.5	30.2	-33.7	32.2	-30.1	25.0
SOARES	-31.8	22.8	-26.1	28.4	-31.3	21.4
RICKETTS	-31.0	25.9	-29.0	34.1	-33.9	23.0
PETROVA	-32.4	24.0	-27.0	30.7	-27.7	26.1
DZINDZALEITAITÉ	-30.5	21.7	-24.6	34.5	-28.6	28.1
ECKHARDT	-26.8	27.0	-30.0	31.4	-24.4	29.0
VASKOUSKAYA	-30.9	26.5	-27.8	33.7	-30.8	28.7
KRYLOVA	-28.4	23.7	-25.8	27.2	-28.6	26.7
MÄKELÄ	-32.1	27.1	-24.0	32.8	-25.8	26.9
LAFOND	-30.3	25.5	-27.8	26.1	-25.0	22.0

Table 12 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 -16.4° , -26.0° and -18.5° , respectively. The mean thigh angular velocity of the swing leg for the hop, step and jump was $555^\circ/\text{s}$, $369^\circ/\text{s}$ and $400^\circ/\text{s}$, respectively.

Table 12. Thigh angle at take-off and mean thigh angular velocity of the swing leg (during the contact phase) for the hop, step and jump.

Athlete	Hop		Step		Jump	
	TO Angle ($^\circ$)	Angular velocity ($^\circ$)	TO Angle ($^\circ$)	Angular velocity ($^\circ$)	TO Angle ($^\circ$)	Angular velocity ($^\circ$)
ROJAS	-25.7	445	-23.9	383	-31.5	289
WILLIAMS	-16.2	582	-19.3	263	-13.6	210
PELETEIRO	-8.7	579	-21.6	436	-5.6	545
PANTUROIU	-19.7	553	-29.1	279	-23.0	389
ORJI	-16.0	544	-28.0	366	-18.1	427
PAPACHRISTOU	-21.0	582	-26.7	398	-23.4	402
PROKOPENKO	-15.5	536	-20.7	352	-21.6	327
FRANKLIN	-13.6	547	-23.1	404	-10.1	395
SOARES	-14.9	535	-38.2	342	-14.2	392
RICKETTS	-13.3	548	-30.7	322	-21.6	308
PETROVA	-15.1	603	-24.2	385	-12.5	535
DZINDZALETAITÉ	-13.2	651	-25.6	332	-24.5	395
ECKHARDT	-13.6	649	-20.7	502	-12.9	517
VASKOUSKAYA	-22.3	495	-34.9	366	-24.7	515
KRYLOVA	-19.8	475	-21.9	382	-13.2	406
MÄKELÄ	-8.6	577	-18.6	449	-17.0	398
LAFOND	-21.6	534	-34.4	304	-27.5	352

Landing analysis

Table 13 shows the angles of the trunk, hip and knee on landing with the sand. The loss in landing is also shown. The largest landing loss was by Mäkelä at 0.20 metres. Five other athletes also recorded a loss on landing. The mean hip angle at landing was 79.6°. The mean knee angle was 122.0°, while the mean trunk angle was 17.2°. Figure 12 shows the landing distance by each athlete. The mean landing distance was 0.42 metres.

Table 13. Landing characteristics in the men's triple jump final.

Athlete	Hip angle (°)	Knee angle (°)	Trunk angle (°)	Landing loss (m)
ROJAS	72.3	121.9	24.2	0.00
WILLIAMS	90.2	128.4	3.7	0.03
PELETEIRO	72.0	107.2	8.9	0.00
PANTUROIU	86.4	131.9	13.0	0.00
ORJI	80.5	138.3	29.1	0.00
PAPACHRISTOU	90.0	101.6	-6.0	0.11
PROKOPENKO	60.3	146.9	46.9	0.17
FRANKLIN	70.6	124.2	36.0	0.00
SOARES	101.7	101.3	-29.3	0.12
RICKETTS	79.6	98.3	-0.7	0.00
PETROVA	76.3	119.9	27.5	0.00
DZINDZALETAITÉ	58.8	121.9	33.8	0.03
ECKHARDT	81.2	133.1	14.8	0.00
VASKOUSKAYA	91.1	107.6	0.9	0.00
KRYLOVA	81.4	136.0	18.5	0.00
MÄKELÄ	62.4	141.8	28.5	0.20
LAFOND	97.6	112.9	43.0	0.00

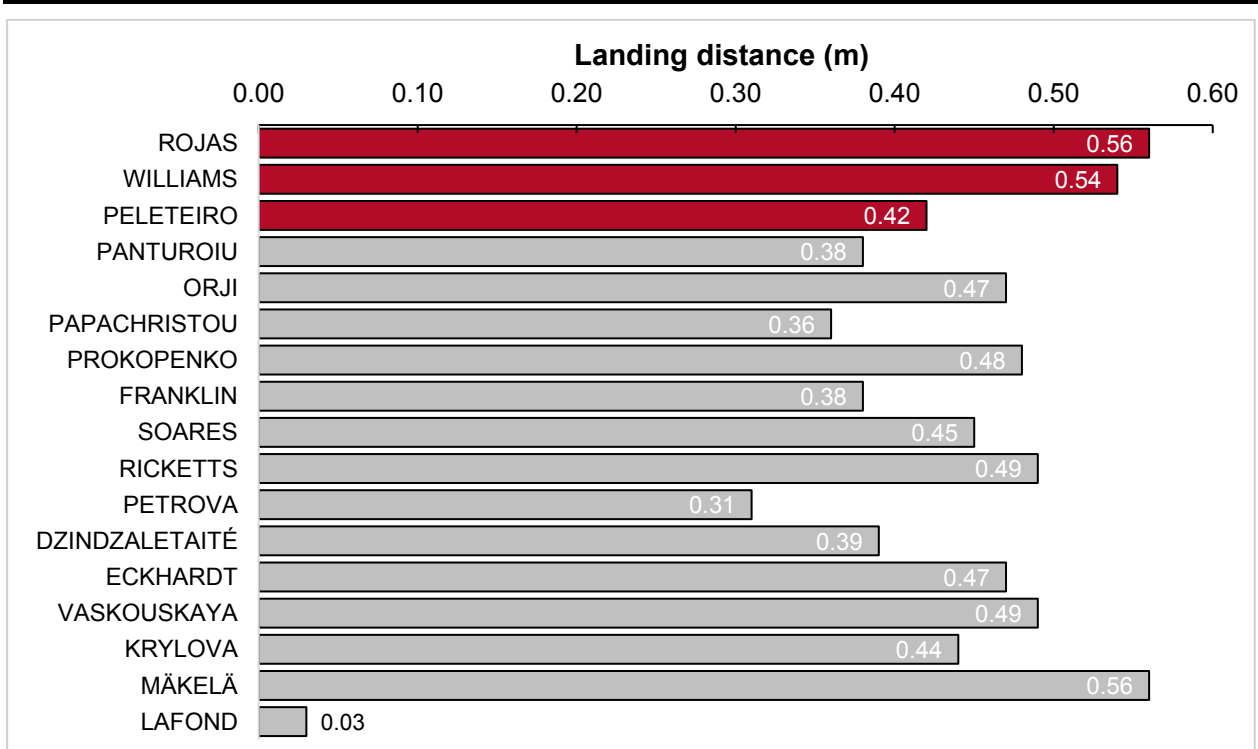


Figure 12. The landing distances for each finalist in the women's triple jump.

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