



BIOMECHANICAL REPORT

FOR THE

IAAF World Championships

LONDON 2017

Long Jump Women's

Dr Catherine Tucker, Dr Gareth Nicholson, Mark Cooke
and Dr Athanassios Bissas

Carnegie School of Sport

Stéphane Merlino

IAAF Project Leader



LEEDS
BECKETT
UNIVERSITY

IAAFTM

Event Directors

Dr Catherine Tucker Mark Cooke
Dr Gareth Nicholson

Project Director

Dr Athanassios Bissas

Project Coordinator

Louise Sutton

Senior Technical Support

Liam Gallagher Aaron Thomas Liam Thomas

Senior Research Officer

Josh Walker

Report Editor

Dr Catherine Tucker

Analysis Support

Dr Lysander Pollitt

Logistics

Dr Zoe Rutherford

Calibration

Dr Brian Hanley

Data Management

Nils Jongerius

Technical Support

Ashley Grindrod
Joshua Rowe

Ruth O'Faolain

Lewis Lawton
Joe Sails

Data Analysts

Dr Catherine Tucker
Mark Cooke

Philip McMorris
Rachel Bradley

Project Team

Dr Tim Bennett

Dr Alex Dinsdale

Helen Gravestock

Masalela Gaesengwe
Mike Hopkinson

Emily Gregg
Parag Parelkar

Amy Brightmore
Callum Guest
Dr Ian Richards
Jack Whiteside
Lara Wilson

Helen Davey
Ruan Jones
William Shaw
Dr Emily Williams

Jamie French
Maria van Mierlo
James Webber
Jessica Wilson
Dr Stephen Zwolinsky

External Coaching Consultant

Toni Minichiello

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INTRODUCTION

The women's long jump final took place on the night of August 11th. Coming into the final, Brittney Reese of the USA was favourite given she had performed a world leading jump of 7.13 metres earlier in the year. Tianna Bartoletta was also a strong contender as she was the Olympic Champion from the previous year. It was an exciting final where Reese clinched the gold medal with the better of her two scoring efforts measured at 7.02 metres. Darya Klishina produced four successive season's bests with her best effort being 7 metres exactly. Bartoletta, despite being a strong contender, had to settle for the bronze medal but she only secured this with her final attempt of 6.97 metres. This attempt beat Ivana Španovic, an early leader, by just one centimetre.

IAAF		World Championships		London		4-13 August 2017		IAAF World Championships LONDON 2017				
RESULTS												
Long Jump Women - Final												
RECORDS		RESULT NAME		COUNTRY		AGE		VENUE		DATE		
World Record		7.52 Galina CHISTYAKOVA		URS		26		Leningrad (Kirov Stadium)		11 Jun 1988		
Championships Record		7.36 Jackie JOYNER-KERSEE		USA		25		Roma (Stadio Olimpico)		4 Sep 1987		
World Leading		7.13 Brittney REESE		USA		31		Chula Vista (OTC), CA		17 Jun 2017		
Area Record		National Record		Personal Best		Season Best						
11 August 2017			19:11 START TIME			20° C			60 %			
						TEMPERATURE			HUMIDITY			
						19° C			68 %			
			20:35 END TIME									
PLACE	NAME	COUNTRY	DATE of BIRTH	ORDER	RESULT	1	2	3	ORDER	4	5	6
1	Brittney REESE	USA	9 Sep 86	10	7.02 +0.1	6.75 -0.6	X -0.9	7.02 +0.1	8	X -0.2	X -0.1	X +0.3
2	Darya KLISHINA	ANA	15 Jan 91	4	7.00 -0.3	6.78 +0.2	6.88 +0.2	X -0.8	6	6.91 +0.8	7.00 -0.3	6.83 +0.4
3	Tianna BARTOLETTA	USA	30 Aug 85	11	6.97 -0.2	6.56 +0.1	6.60 -0.1	X +0.3	3	6.64 -0.3	6.88 +1.1	6.97 -0.2
4	Ivana ŠPANOVIĆ	SRB	10 May 90	3	6.96 +0.1	X +1.3	6.96 +0.1	6.77 -0.9	7	X -0.9	X -0.1	6.91 +0.5
5	Lorraine UGEN	GBR	22 Aug 91	1	6.72 +0.5	X -0.5	X -0.7	6.72 +0.5	5	X -0.8	X 0.0	6.40 +0.3
6	Brooke STRATTON	AUS	12 Jul 93	12	6.67 -0.9	6.27 -0.9	6.54 -0.4	6.67 -0.9	4	6.55 +0.2	6.67 0.0	6.64 +0.2
7	Chantel MALONE	IVB	2 Dec 91	5	6.57 -0.1	6.52 +0.3	6.44 +0.1	6.57 -0.1	2	X +0.4	X +1.1	6.52 -0.8
8	Blessing OKAQBARE-IŌHOTEŌ	NGR	9 Oct 88	2	6.55 +0.2	6.40 +0.4	6.55 +0.2	6.47 +1.2	1	6.49 -0.2	X +0.2	6.31 0.0
9	Lauma ĢRIVA	LAT	27 Oct 84	7	6.54 +1.0	6.54 +1.0	X +0.4	6.42 +0.6				
10	Claudia SALMAN-RATH	GER	25 Apr 86	8	6.54 +0.8	6.39 +0.7	6.29 +0.2	6.54 +0.8				
11	Eilane MARTINS	BRA	26 May 86	6	6.52 +1.2	6.52 +1.2	X -0.1	X -0.1				
12	Alina ROTARU	ROU	5 Jun 93	9	6.46 -0.3	6.29 -0.2	6.20 +0.3	6.46 -0.3				
Timing and Measurement by SEIKO						AT-LJ-W-f--A--RS1..V1			Issued at 21:02 on Friday, 11 August 2017			
Official Partners												
TDK		TOYOTA		asics		SEIKO		EURIOVISION		TBS		

METHODS

Six 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 completed their last three steps before take-off until landing.

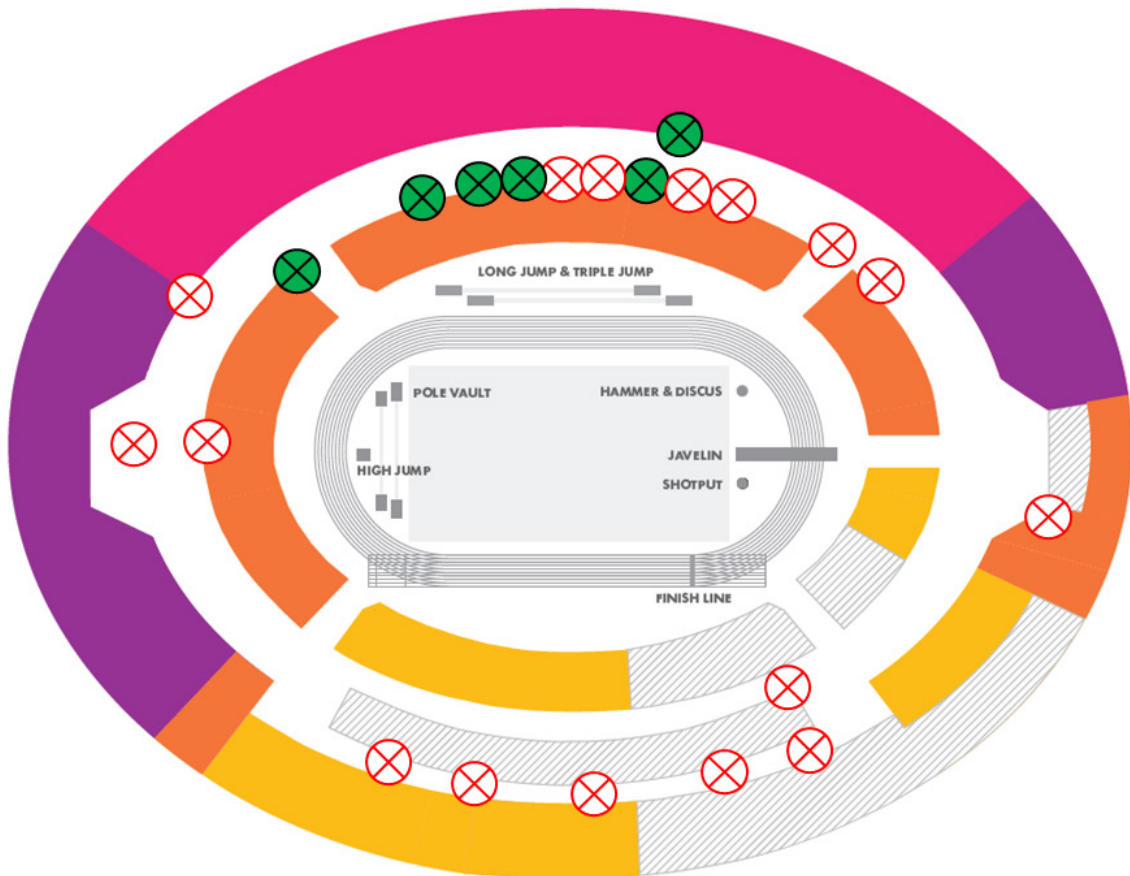


Figure 1. Camera locations within the stadium for the women's long jump final (shown in green).

Seven cameras were used to record the action during the long 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 moved through the calibrated area of the run-up and take-off. Four Canon EOS 700D cameras operating at 60 Hz (shutter speed: 1/1000; ISO: 1600; SHD: 1280x720 px) were positioned strategically along the runway with three of these being paired with a Sony PXW-FS5 camera each as a precaution against the unlikely event of data capture loss. A single Canon EOS-700D camera was positioned with its optical axis perpendicular to the landing pit to capture motion in the sagittal plane of landing. However, because of the lack

of availability of this specific camera position during the final, it was not possible to analyse the landing position.

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.

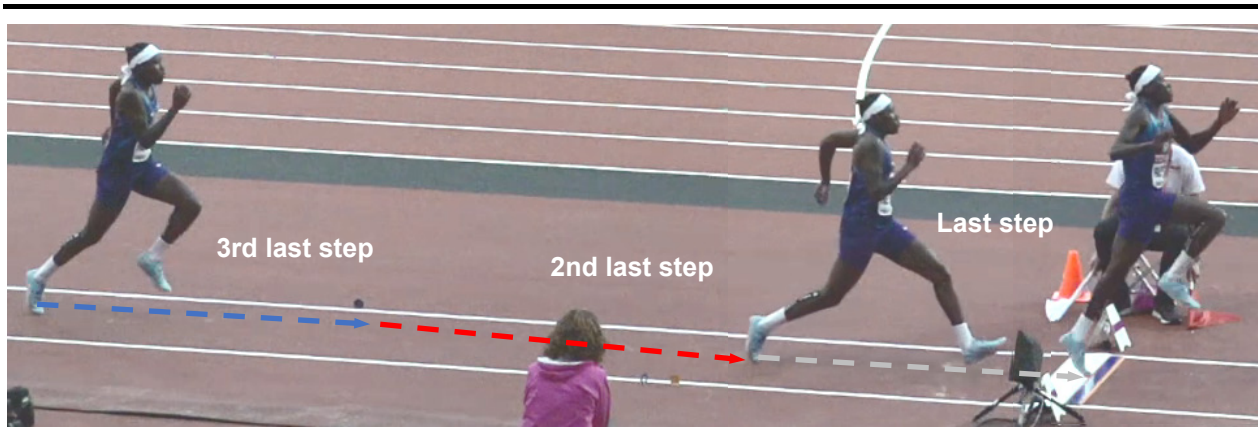


Figure 3. Last three steps in the approach phase of the long jump.

Table 1. Definitions of variables examined in the long jump.

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 (3rd last, 2nd last, last)	The length of the third-to-last, second-last and last approach steps measured from the foot tip in each step to the next foot tip.
Change in step length (3rd last / 2nd last and 2nd last / last)	The percentage difference in length between each step and the previous step.
Step width (3rd last, 2nd last, last)	The side-to-side displacement from the toe off of each step to the toe-off of the next step.
Velocity (3rd last step, 2nd last step, last step)	The mean horizontal (anteroposterior direction) velocity of the athlete measured during each of the last three steps before take-off.
Horizontal velocity at take-off	The athlete's horizontal centre of mass (CM) velocity (anteroposterior direction) at the instant of take-off.
Vertical velocity at take-off	The velocity in the vertical direction of the athlete's CM at the instant of take-off.

Loss in horizontal velocity	The change in horizontal velocity from touchdown (TD) on the board to take-off from the board.
CM lowering	The reduction in CM height from take-off of the last step to the minimum CM height during contact with the board.
Contact time (last three steps)	The time spent in contact during the support phase of the last three steps.
Trunk angle	The angle of the trunk relative to the horizontal and considered to be 90° in the upright position.
Take-off angle	The angle of the athlete's CM at take-off from the board relative to the horizontal.
Body inclination angle at touchdown and take-off	The angle of a line between the athlete's CM and contact foot relative to the vertical at the instant of touchdown and take-off.
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.
Knee range of motion	The change in knee angle from TD on the board to its minimum while on the take-off board.
Knee angular velocity	The mean rate of change of the knee angle from touchdown on the board to reaching its minimum on the board.
Thigh angle of swing leg	The angle of the thigh of the swinging leg measured from the horizontal at take-off.
Thigh angular velocity of swing leg	The mean angular velocity of the thigh of the swinging leg from initial contact to take-off from the board.

Note: CM = centre of mass.

RESULTS

Overall analysis

Table 2 shows the official best distance of each athlete alongside a comparison with their personal and season's bests. The mean jump distance was 6.71 metres and the mean difference compared with their season's bests was -0.17 metres and compared with their personal bests was -0.27 metres.

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	PB (m)	Comparison with PB (m)
REESE	1	7.02	7.13	-0.11	7.31	-0.29
KLISHINA	2	7.00	6.84	0.16	7.05	-0.05
BARTOLETTA	3	6.97	7.01	-0.04	7.17	-0.20
ŠPANOVIC	4	6.96	7.24	-0.28	7.24	-0.28
UGEN	5	6.72	6.97	-0.25	6.97	-0.25
STRATTON	6	6.67	6.79	-0.12	7.05	-0.38
MALONE	7	6.57	6.67	-0.10	6.69	-0.12
OKAGBARE-IGHOTEGUONOR	8	6.55	6.77	-0.22	7.00	-0.45
GRIVA	9	6.54	6.72	-0.18	6.86	-0.32
SALMAN-RATH	10	6.54	6.94	-0.40	6.94	-0.40
MARTINS	11	6.52	6.69	-0.17	6.72	-0.20
ROTARU	12	6.46	6.78	-0.32	6.78	-0.32

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

Table 3 shows distance characteristics of each athlete's best jumps in relation to their effective distance and distance lost at the take-off board. The mean loss at the take-off board was 0.05 metres.

Table 3. Distance characteristics of the individual best jumps.

Athlete	Analysed attempt	Official distance (m)	Effective distance (m)	Take-off loss (m)
REESE	2	7.02	7.03	0.01
KLISHINA	5	7.00	7.01	0.01
BARTOLETTA	6	6.97	7.04	0.07
ŠPANOVIĆ	2	6.96	7.03	0.07
UGEN	3	6.72	6.74	0.02
STRATTON	5	6.67	6.68	0.01
MALONE	3	6.57	6.69	0.12
OKAGBARE-IGHOTEGUONOR	2	6.55	6.71	0.16
GRIVA	1	6.54	6.55	0.01
SALMAN-RATH	3	6.54	6.63	0.09
MARTINS	1	6.52	6.55	0.03
ROTARU	3	6.46	6.49	0.03

Approach phase analysis

Table 4 shows the step lengths of each finalists during their last three steps before the take-off board. The percentage change in step length from the third- to second-last, and in the second-last to last steps, is also presented. The mean change from the third-last to second-last step was an increase of 9%. The mean change from the second-last to last step was a decrease of 10%.

Table 4. Step length characteristics of last three steps in best individual jumps.

Step lengths of last three steps before take-off			Change in step length		
	■ 3rd last step length (m)	■ 2nd last step length (m)	■ Last step length (m)	3 rd last / 2 nd last (%)	2 nd last / last (%)
REESE	2.05	2.30	1.87	+12	-19
KLISHINA	2.12	2.19	1.98	+3	-10
BARTOLETTA	2.01	2.22	2.01	+10	-9
ŠPANOVIC	1.86	2.37	2.06	+27	-13
UGEN	2.34	2.64	2.10	+13	-20
STRATTON	2.04	2.06	2.00	+1	-3
MALONE	2.20	2.16	2.23	-2	+3
OKAGBARE-IGHOTEGUONOR	2.04	2.30	1.97	+13	-14
GRIVA	1.97	2.15	2.08	+9	-3
SALMAN-RATH	2.00	2.20	1.98	+10	-10
MARTINS	2.05	2.13	2.02	+4	-5
ROTARU	2.13	2.25	1.99	+6	-12

Table 5 shows the step time of the last three steps for each athlete. Figures 4-6 show the flight and contact times of each of those last three steps to the take-off board. The mean contact time for the third-last step was 0.105 seconds, for the second-last step was 0.112 seconds and the for the last step was 0.113 seconds. The mean flight time for the third-last step was 0.134 seconds, for the second-last step was 0.128 seconds and the for the last step was 0.070 seconds.

Table 5. Step times of the last three steps to the take-off board.

Athlete	3 rd last step (s)	2 nd last step (s)	Last step (s)
REESE	0.235	0.250	0.175
KLISHINA	0.230	0.240	0.190
BARTOLETTA	0.235	0.220	0.170
ŠPANOVIC	0.250	0.225	0.170
UGEN	0.265	0.260	0.185
STRATTON	0.210	0.225	0.190
MALONE	0.240	0.260	0.205
OKAGBARE- IGHOTEGUONOR	0.240	0.240	0.170
GRIVA	0.245	0.250	0.185
SALMAN-RATH	0.240	0.235	0.190
MARTINS	0.225	0.230	0.180
ROTARU	0.245	0.245	0.190

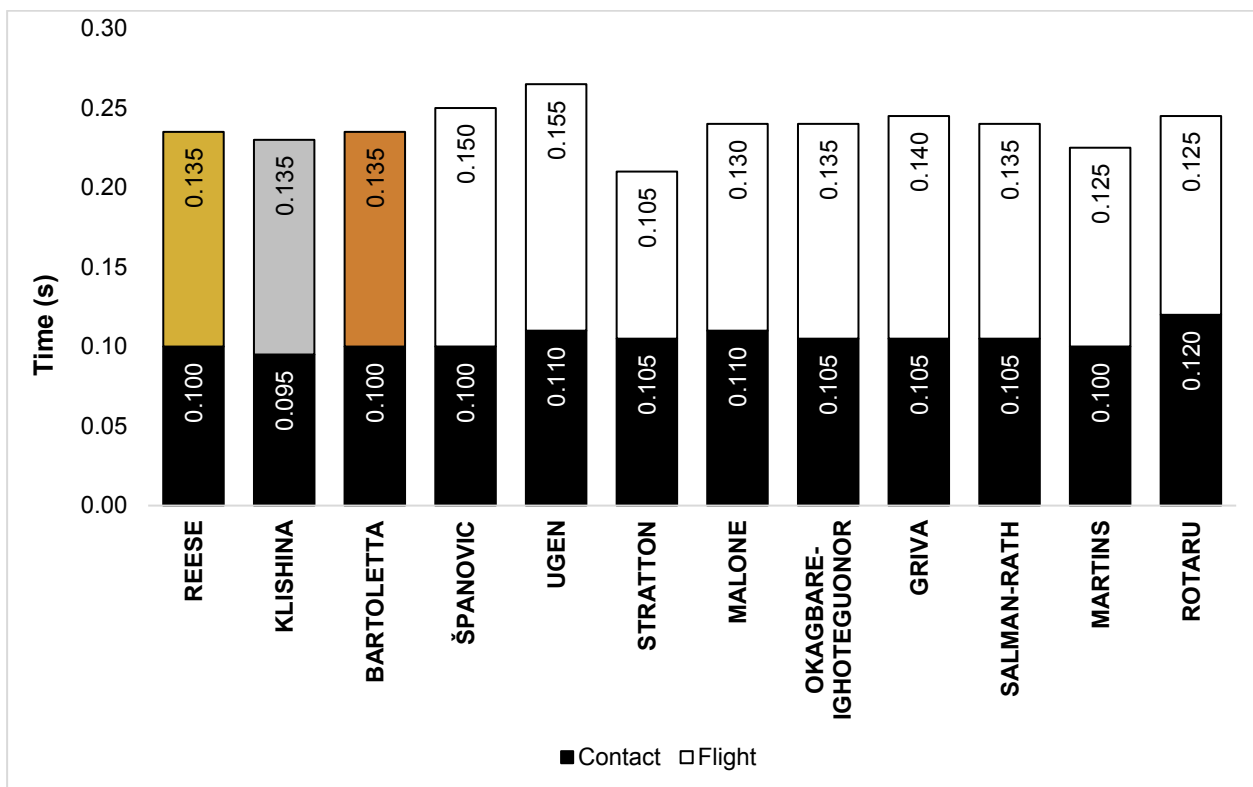


Figure 4. Contact and flight times for each finalist during the third-last step in their approach to the take-off board.

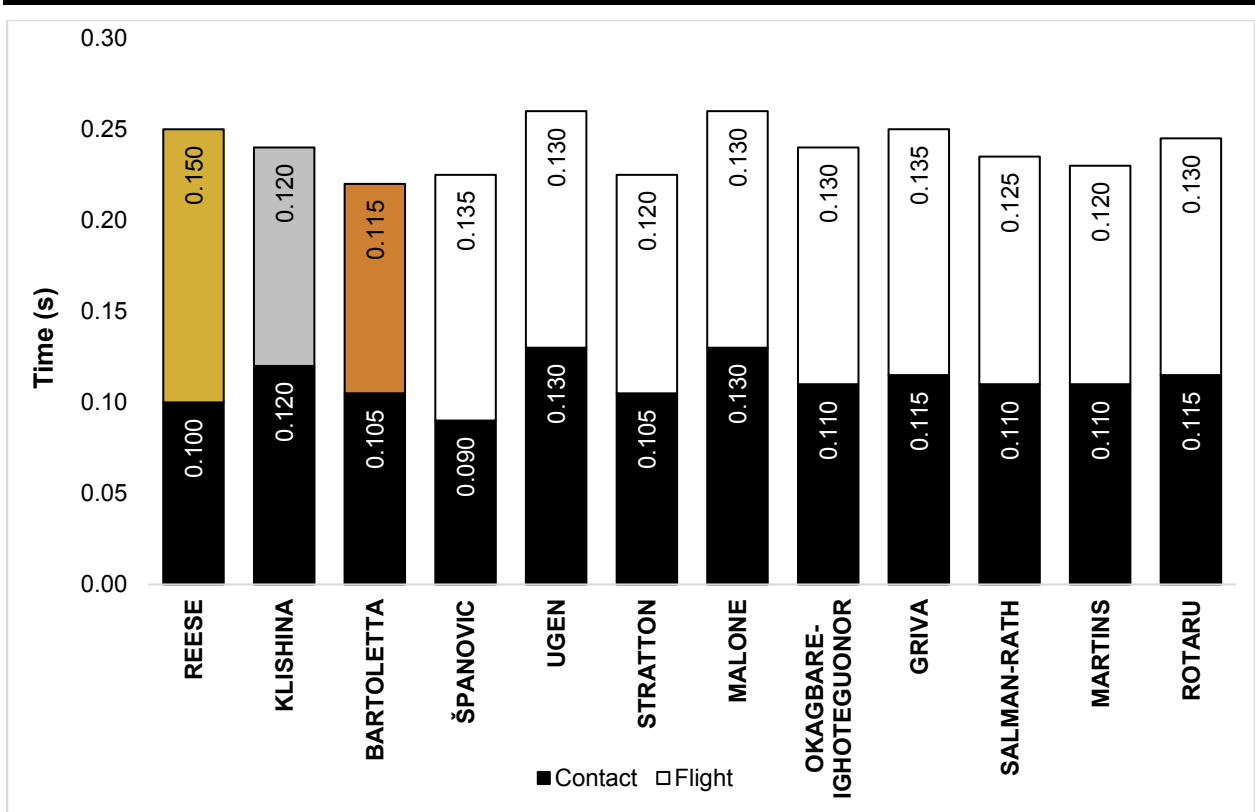


Figure 5. Contact and flight times for each finalist during the second-last step in their approach to the take-off board.

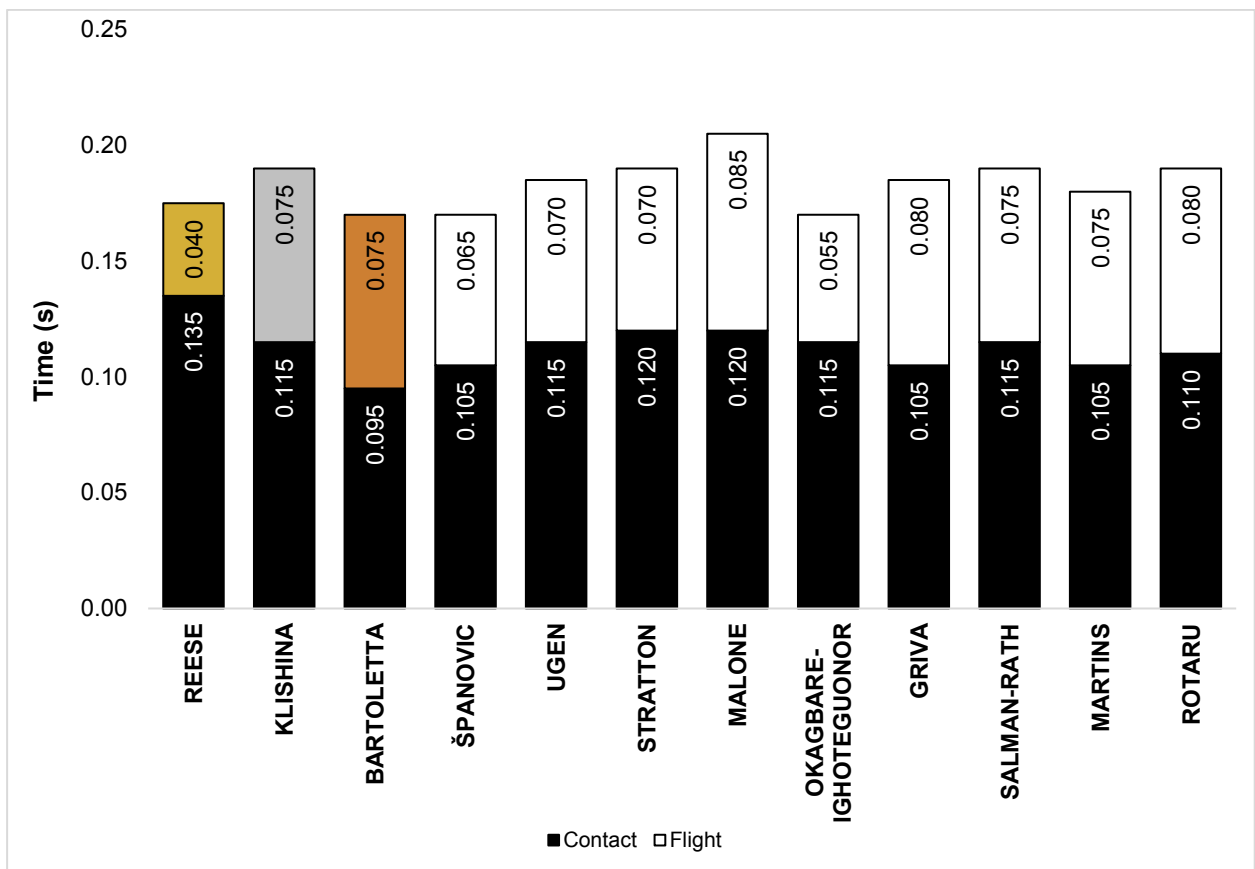


Figure 6. Contact and flight times for each finalist during the last step in their approach to the take-off board.

Table 6 shows the step width for each of the last three steps and changes between them.

Table 6. Step width for the last three steps along with the changes (Δ) between each step.

Athlete	3 rd last step (m)	2 nd last step (m)	Last step (m)	Δ 3 rd – 2 nd last step (m)	Δ 2 nd last - last step (m)
REESE	0.10	0.13	0.13	0.03	0.00
KLISHINA	0.13	0.15	0.09	0.02	-0.06
BARTOLETTA	0.06	0.35	0.19	0.29	-0.16
ŠPANOVIĆ	0.09	0.26	0.00	0.17	-0.26
UGEN	0.17	0.19	0.08	0.02	-0.11
STRATTON	0.18	0.21	0.19	0.03	-0.02
MALONE	0.04	0.16	0.03	0.12	-0.13
OKAGBARE-IGHOTEGUONOR	0.09	0.14	0.28	0.05	0.14
GRIVA	0.14	0.20	0.05	0.06	-0.15
SALMAN-RATH	0.03	0.15	0.17	0.12	0.02
MARTINS	0.09	0.19	0.18	0.10	-0.01
ROTARU	0.07	0.13	0.20	0.06	0.07

Note: Positive values for change in step width indicate an increase between steps and negative values indicate a reduction in step width between steps.

Figures 7 and 8 show the horizontal velocities for the last three steps for all finalists. The mean change in velocity from the third-last to second-last step was a reduction of 0.06 m/s. The mean change in velocity from the second-last to last step was a reduction of 0.51 m/s.

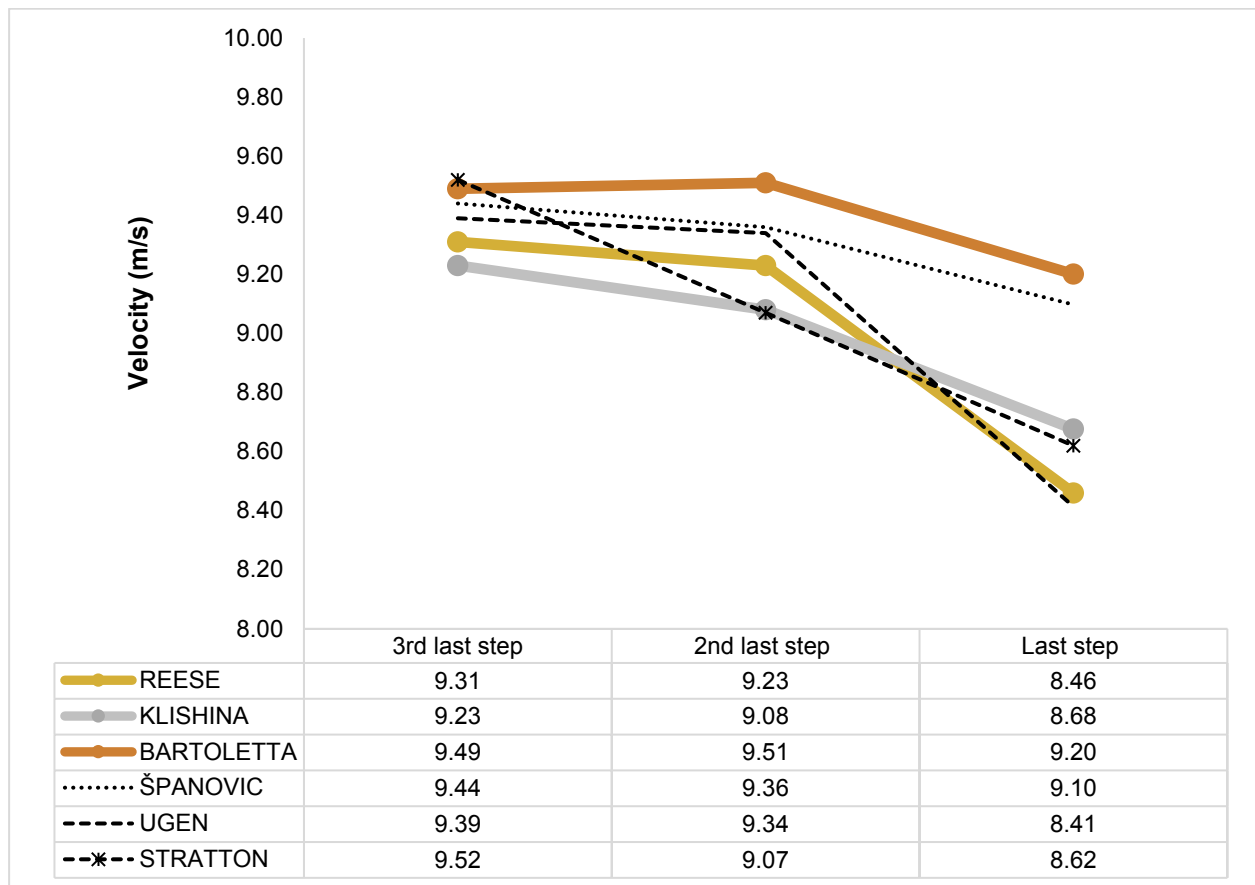


Figure 7. Change in horizontal velocity during the last three approach steps for the top six finishers.

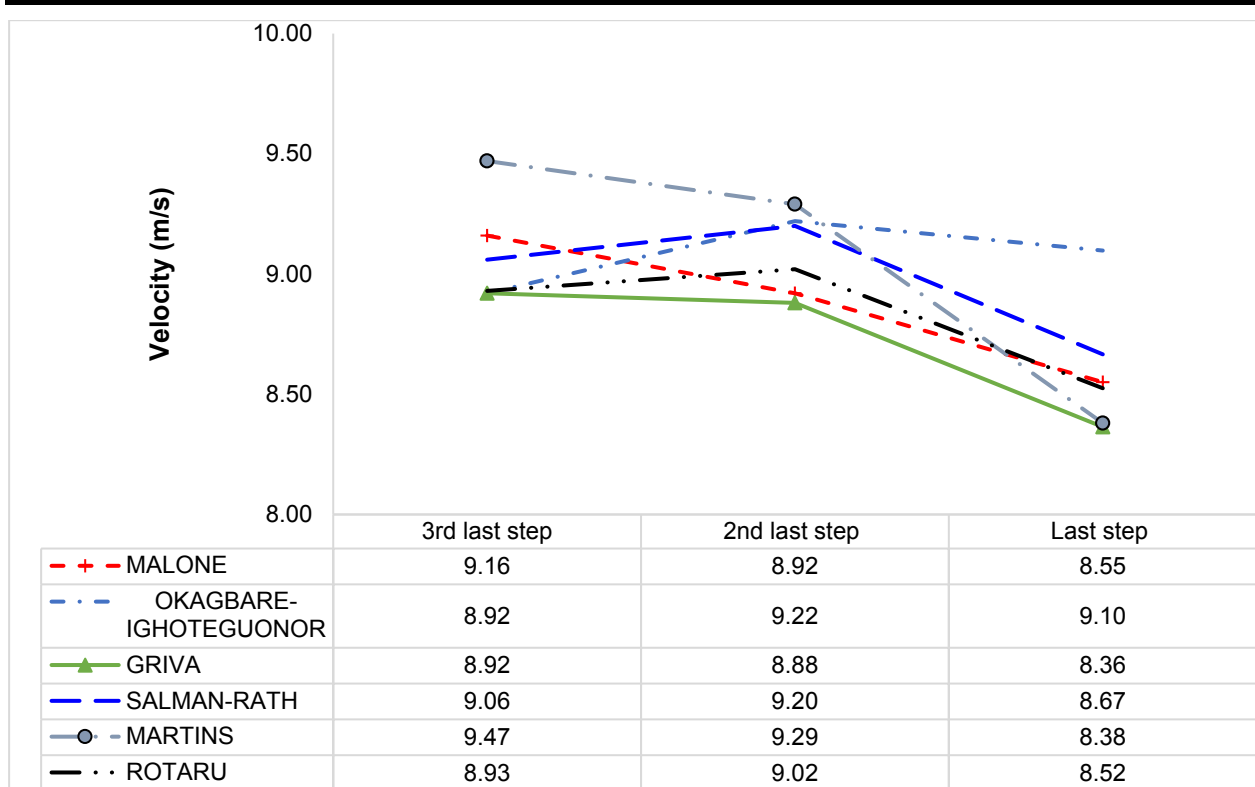


Figure 8. Change in horizontal velocity during the last three approach steps for the bottom six finishers.

Take-off analysis

Table 7 shows the velocity components of the CM at take-off along with the loss in horizontal velocity during contact with the take-off board. The mean horizontal velocity at TO was 7.94 m/s, while the mean vertical velocity at TO was 3.09 m/s. The mean change in horizontal velocity was -1.32 m/s. The lowering of the CM during contact with the board is also displayed within the table. The mean lowering was 3 centimetres. Figure 9 shows the relationship between the horizontal (anteroposterior) and vertical velocity at take-off.

Table 7. CM velocities (horizontal, vertical and resultant) during the final step and at take-off.

Athlete	Horizontal velocity at TO (m/s)	Vertical velocity at TO (m/s)	Change in horizontal velocity (TD - TO) (m/s)	Resultant velocity at TO (m/s)	CM lowering (cm)
REESE	8.23	2.73	-1.01	8.67	1
KLISHINA	8.27	3.42	-1.29	8.95	3
BARTOLETTA	7.72	2.86	-1.48	8.23	2
ŠPANOVIC	7.91	3.26	-1.41	8.56	4
UGEN	7.20	3.46	-2.37	7.99	1
STRATTON	7.98	3.27	-1.01	8.62	2
MALONE	8.09	3.07	-0.91	8.65	2
OKAGBARE-IGHOTEGUONOR	8.98	3.26	-1.41	9.55	3
GRIVA	7.57	3.31	-1.40	8.26	6
SALMAN-RATH	7.78	2.65	-1.15	8.22	1
MARTINS	8.23	3.22	-1.06	8.84	2
ROTARU	7.37	2.51	-1.37	7.79	3

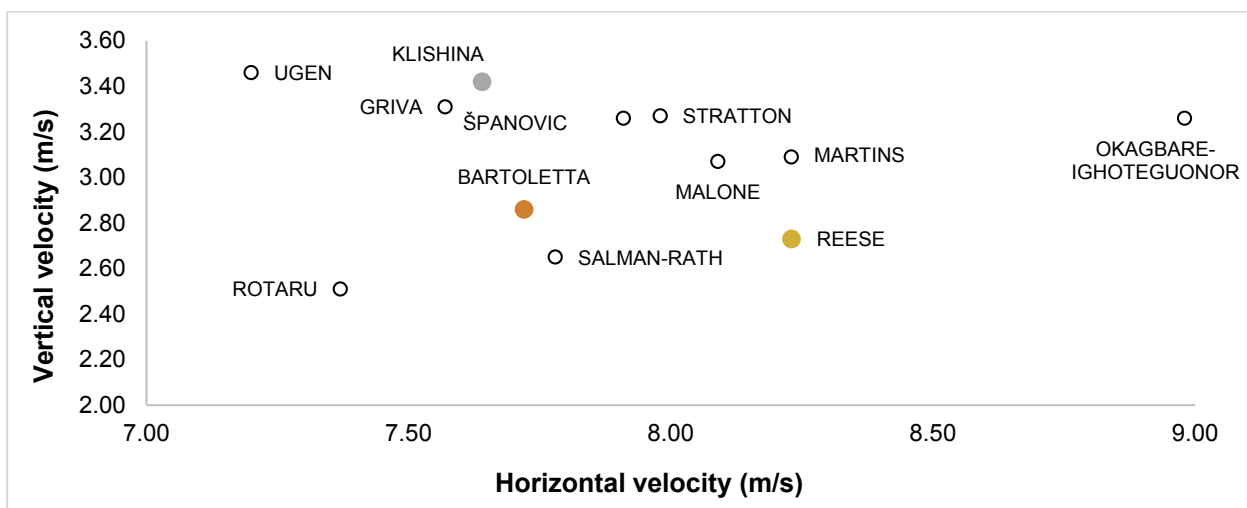


Figure 9. Scatterplot of horizontal (anteroposterior) vs. vertical velocity at take-off for all finalists.

The take-off angles for each athlete are shown in Table 8. The CM angle at take-off, the angle of the trunk, the inclination angle at touchdown on the board and take-off from the board are also shown. The mean take-off angle was 21.3°, the mean trunk angle at take-off was 94.4°, while the angle of the lead thigh at take-off was -17.0°. The mean body inclination angle at touchdown was -36.7°, while its value at take-off was 15.8°. The change in this angle from touchdown to take-off was 52.5°.

Table 8. Angular data of the CM, trunk and swinging leg for each athlete's individual best jump.

Athlete	TO angle (°)	Body inclination angle at TD (°)	Body inclination angle at TO (°)	Trunk angle at TO (°)	Lead thigh angle at TO (°)	Mean lead thigh angular velocity (°/s)
REESE	18.4	-39.4	17.5	84.6	-16.1	514
KLISHINA	22.5	-36.8	12.6	88.4	-11.8	563
BARTOLETTA	20.3	-35.5	15.2	97.8	-28.4	407
ŠPANOVIC	22.4	-38.6	19.1	97.2	-22.7	497
UGEN	25.7	-37.5	13.6	84.3	-14.4	543
STRATTON	22.3	-37.0	17.9	89.8	-11.1	581
MALONE	20.8	-36.3	13.0	99.9	-14.9	552
OKAGBARE-IGHOTEGUONOR	20.0	-38.2	15.3	103.2	-22.7	393
GRIVA	23.6	-35.2	16.4	95.6	-17.8	515
SALMAN-RATH	18.8	-34.4	18.1	92.7	-17.1	518
MARTINS	21.4	-35.9	13.8	96.1	-16.4	549
ROTARU	18.8	-35.1	17.0	102.7	-10.9	533

Note: A negative body inclination angle indicates that the CM is behind the foot at contact. A negative lead thigh angle means the thigh is below the horizontal.

Table 9 displays the knee angle at touchdown (TD) and the minimum knee angle achieved on the board. The mean knee angle at TD on the board was 169.9° while the mean minimum knee angle on the board was 138.6°. The mean knee range of motion was 31.3°. The mean rate of change of this knee angle was 465°/s.

Table 9. Characteristics of the contact leg on the take-off board.

Athlete	Knee angle at TD (°)	Minimum knee angle (°)	Knee range of motion (°)	Mean knee angular velocity (°/s)
REESE	156.0	137.1	18.9	-379
KLISHINA	172.4	144.4	28.0	-311
BARTOLETTA	174.0	133.2	40.8	-493
ŠPANOVIC	167.5	141.6	25.9	-370
UGEN	163.8	131.5	32.3	-587
STRATTON	176.7	142.6	34.1	-682
MALONE	155.8	132.9	22.9	-459
OKAGBARE-IGHOTEGUONOR	174.3	150.6	23.7	-238
GRIVA	177.5	145.2	32.3	-381
SALMAN-RATH	175.8	138.5	37.3	-533
MARTINS	168.5	132.3	36.2	-604
ROTARU	176.7	133.3	43.4	-543

Note: Negative angular velocity values for the knee indicate the knee is flexing.

CM trajectories (vertical)

Figures 10-13 on the following pages show the changes in the height of the CM from toe-off of the last step until take-off from the board. These data have been normalised to the height of the CM at toe-off of the last step.

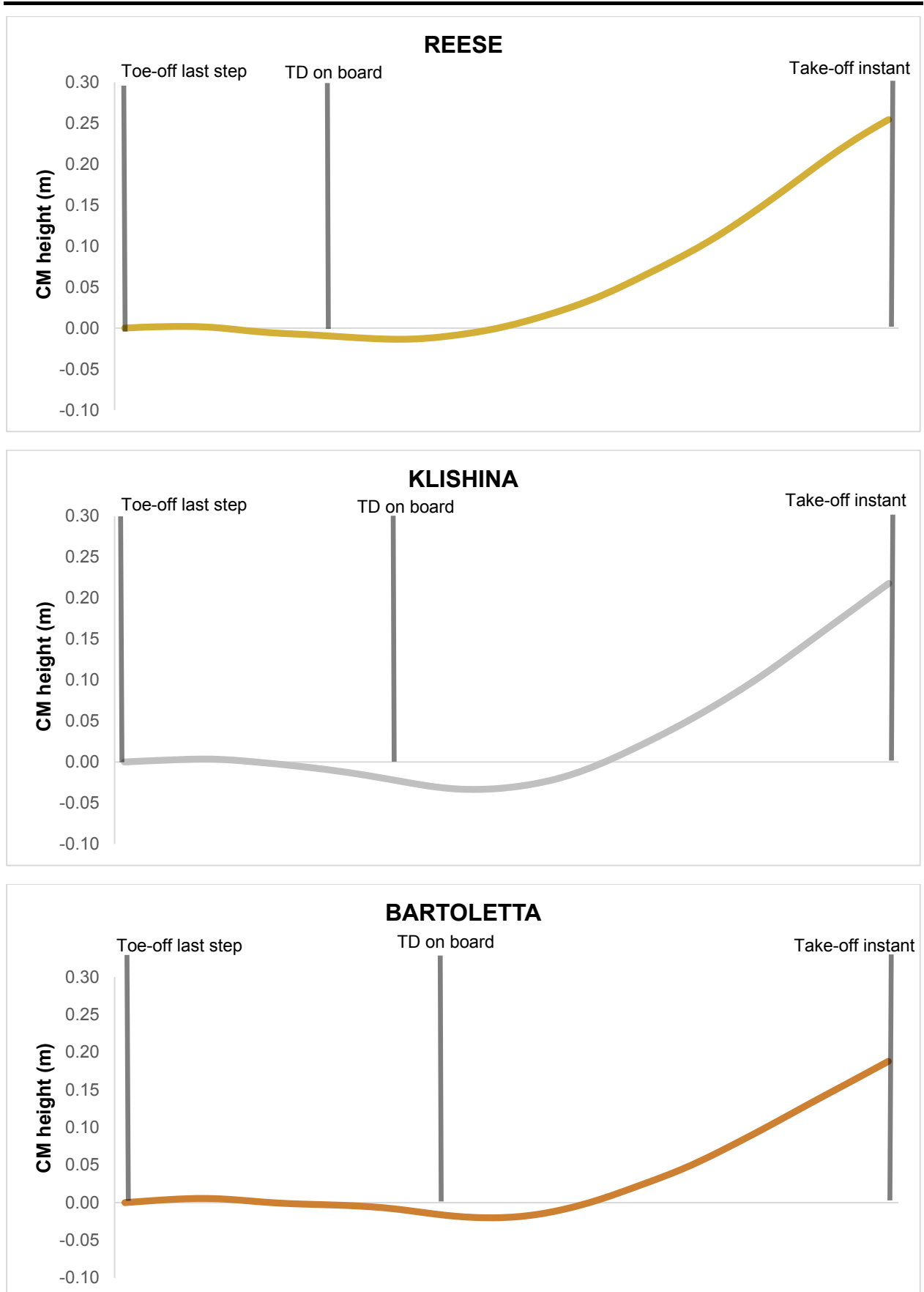


Figure 10. Change in the height of the CM from touchdown (TD) of the last step until the instant of take-off from the board for the medallists.

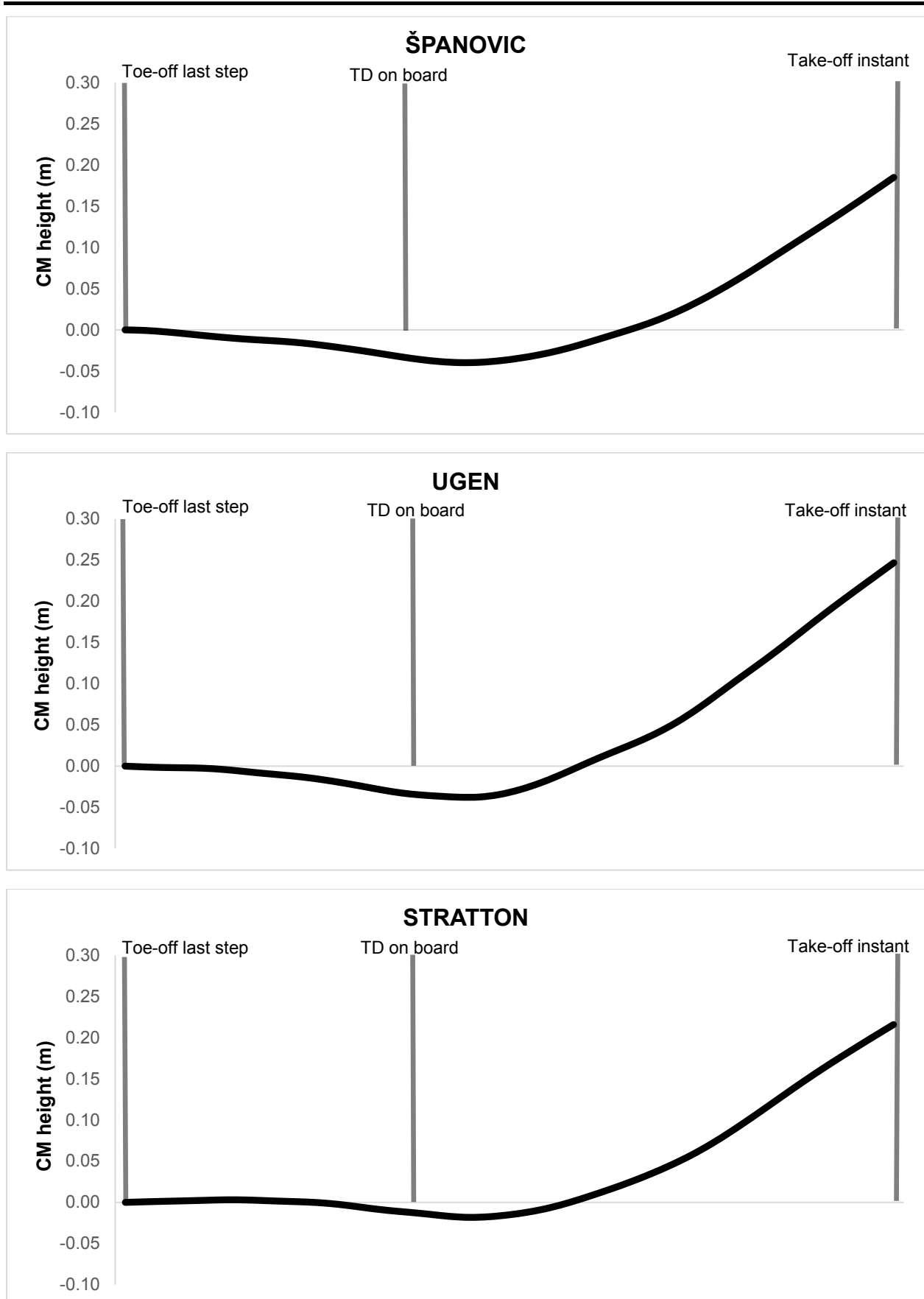


Figure 11. Change in the height of the CM from touchdown (TD) of the last step until the instant of take-off from the board for the fourth, fifth and sixth placed athletes.

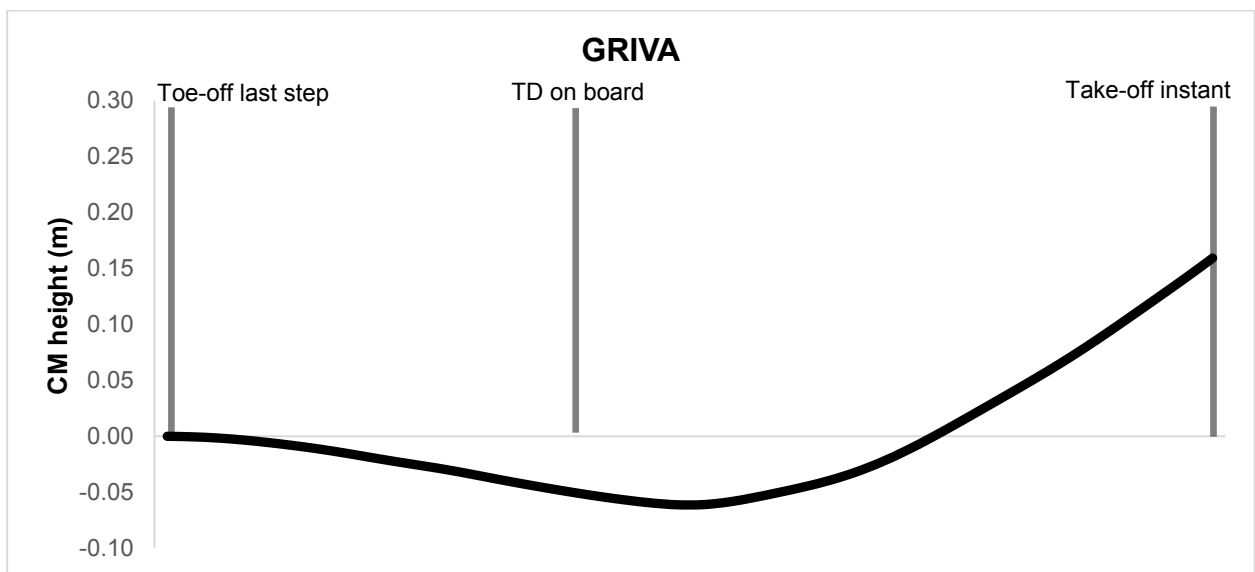
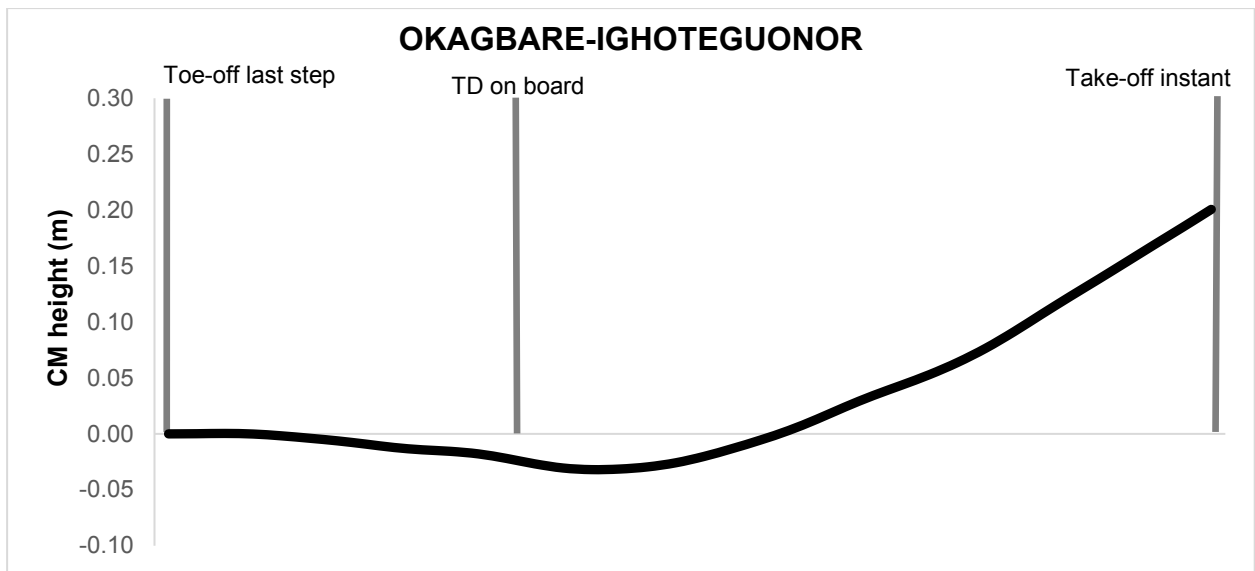
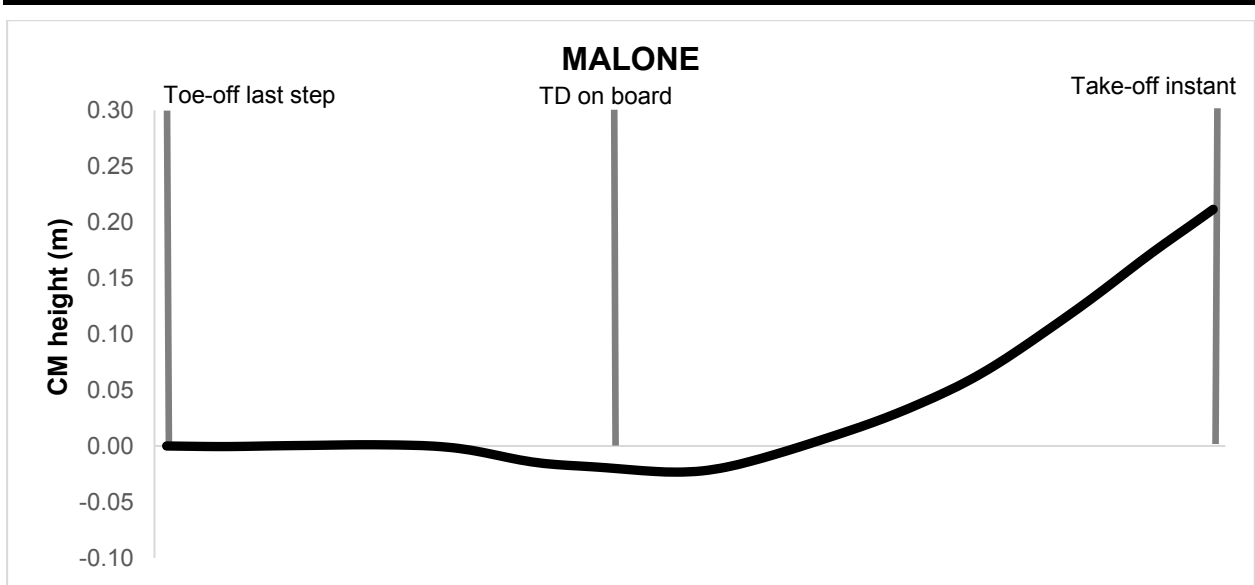


Figure 12. Change in the height of the CM from touchdown (TD) of the last step until the instant of take-off from the board seventh, eighth and ninth placed athletes.

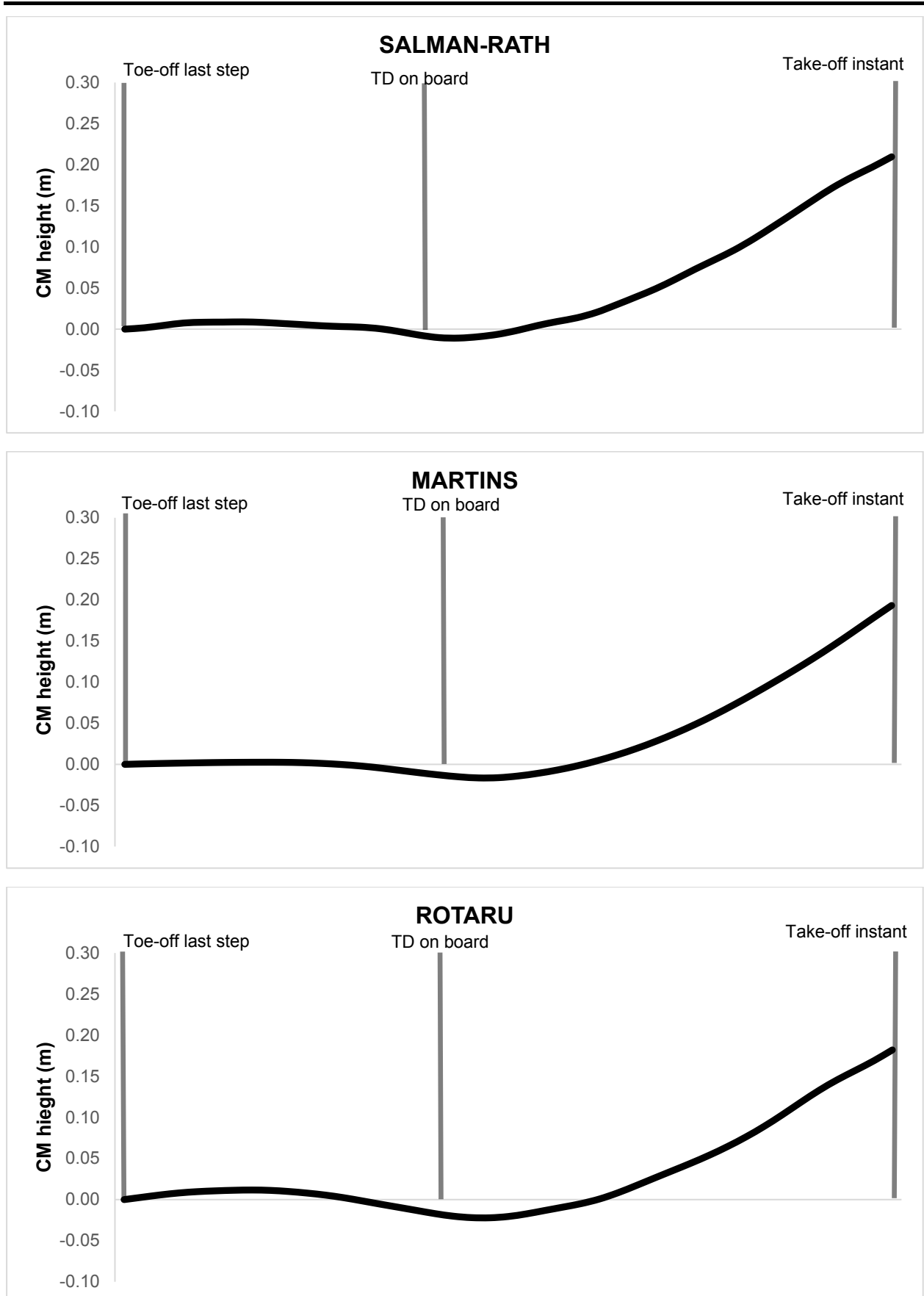


Figure 13. Change in the height of the CM from touchdown (TD) of the last step until the instant of take-off from the board tenth, eleventh and twelfth placed athletes.

CM trajectories (aerial perspective)

Figures 14-17 show the changes in the horizontal (mediolateral and anteroposterior) CM position (blue line) during the last step to the take-off board. Please note that the black filled in rectangle indicates the position of the take-off board and the dashed black lines refer to the events of touchdown of the last step (TD last step), toe-off of the last step (TO last step), touchdown on the board (TD on board) and take-off from the board (Take-off).

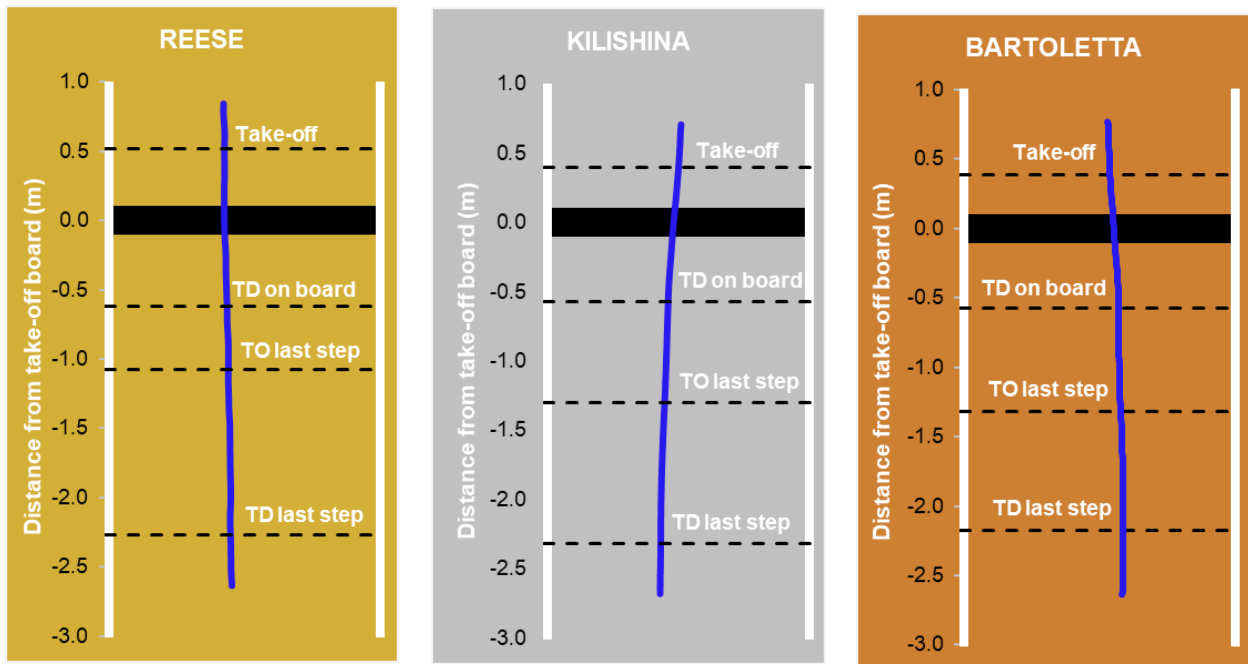


Figure 14. Horizontal CM trajectory (mediolateral and anteroposterior directions) for the gold (Reese), silver (Kishina) and bronze (Bartoletta) medallists during the last step before take-off.

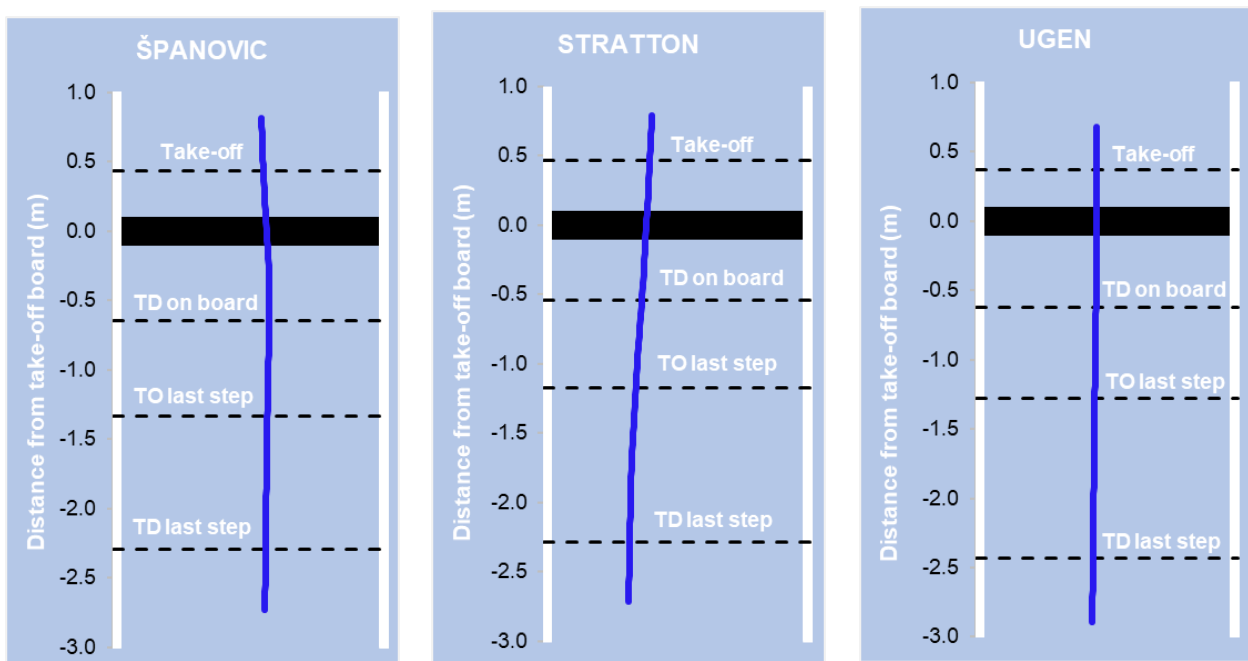


Figure 15. Horizontal CM trajectory (mediolateral and anteroposterior directions) for the fourth (Španovic), fifth (Ugen) and sixth (Stratton) placed athletes during the last step before take-off.

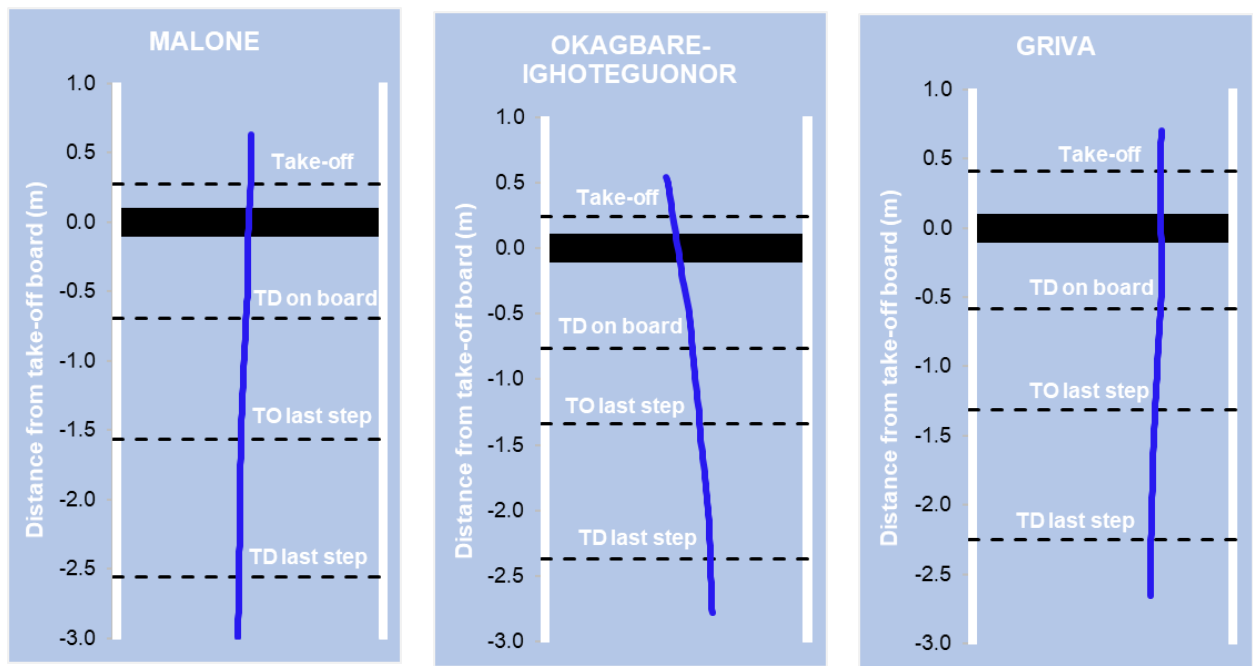


Figure 16. Horizontal CM trajectory (mediolateral and anteroposterior directions) for the seventh (Malone), eighth (Okagbare-Ighoteguonor) and ninth (Griva) placed athletes during the last step before take-off.

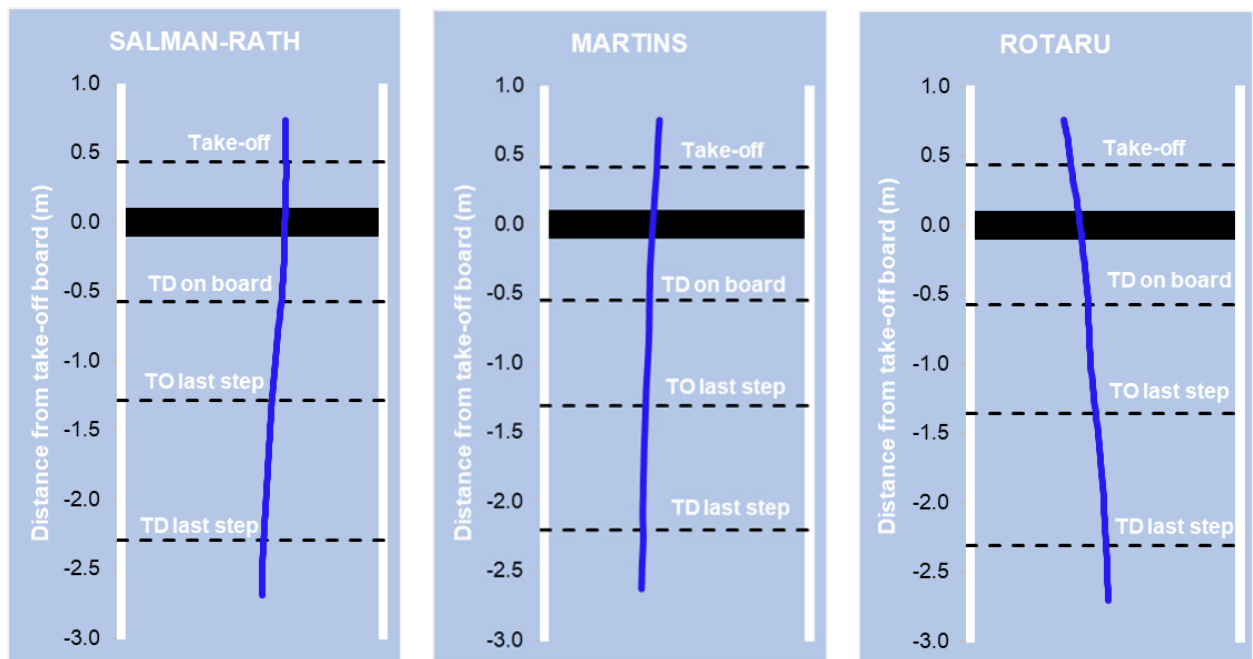


Figure 17. Horizontal CM trajectory (mediolateral and anteroposterior directions) for the tenth (Salman-Rath), eleventh (Martins) and twelfth (Rotaru) placed athletes during the last step before take-off.

COACH'S COMMENTARY

The aim of the long jump is simply to run as fast possible and to jump as high as possible from the take-off board. It demands strong legs for jumping from the board as well as being able to coordinate the movements of take-off, flight and landing. This report focussed on the crucial parts of the run-up (approach phase) and take-off. The velocities reached on the runway are similar to those of a sprinter (velocities in the women's final ranged from 8.88 – 9.52 m/s in the third last and penultimate step) but, unlike the sprinter, the long jumper has to control their speed in approaching the take-off board and place their foot as accurately as possible on the take-off board.

The development of high velocities, coupled with the short contact time of take-off (0.095 – 0.135 s) in the run up, means that the athletes' take-off angles will never reach the theoretical optimum angle for the longest possible range. Therefore the take-off angles are much less than that (women's final range: 18.4° – 25.7°).

On first glance at the distance characteristics of the best jumps (Table 3), it is apparent there was much better accuracy at the take-off board for the gold (Reese) and silver (Klishina) medallists compared with the bronze medallist (Bartoletta). The loss at take-off of only 1 centimetre for the gold and silver medallists compared with Bartoletta's loss of 7 centimetres could have been costly when looking at the effective distance in Table 3 and denied Bartoletta better than third position.

The transition to from the approach phase (run-up) to take-off is probably one of the most important elements of long jumping technique. To jump the longest distance, the athlete must have a large horizontal velocity at the end of the run-up and the foot placed as accurately as possible on the take-off board as discussed previously. Most of the finalists, apart from Malone, used the typical strategy of a longer penultimate step and a shorter last step to prepare for take-off. Generally, athletes increased their step length between the third last and second last steps (mean increase 6%) whereas for the last step, there was a mean reduction in step length of 9%. Reese had one of the largest reductions in step length at 19% for the last step. This approach of a longer penultimate and shorter last step can lower the height of the centre of mass (CM) in the penultimate step and therefore allow the athlete to have a higher take-off height in the last step.

Interestingly, Bartoletta, had the highest mean last step velocity (Figure 7) but lost more velocity on the take-board (1.48 m/s) in comparison with the other two medallists which led to a lower take-off velocity (7.72 m/s) in comparison with Reese (8.23 m/s) and Klishina (8.27 m/s).

It was interesting that Reese had one of the largest losses in her mean horizontal velocity (0.77 m/s) from the second-last to the last step. This was also accompanied by having the longest time on the take-off board (0.135 s) of all the finalists. It is apparent that she uses this long contact time on the board to allow herself get to a very high CM position at take-off (Figure 10) but she is also able to apply a force quickly highlighting her amazing strength on the take-off board to increase this take-off height and achieve one of the highest horizontal velocities at take-off (Table 7).

One interesting case from the non-medallists in terms of velocity is that of Okagbare-Ighotegunor. As a sprinter and semi-finalist in the 100 metre sprints, it is no surprise that she had high velocity in her approach. She did maintain this velocity during contact with the board and had the highest take-off velocity of 8.98 m/s and lost only 0.25 m/s on the take-off board. However, the accuracy with her placement of her take-off foot was poor and she lost the most of any other finalist on the take-off board. This illustrates the point that velocity is important but it is only important with good foot placement on the board to help maximise distance. It also appears from looking at the angle of the trunk that she was leaning their trunk back the most (trunk angle of 103.2°) compared with the Reese who was able to have a more upright trunk position (84.6°) meaning her CM position was not as far forward at take-off. This is also indicated by the distance her CM position was in front of the take-off board at take-off (Figure 16) compared with that of Reese in Figure 14.

CONTRIBUTORS

Dr Catherine Tucker is a Senior Lecturer in Sport and Exercise Biomechanics at Leeds Beckett University. Catherine graduated with First Class Honours in Sport and Exercise Sciences from the University of Limerick and subsequently completed a PhD in sports biomechanics, also at the University of Limerick. Catherine's main research interests centre on the biomechanics of striking movements, particularly golf. She is also interested in movement variability with respect to gait and how it relates to movement outcome / injury reduction.



Dr Gareth Nicholson is a Senior Lecturer in Sport and Exercise Biomechanics at Leeds Beckett University and is Course Leader for the MSc Sport & Exercise Biomechanics pathway. Gareth has First Class Honours in BSc Sport and Exercise Science as well as an MSc in Sport & Exercise Science and a PhD from Leeds Beckett University. Gareth's research interests are in the measurement and development of strength and power. Gareth currently supervises a range of health and performance-related research projects.



Mark Cooke is a Lecturer in Sport and Exercise Biomechanics at Leeds Beckett University. Mark has First Class Honours in BSc Sport and Exercise Science and is currently doing a PhD at Leeds Beckett University evaluating the use of intermittent normobaric hypoxia as a means of pre-acclimatisation. Mark's research interests also include the design and development of equipment to enable participation in outdoor and adventures activities for individuals with movement difficulties.



Dr Athanassios Bissas is the Head of the Biomechanics Department in the Carnegie School of Sport at Leeds Beckett University. His research includes a range of topics but his main expertise is in the areas of biomechanics of sprint running, neuromuscular adaptations to resistance training, and measurement and evaluation of strength and power. Dr Bissas has supervised a vast range of research projects whilst having a number of successful completions at PhD level. Together with his team he has produced over 100 research outputs and he is actively involved in research projects with institutions across Europe.



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.

