BIOMECHANICAL REPORT

FOR THE

IAAF™

WORLD INDOOR CHAMPIONSHIPS 2018

Triple Jump Men

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IAAF™

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INTRODUCTION

The men's triple jump took place on the evening of Saturday 3rd March. It was a contest which ebbed and flowed with the lead being exchanged multiple times. Following the first round of the final it was Portugal's Nelson Évora who led with a jump of 17.14 metres. However, it was Brazil's Almir Dos Santos who jumped into the lead with an effort of 17.22 metres. Évora regained the lead in round three with a jump of 17.40 metres. It was after this point that the USA's Will Claye, a former winner of this event, started to exert his influence. His fourth round jump of 17.43 metres was not to be beaten. Dos Santos secured the silver medal with a personal best jump of 17.41 metres in the fifth round. Évora and Alexis Copello could not improve in the final rounds and therefore had to settle for third and fourth, respectively.

IAAF World Indoor Championships
Birmingham (GBR) 1–4 March 2018

RESULTS

Triple Jump Men – Final

RECORDS		RESULT	NAME	COUNTRY	AGE	VENUE	DATE
World Indoor Record	WIR	17.92	Teddy TAMGHO	FRA	22	Paris-Bercy (Palais Omnisports)	6 Mar 2011
World Indoor Record	WIR	17.92	Teddy TAMGHO	FRA	22	Paris-Bercy (Palais Omnisports)	6 Mar 2011
Championship Record	CR	17.90	Teddy TAMGHO	FRA	21	Doha (Aspire Dome)	14 Mar 2010
World Leading	WL	17.43	WILL CLAYE	USA	27	Birmingham	3 Mar 2018
Area Indoor Record	AIR	National Indoor Record	NIR	Personal Best	PB	Season Best	SB

3 March 2018   19:08 START TIME
20:35 END TIME

PLACE	NAME	COUNTRY	DATE of BIRTH	ORDER	RESULT		1	2	3	ORDER	4	5	6
1	Will CLAYE	USA	13 Jun 91	13	17.43	WL	16.89	16.86	16.76	4	17.43	17.35	17.31
2	Almir DOS SANTOS	BRA	4 Sep 93	14	17.41	PB	16.70	17.22	16.97	7	X	17.41	X
3	Nelson ÉVORA	POR	20 Apr 84	15	17.40	NIR	17.14	X	17.40	8	17.25	X	16.71
4	Alexis COPELLO	AZE	12 Aug 86	5	17.17	SB	X	17.17	17.05	6	16.82	X	X
5	Chris CARTER	USA	11 Mar 89	11	17.15		16.76	16.70	16.75	1	17.04	17.15	
6	Hugues Fabrice ZANGO	BUR	25 Jun 93	12	17.11		16.16	16.57	17.11	5	16.71	16.87	
7	Yaming ZHU	CHN	4 May 94	4	16.87	PB	16.66	16.86	16.81	3	16.87	16.38	
8	Bin DONG	CHN	22 Nov 88	10	16.84	SB	X	16.84	X	2	16.71	16.10	
9	Cristian NÁPOLES	CUB	27 Nov 98	6	16.70		X	X	16.70				
10	Elvijs MISANS	LAT	8 Jul 89	1	16.55	SB	X	X	16.55				
11	Max HEß	GER	13 Jul 96	7	16.47		X	X	16.47				
12	Momchil KARAILIEV	BUL	21 May 82	2	16.14		16.03	16.14	X				
13	Clive PULLEN	JAM	18 Oct 94	3	16.13		X	16.13	X				
14	Fabrizio DONATO	ITA	14 Aug 76	8	15.96		15.96	X	X				
15	Andy DÍAZ	CUB	25 Dec 96	9	15.37	SB	X	15.37	r				

Timing and Measurement by SEIKO   AT-TJ-M-f--A--.RS1..v1   Issued at 20:37 on Saturday, 03 March 2018

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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 step before the take-off board and their hop, step and jump.
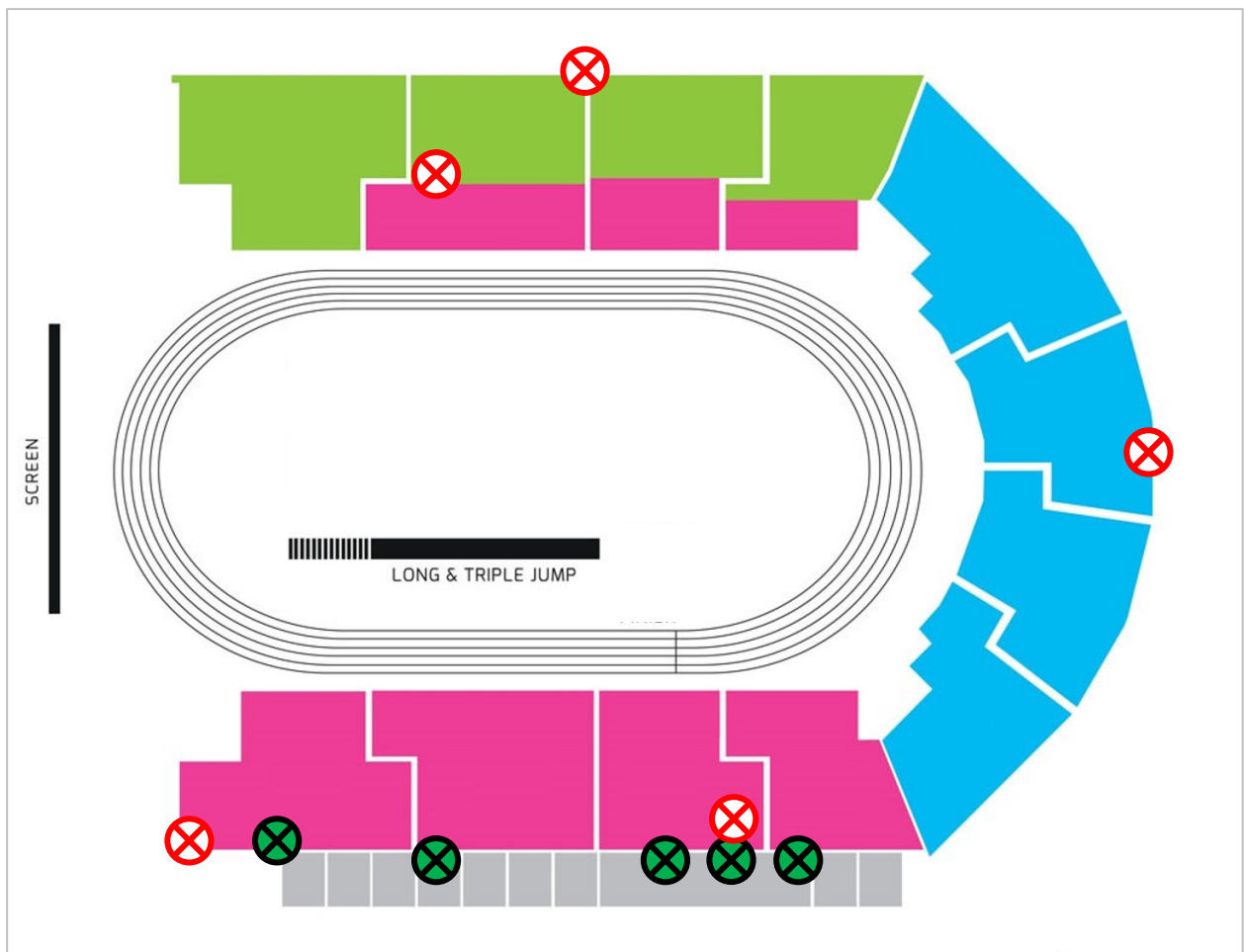
Figure 1. Camera layout for the men's triple jump indicated by green-filled circles.

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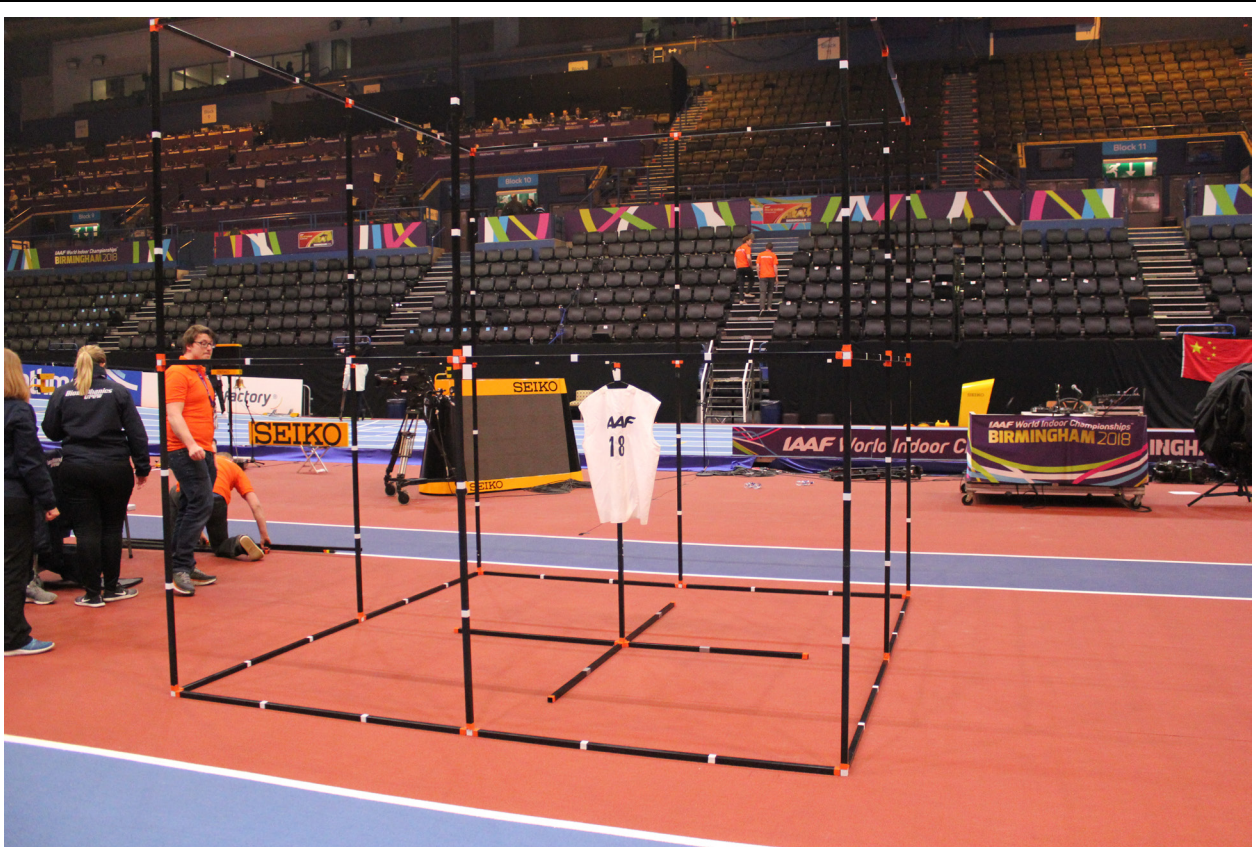
Figure 2. The calibration frame was constructed and filmed before and after the competition.

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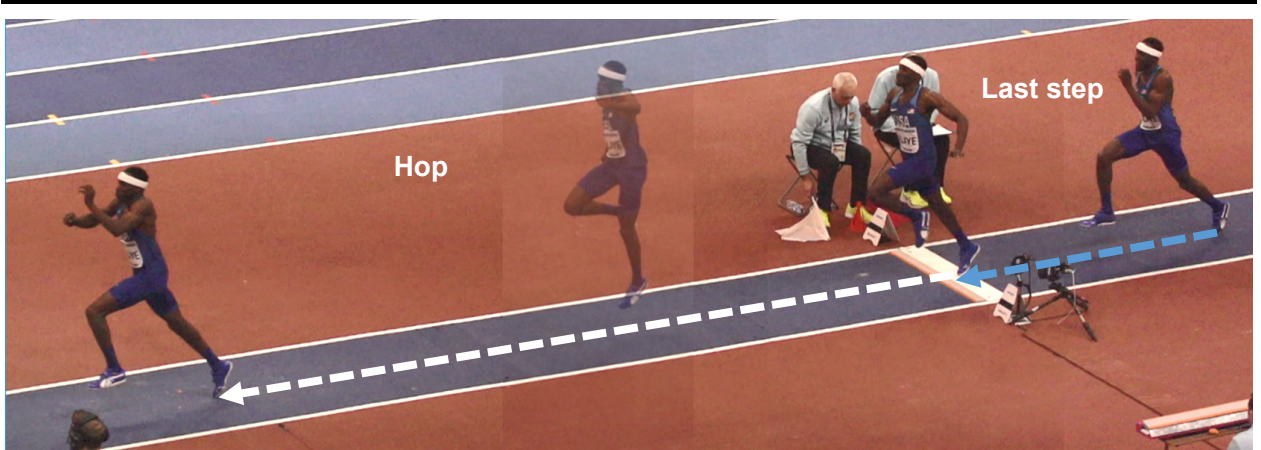
Figure 3. The last step before the take-off board and the hop phase in the triple jump.

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 (last step before take-off board)	The length of the last approach step 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 six 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)
CLAYE	1	17.43	17.28	0.15	17.70	−0.27
DOS SANTOS	2	17.41	17.37	0.04	17.37	0.04
ÉVORA	3	17.40	17.30	0.10	17.33	0.07
COPELLO	4	17.17	16.98	0.19	17.24	−0.07
CARTER	5	17.15	17.20	−0.05	17.20	−0.05
ZANGO	6	17.11	17.23	−0.12	17.23	−0.12
ZHU	7	16.87	16.79	0.08	16.72	0.15
DONG	8	16.84	-	-	17.41	−0.57
NÁPOLES	9	16.70	17.02	−0.32	17.02	−0.32
MISANS	10	16.55	16.49	0.06	17.02	−0.47
HESS	11	16.47	16.84	−0.37	17.52	−1.05
KARAILIEV	12	16.14	16.69	−0.55	17.16	−1.02
PULLEN	13	16.13	16.71	−0.58	17.19	−1.06
DONATO	14	15.96	16.94	−0.98	17.73	−1.77
DÍAZ	15	15.37	-	-	17.40	−2.03

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 Dos Santos with a loss of 0.004 metres, and the largest loss was by Donato with a loss of 0.292 metres. The mean loss was 0.08 metres. Table 4 on the next page shows the step lengths of each finalist for the last step 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)
CLAYE	4	17.43	17.514	0.084
DOS SANTOS	5	17.41	17.414	0.004
ÉVORA	3	17.40	17.413	0.013
COPELLO	2	17.17	17.215	0.045
CARTER	5	17.15	-	-
ZANGO	3	17.11	17.262	0.152
ZHU	4	16.87	16.927	0.057
DONG	2	16.84	17.017	0.177
NÁPOLES	3	16.70	16.771	0.071
MISANS	3	16.55	16.572	0.022
HESS	3	16.47	16.488	0.018
KARAILIEV	2	16.14	16.145	0.005
PULLEN	2	16.13	16.192	0.062
DONATO	1	15.96	16.252	0.292
DÍAZ	2	15.37	15.493	0.123

Note: The take-off distances were provided by deltatre and there was no value recorded for Carter.

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

Athlete	Last (m)	Hop (m)	Step (m)	Jump (m)
CLAYE	2.29	6.014	5.56	5.94
DOS SANTOS	2.26	6.444	5.04	5.93
ÉVORA	2.24	6.303	5.23	5.88
COPELLO	2.28	6.185	5.40	5.63
CARTER	2.31	-	-	-
ZANGO	2.29	5.942	5.32	6.00
ZHU	2.25	6.507	4.61	5.81
DONG	2.31	6.147	5.15	5.72
NÁPOLES	2.26	5.911	5.20	5.66
MISANS	2.30	6.342	4.92	5.31
HESS	2.38	5.728	5.34	5.42
KARAILIEV	2.38	5.825	4.91	5.41
PULLEN	2.00	-	-	-
DONATO	2.41	6.212	5.60	4.44
DÍAZ	2.10	5.663	4.48	5.35

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

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
CLAYE	34.3	31.7	33.9	Balanced
DOS SANTOS	37.0	28.9	34.1	Hop-dominated
ÉVORA	36.2	30.0	33.8	Hop-dominated
COPELLO	35.9	31.4	32.7	Hop-dominated
CARTER	-	-	-	-
ZANGO	34.4	30.8	34.8	Balanced
ZHU	38.4	27.2	34.3	Hop-dominated
DONG	36.1	30.3	33.6	Balanced
NÁPOLES	35.2	31.0	33.7	Balanced
MISANS	38.3	29.7	32.0	Hop-dominated
HESS	34.7	32.4	32.9	Balanced
KARAILIEV	36.1	30.4	33.5	Hop-dominated
PULLEN	-	-	-	-
DONATO	38.2	34.5	27.3	Hop-dominated
DÍAZ	36.6	28.9	34.5	Hop-dominated
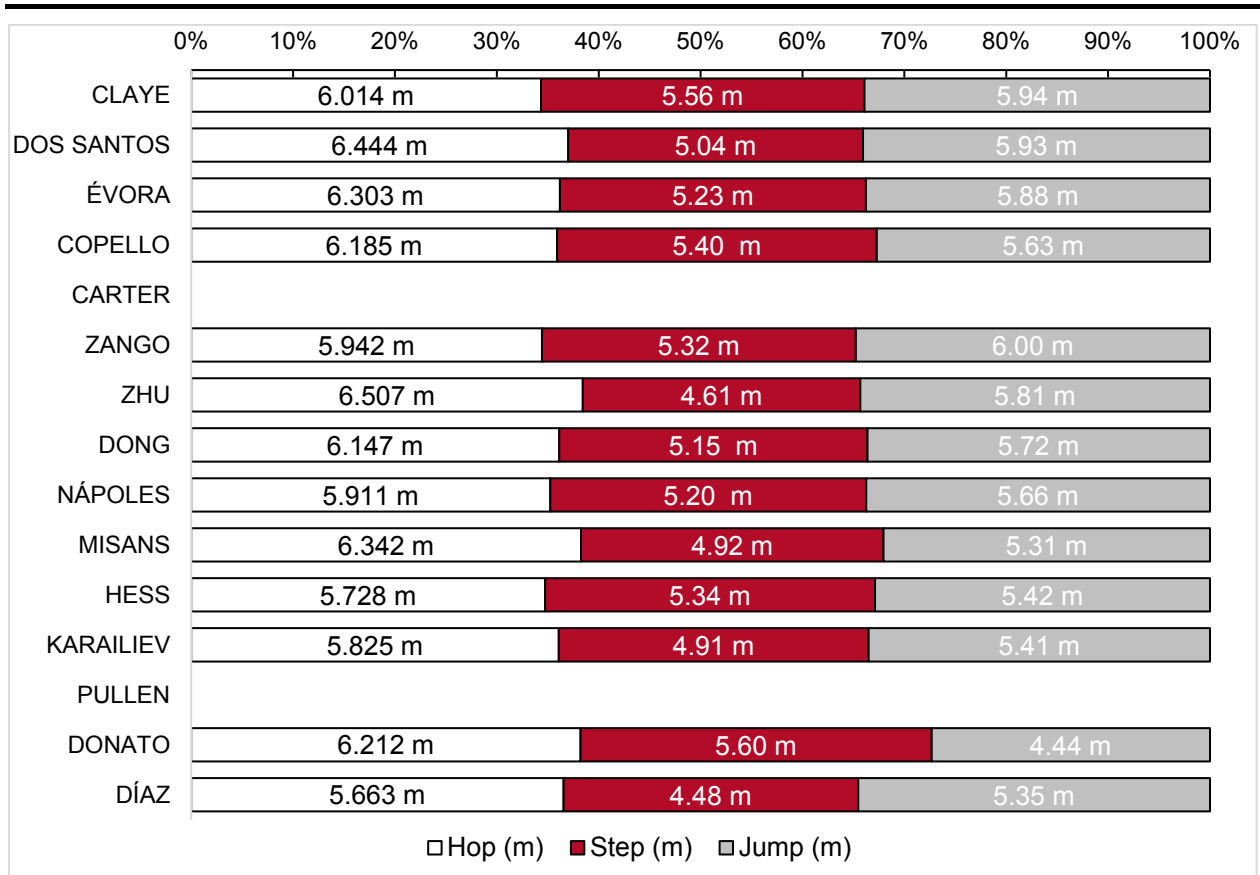
Figure 4. Relative percentage of hop, step and jump lengths (relative to effective distance) along with step length in metres.

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.
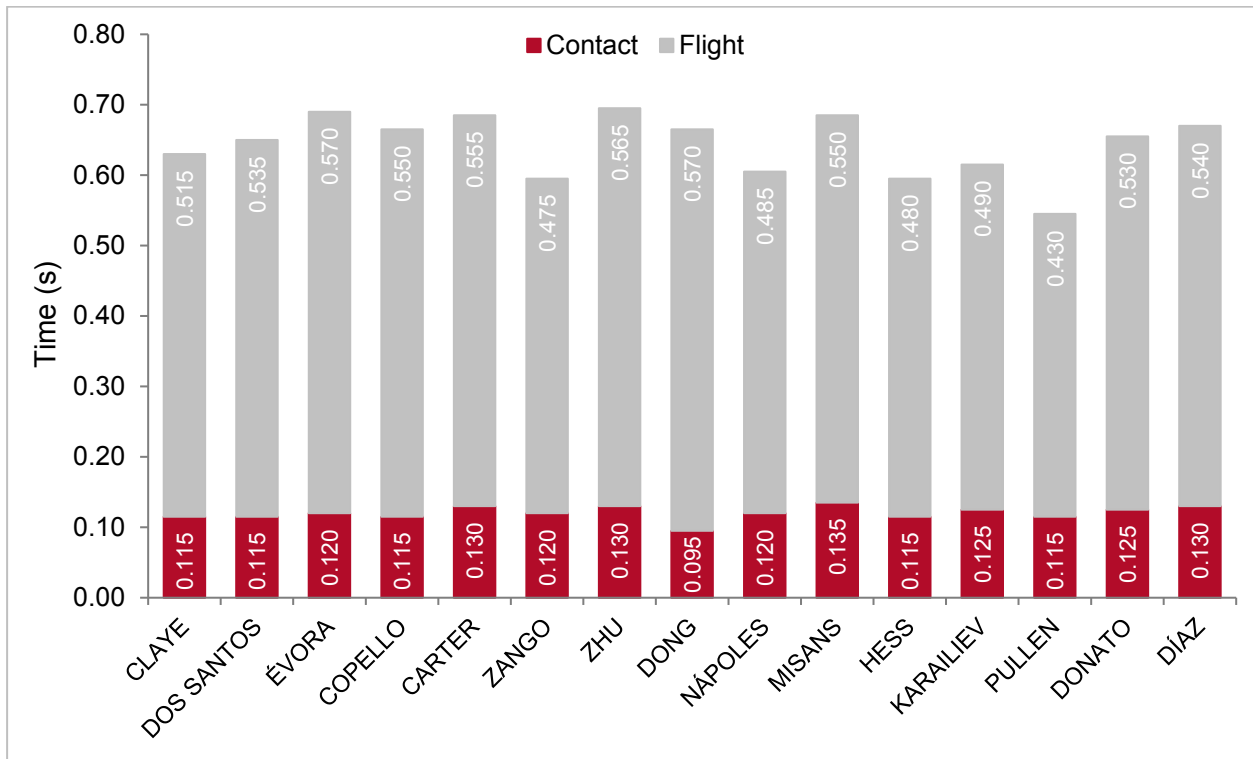
Figure 5. Contact and flight times for the hop phase of the triple jump for all finalists.
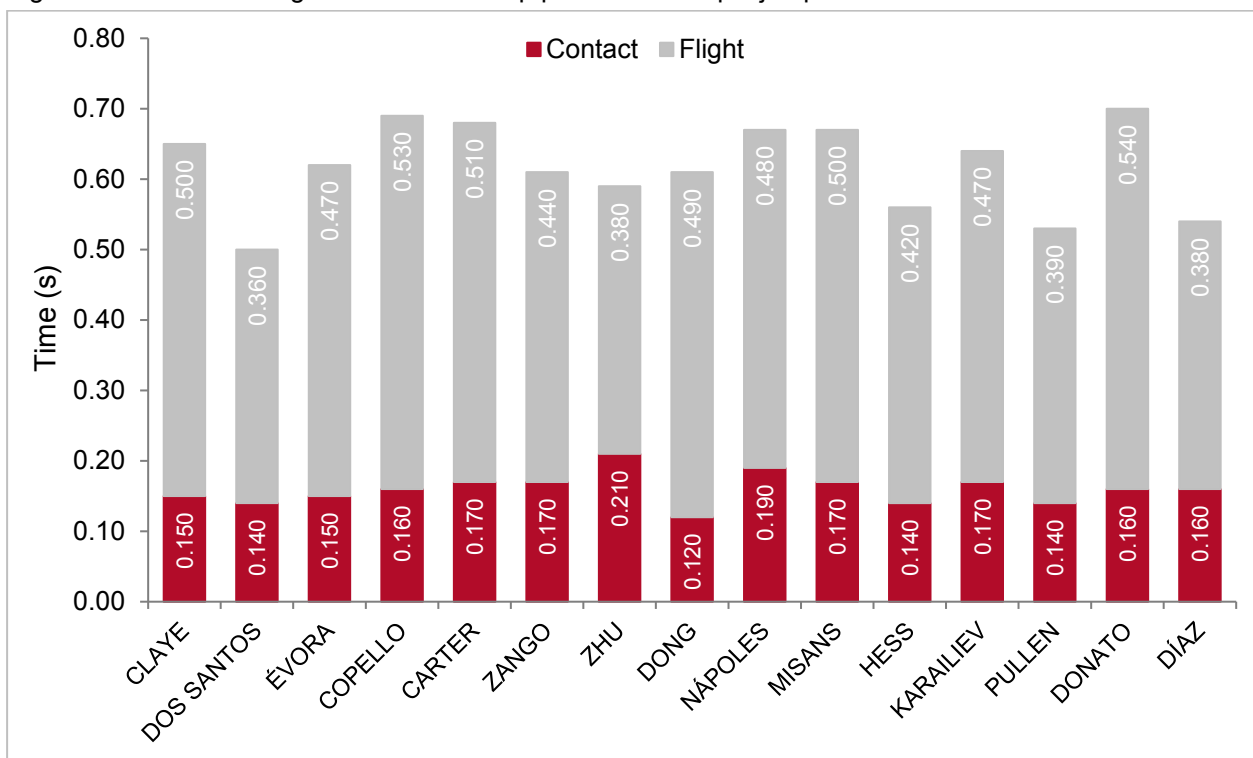
Figure 6. Contact and flight times for the step phase of the triple jump for all finalists.
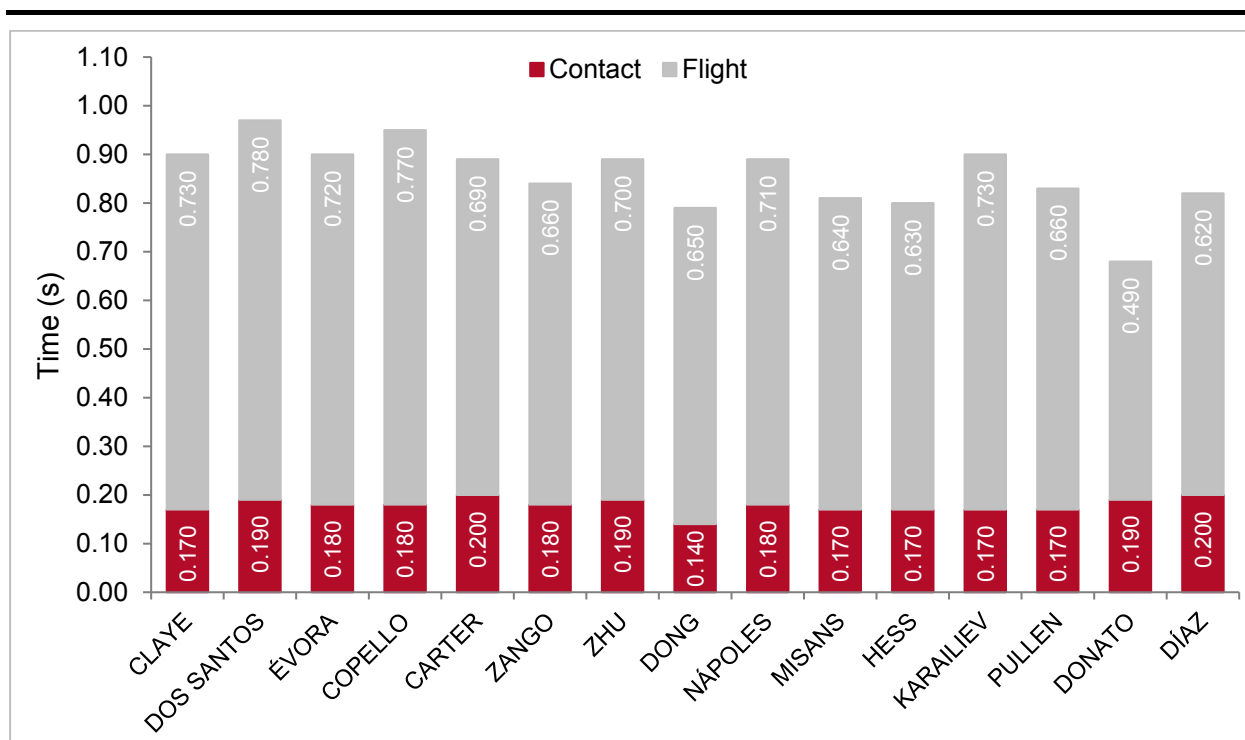
Figure 7. Contact and flight times for the jump phase of the triple jump for all finalists.

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

Athlete	Last (s)	Hop (s)	Step (s)	Jump (s)
CLAYE	0.200	0.630	0.650	0.900
DOS SANTOS	0.195	0.650	0.500	0.970
ÉVORA	0.195	0.690	0.620	0.900
COPELLO	0.205	0.665	0.690	0.950
CARTER	0.180	0.685	0.680	0.890
ZANGO	0.210	0.595	0.610	0.840
ZHU	0.195	0.695	0.590	0.890
DONG	0.215	0.665	0.610	0.790
NÁPOLES	0.200	0.605	0.670	0.890
MISANS	0.205	0.685	0.670	0.810
HESS	0.220	0.595	0.560	0.800
KARAILIEV	0.225	0.615	0.640	0.900
PULLEN	0.185	0.545	0.530	0.830
DONATO	0.220	0.655	0.700	0.680
DÍAZ	0.200	0.670	0.540	0.820

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 9.34 m/s, 8.12 m/s and 6.72 m/s, respectively. The mean vertical velocity at take-off for the hop, step and jump was 2.64 m/s, 2.46 m/s and 2.92 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)
CLAYE	9.66	2.55	8.10	2.76	6.46	3.42
DOS SANTOS	9.73	2.76	8.68	2.15	6.74	3.39
ÉVORA	9.24	2.89	8.14	2.65	6.60	3.01
COPELLO	9.11	2.90	7.59	2.86	5.90	3.73
CARTER	9.20	2.91	7.99	2.61	6.45	2.95
ZANGO	9.84	2.41	8.77	2.43	7.11	2.97
ZHU	9.33	2.81	7.86	2.07	6.53	2.96
DONG	9.23	2.87	8.15	2.84	7.18	2.79
NÁPOLES	9.41	2.38	7.92	2.65	6.23	3.38
MISANS	8.95	2.74	8.18	2.08	6.99	2.57
HESS	9.57	2.52	8.39	2.55	7.02	2.48
KARAILIEV	9.10	2.45	7.61	2.52	6.39	3.22
PULLEN	9.68	2.12	8.99	1.89	7.73	2.65
DONATO	9.32	2.58	7.82	2.80	6.79	1.46
DÍAZ	8.74	2.75	7.67	2.04	6.69	2.82

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 4 cm, 18 cm and 17 cm, respectively.

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

Athlete	Hop (cm)	Step (cm)	Jump (cm)
CLAYE	6	16	17
DOS SANTOS	2	16	14
ÉVORA	4	19	16
COPELLO	4	23	19
CARTER	6	16	23
ZANGO	5	10	14
ZHU	4	18	15
DONG	3	16	11
NÁPOLES	4	19	17
MISANS	4	23	14
HESS	5	16	17
KARAILIEV	4	25	20
PULLEN	4	14	15
DONATO	4	20	19
DÍAZ	4	18	18

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 −0.59 m/s, between the hop and step was −1.22 m/s and between the step and jump was −1.40 m/s.
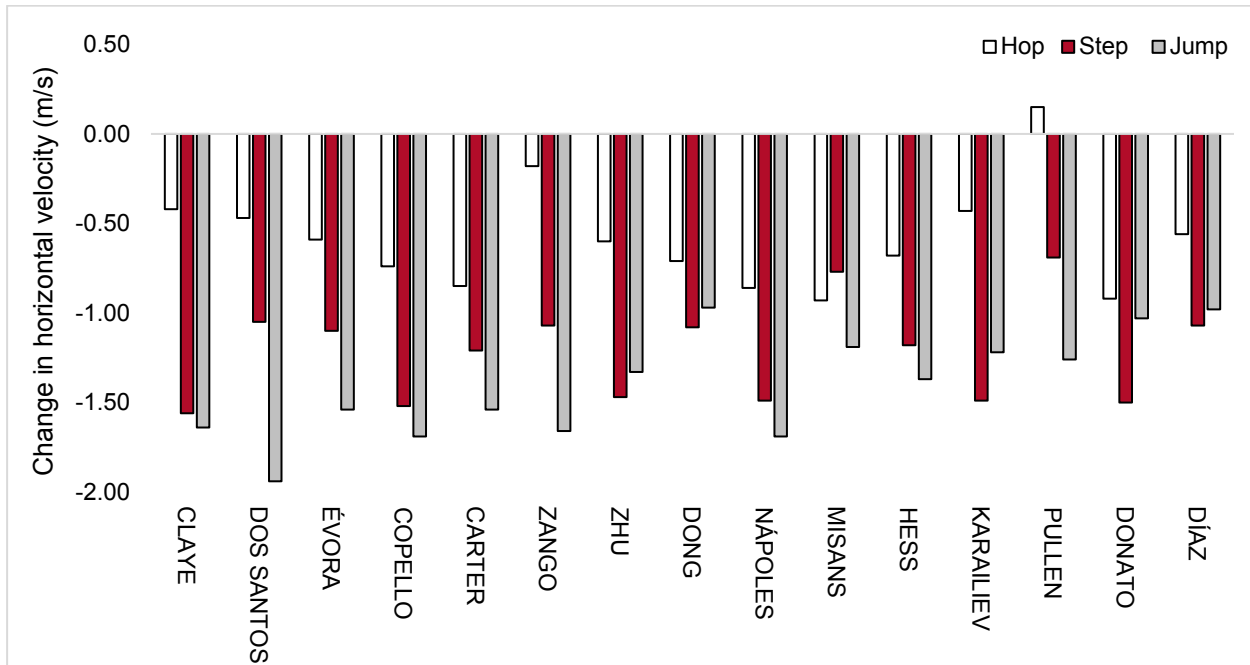
Figure 8. The change in horizontal velocity for the hop, step and jump for each finalist.

Figures 9 and 10 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 15.8°, for the step was 16.9° and for the jump was 23.5°.

	Hop	Step	Jump
CLAYE	14.8	18.8	27.9
DOS SANTOS	15.8	13.9	26.7
ÉVORA	17.4	18.0	24.5
COPELLO	17.6	20.6	32.3
CARTER	17.5	18.1	24.6
ZANGO	13.8	15.5	22.7
ZHU	16.7	14.8	24.4
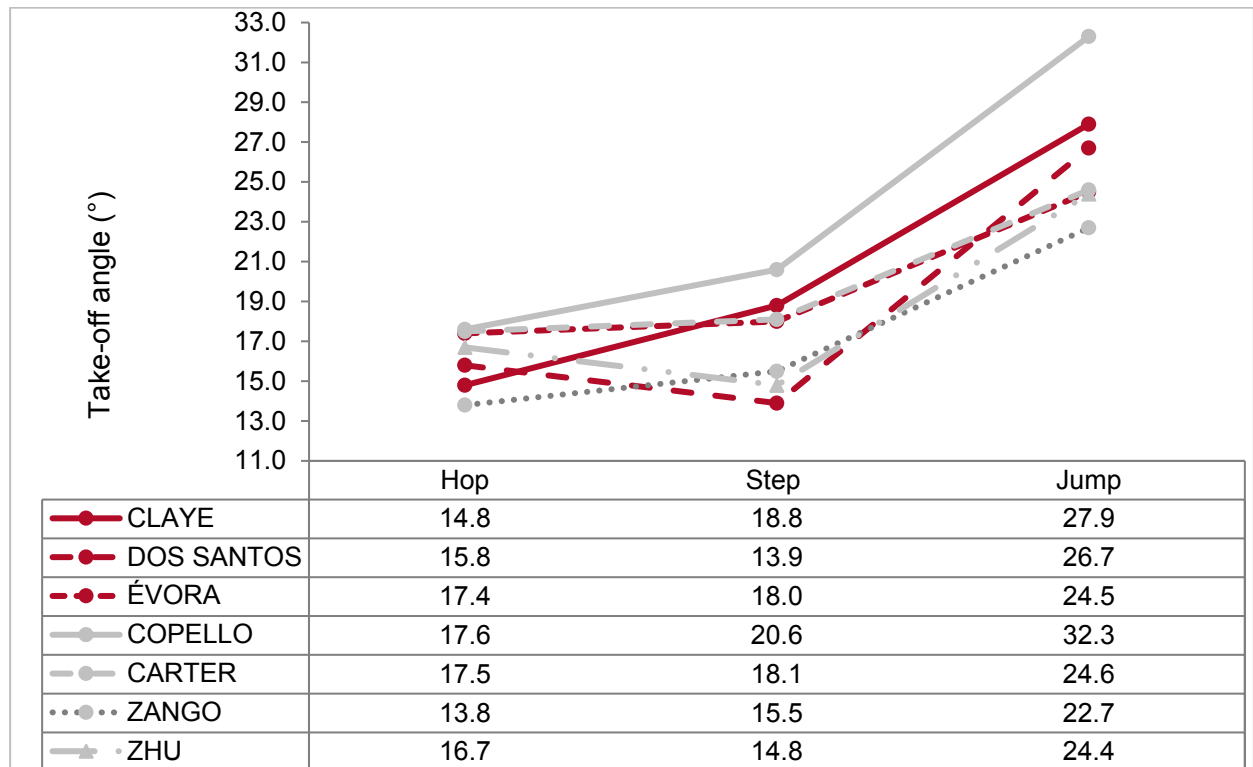
Figure 9. Take-off angle in the hop, step and jump for the top 7 finalists.

	Hop	Step	Jump
DONG	17.3	19.2	21.2
NÁPOLES	14.2	18.5	28.5
MISANS	17.0	14.3	20.2
HESS	14.8	16.9	19.4
KARAILIEV	15.1	18.3	26.7
PULLEN	12.4	11.9	18.9
DONATO	15.5	19.7	12.2
DÍAZ	17.4	14.9	22.8
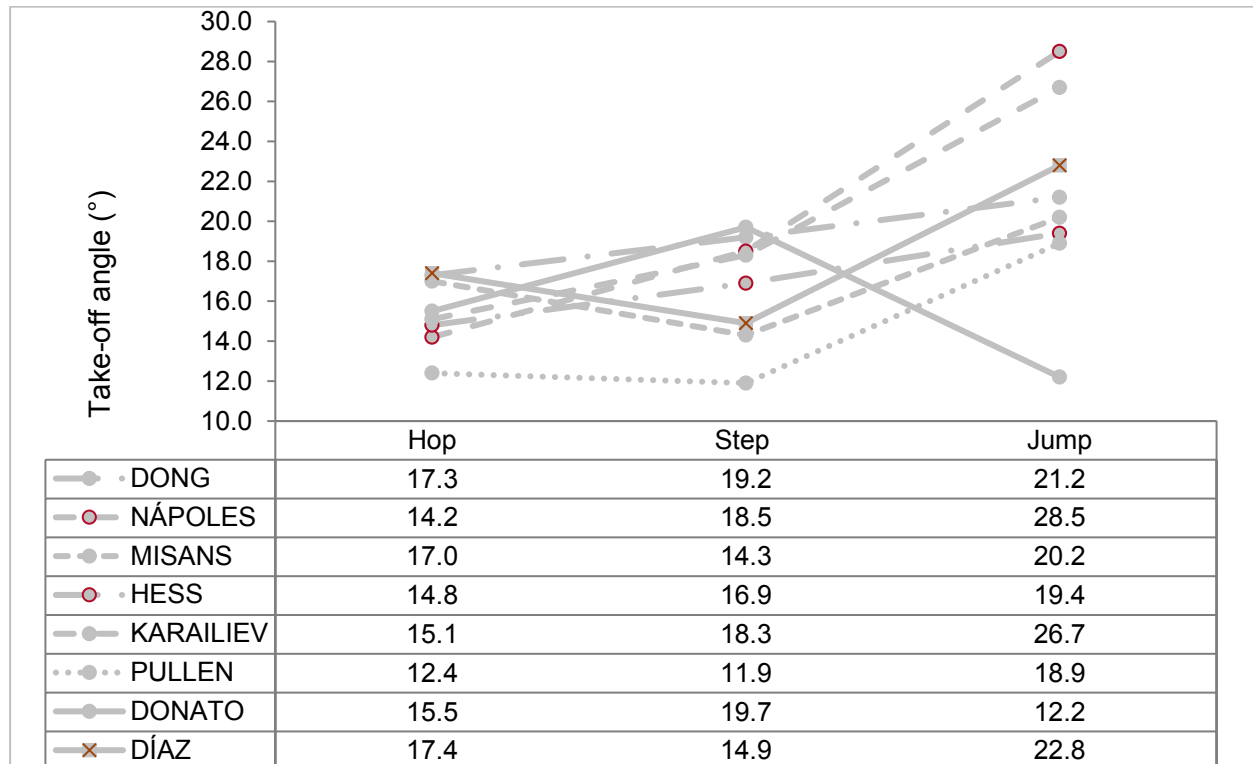
Figure 10. Take-off angle in the hop, step and jump for the bottom 8 finalists.

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 19.1°, 36.0° and 37.9°, 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 (°)
CLAYE	149.7	145.1	4.6	162.2	130.0	32.2	169.7	123.2	46.5
DOS SANTOS	163.5	148.4	15.1	161.3	133.0	28.3	168.6	122.7	45.9
ÉVORA	154.5	143.4	11.1	167.2	130.4	36.8	159.3	119.3	40.0
COPELLO	152.7	142.9	9.8	162.6	123.4	39.2	171.5	118.3	53.2
CARTER	152.9	132.8	20.1	157.9	116.8	41.1	176.3	121.1	55.2
ZANGO	149.4	126.4	23.0	166.7	124.7	42.0	175.1	134.0	41.1
ZHU	159.0	132.6	26.4	160.5	117.8	42.7	172.7	125.5	47.2
DONG	164.4	139.4	25.0	165.6	146.4	19.2	166.7	142.3	24.4
NÁPOLES	153.6	132.6	21.0	165.3	120.7	44.6	156.2	136.6	19.6
MISANS	157.3	136.3	21.0	166.7	122.9	43.8	150.8	132.7	18.1
HESS	159.3	133.7	25.6	162.9	128.4	34.5	146.7	111.4	35.3
KARAILIEV	157.2	134.2	23.0	162.8	124.0	38.8	170.7	132.5	38.2
PULLEN	152.6	127.8	24.8	162.4	123.7	38.7	164.9	123.9	41.0
DONATO	160.8	138.7	22.1	166.1	135.7	30.4	140.9	118.0	22.9
DÍAZ	154.5	140.4	14.1	165.5	137.4	28.1	159.8	120.2	39.6

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 −2.8°, −13.6° and −6.9°, 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 (°)	TO (°)	TD (°)	TO (°)	TD (°)	TO (°)
CLAYE	5.6	3.9	−2.2	14.7	1.8	3.7
DOS SANTOS	−4.1	8.0	−5.9	2.2	−11.3	4.1
ÉVORA	−3.9	6.3	−0.7	15.6	1.6	9.0
COPELLO	−2.1	1.9	0.7	9.7	2.1	15.3
CARTER	5.9	0.5	−2.7	15.2	9.7	23.3
ZANGO	4.7	4.6	−7.4	11.9	7.5	14.1
ZHU	0.9	2.6	−1.6	4.9	−2.5	6.4
DONG	−2.0	−2.9	−1.3	8.8	3.8	5.6
NÁPOLES	−0.2	4.1	−5.1	15.9	−5.5	13.7
MISANS	−1.8	2.8	−0.5	14.8	8.0	14.8
HESS	−3.7	−2.6	−1.4	7.4	−1.5	0.7
KARAILIEV	0.2	5.7	−5.2	10.5	−0.5	5.9
PULLEN	10.0	3.3	−6.9	3.1	−1.9	10.0
DONATO	0.6	6.0	−2.2	15.7	20.1	5.0
DÍAZ	0.0	8.6	−0.1	10.6	2.1	5.0

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 55.6°, 59.7° and 57.7°, 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 (°)
CLAYE	−30.5	25.6	−33.7	28.6	−31.9	25.4
DOS SANTOS	−26.3	26.2	−24.2	32.6	−36.2	22.5
ÉVORA	−32.3	25.1	−28.2	30.3	−30.4	27.2
COPELLO	−30.7	22.8	−30.9	28.2	−30.5	24.9
CARTER	−34.4	25.8	−34.5	32.7	−33.4	29.3
ZANGO	−30.2	29.6	−33.8	32.2	−33.7	22.8
ZHU	−30.5	24.4	−28.5	33.3	−31.4	23.4
DONG	−25.5	20.6	−23.3	21.0	−27.1	25.7
NÁPOLES	−31.8	27.0	−36.7	33.7	−28.5	28.1
MISANS	−32.1	26.5	−27.9	34.2	−32.7	29.3
HESS	−29.3	25.5	−25.3	30.1	−27.8	26.3
KARAILIEV	−29.3	26.9	−28.6	31.1	−31.8	25.7
PULLEN	−27.5	27.5	−30.2	31.7	−30.0	29.5
DONATO	−30.0	25.4	−31.6	23.2	−30.1	26.3
DÍAZ	−31.7	23.3	−25.6	29.4	−36.1	27.4

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 −14.2°, −24.2° and −17.6°, respectively. The mean thigh angular velocity of the swing leg for the hop, step and jump was 578 °/s, 365 °/s and 352 °/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 (°)	Angular velocity (°)	TO Angle (°)	Angular velocity (°)	TO Angle (°)	Angular velocity (°)
CLAYE	−23.1	506	−29.4	347	−18.7	385
DOS SANTOS	−16.4	572	−24.2	352	−15.9	349
ÉVORA	−18.2	548	−28.2	400	−7.8	400
COPELLO	−12.2	595	−26.0	389	−19.7	402
CARTER	−11.7	641	−13.9	261	−12.4	239
ZANGO	−22.3	541	−26.4	229	−37.2	253
ZHU	1.3	657	−11.1	370	−11.6	384
DONG	−9.0	666	−36.7	413	−24.6	412
NÁPOLES	−19.8	462	−17.9	429	−17.6	336
MISANS	−1.3	609	−25.5	390	−30.9	281
HESS	−17.6	585	−22.2	426	7.2	456
KARAILIEV	−15.3	538	−18.8	390	−22.6	332
PULLEN	−23.8	610	−28.4	408	−12.8	398
DONATO	−3.4	603	−28.5	366	−23.1	310
DÍAZ	−20.6	536	−26.2	320	−16.1	361

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 Misans at 0.23 metres. Four other athletes also recorded a loss on landing. The mean hip angle at landing was 78.7°. The mean knee angle was 131.6°, while the mean trunk angle was 19.2°. Figure 11 shows the landing distance by each athlete. The mean landing distance was 0.50 metres.

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

Athlete	Hip angle (°)	Knee angle (°)	Trunk angle (°)	Landing loss (m)
CLAYE	69.7	146.8	51.6	0.00
DOS SANTOS	76.7	113.2	5.8	0.00
ÉVORA	96.0	137.9	−1.3	0.13
COPELLO	91.8	89.4	−8.0	0.12
CARTER	82.8	138.0	24.8	0.00
ZANGO	84.9	153.3	16.7	0.00
ZHU	71.3	132.8	28.4	0.00
DONG	70.0	123.8	23.9	0.00
NÁPOLES	66.8	109.1	23.8	0.00
MISANS	77.7	129.2	16.3	0.23
HESS	65.7	127.4	22.3	0.07
KARAILIEV	76.2	151.9	37.8	0.02
PULLEN	89.9	131.6	10.9	0.00
DONATO	88.3	135.1	3.8	0.00
DÍAZ	72.8	154.9	31.1	0.00

Landing distance (m)

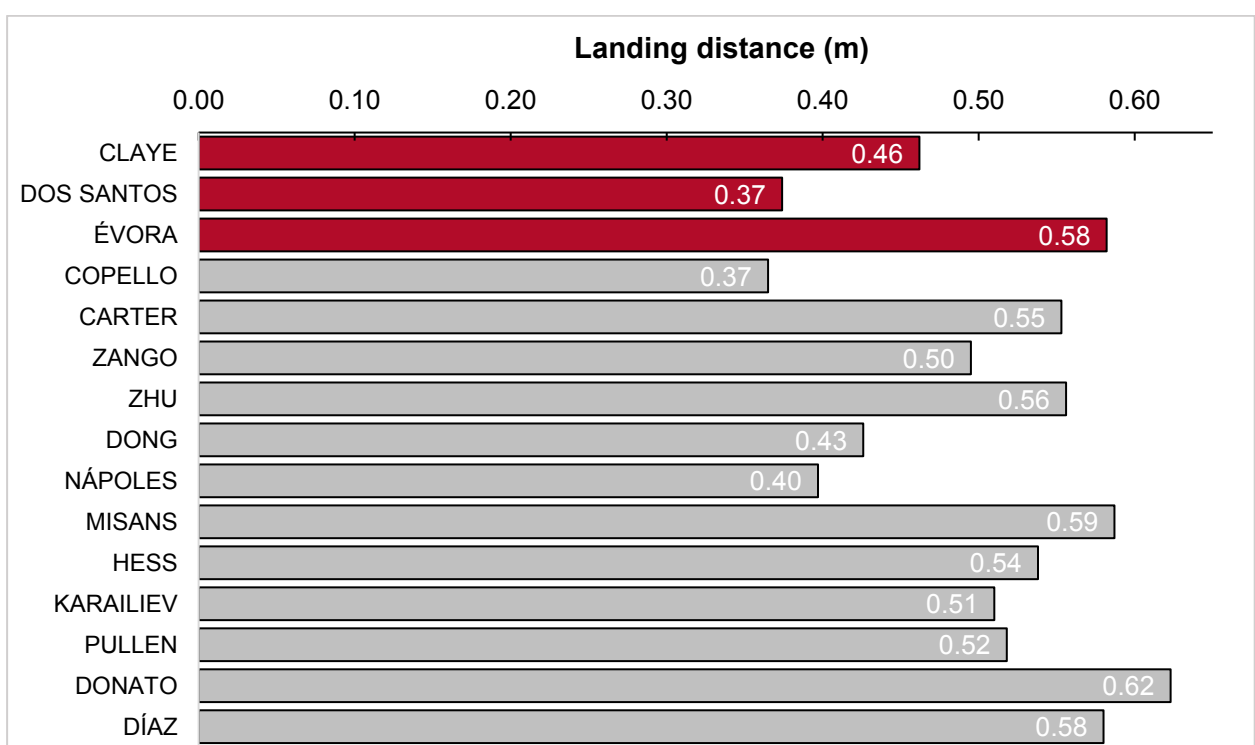|	Landing distance (m)
CLAYE	0.46
DOS SANTOS	0.37
ÉVORA	0.58
COPELLO	0.37
CARTER	0.55
ZANGO	0.50
ZHU	0.56
DONG	0.43
NÁPOLES	0.40
MISANS	0.59
HESS	0.54
KARAILIEV	0.51
PULLEN	0.52
DONATO	0.62
DÍAZ	0.58

Figure 11. The landing distances for each finalist in the men's triple jump.

COACH'S COMMENTARY

Introduction

The triple jump is a technical and extremely demanding event where the athlete has to perform 3 successive bounds after run-up.

The history of the triple jump has been built through athletes such as:

- Adhemar da Silva
- Joseph Schmidt
- Victor Saneyev
- Willie Banks
- Khristo Markov
- Mike Conley
- Christian Olsson
- Nelson Évora

As well as this there have been five jumpers over 18 metres (outdoors): Pedro Pablo Pichardo, Teddy Tamgho, Kenny Harrison, Christian Taylor and the world record holder Jonathan Edwards at 18.29 m.

Previous research on triple jump has led to 2 different arm styles:

1. The double arm method (simultaneous arm action)
2. The single arm method (alternated arm action)

The first allows a shorter ground contact with a more compact rebound, while the second matches more with a continuum of the run-up and a pursuit of more elasticity (commonly used in women's competitions).

This commentary will focus on the medallists Will Claye, Nelson Évora and Almir Junior. It will be very instructive to compare and detect the relevant features of their performances, knowing that only 3 cm separated the gold medal from the bronze medal.

 Analysis and comparison of kinematic parameters

Data selected for analysis and comparison

- Table 4
- Table 5

- Table 7
- Figures 8

Comparison of performance data

Nelson Évora

Opting for a hop-dominant style (6.30 m, or 36% of the total distance), Nelson is looking for a compensation of his low velocity coming off the board, 9.24 m/s (the slowest of the medallists). His 2.89 m/s vertical velocity, the biggest of all medallists and the 3rd of all competitors, underlines the fact that the elevation allows him to make his hop phase bigger. His take-off angle is also one of the largest, 17.4°. Furthermore, when we crosscheck the data with the video, we can notice a "preparation" of the impulse with a lowering of the hips leading to a hop phase with a large flight angle. In addition, the jump phase looks like bouncier as the total of the hop and step is 11.53 m, longer than the other medallists).

Almir Dos Santos Junior

Like Évora, his triple jump is hop-dominant, 6.44 m or 37%. Yet, he is the fastest of the medallist in the horizontal velocity at take-off from the board (9.73 m/s). the striking thing is his step phase, 5.04 m long with a much lower vertical velocity than his rivals (2.25 m/s compared to 2.65 m/s for Évora and 2.76 m/s for Claye) and a low take-off angle of 13.9° (the 2nd lowest of the competition). As evidenced by the video, it results in an ineffective landing which eventually affects the total distance of the triple jump.

Will Claye

Although his triple jump phases are more balanced than the other medallists, it is nevertheless important to dig into his step phase, 5.56 m long with a take-off angle of 18.8°, much larger than his hop which was 14.8° - this was the highest vertical velocity of the competition. It should be noted that his hop phase has been sacrificed for in favour to a larger step. However, it didn't prevent him to obtain a larger angle for the jump phase than his rivals (27.9°, compared to 26.7° for Dos Santos and 24.5° for Évora), which is linked with his significant horizontal velocity loss (−1.2m/s between the hop and jump)

It would have been very interesting to obtain measurements for the last steps before the board in order to get a global picture of the form of the jumpers before the board (velocity, trunk, hips). It should be noted that it's not necessary to analyse all the phases of the triple jumps as some are just a consequence and not the cause of the previous one.

Potential improvements for these jumpers

Nelson Évora

Having highlighted the structure of his performance, it seems that Nelson should work on the preparation of the impulse to obtain a more horizontal orientation, which will result in a better velocity conservation and a better balance of the three phases of the triple jump. Watch the video, a work on the quality of the take-off from the board would be beneficial.

Almir Dos Santos Junior

Relatively new in the event, his jumping is much perfectible. Almir should harmonise his jump through a shorter hop (6.44 m) which would reduce the velocity loss at the landing before the step phase impulse. As a result, it would increase his step phase without affecting the length of his jump phase.

Will Claye

Video and data analysis of his 6.014 m hop concur to the fact that a more complete impulse on the board (pushing fully) would result in a larger hop distance. Through the energy stored, he would still be able to produce a 5.56 m step, without having to increase its take-off angle. Indeed, during his 18.05 m in Eugene 2017, his jump was more orientated toward this.

Conclusion

After having analysed the performances of the medallists, it becomes clear that Willi Claye is the one with the better balance in the phases of his triple jump, which could explain his first place.

Almir Dos Santos is the one with the biggest margin of progression. However, the triple jumps of hoss two opponents are also potentially intestesting.

With this previous comparison two questions come to mine:

1. Can Almir Dos Santos change his technique at that age, even if this mean to temporarily have a performance regression?
2. Is having a balanced style like Claye, the absolute way to jump far? Shouldn't athletes jump with in line with their innate strengths?

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 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.

Triple jump specialist since 2005, Teddy Tamgho is the current world record holder in the discipline. In 2013, he became world champion with 18.04 m and the third man in the history to cross the 18 metre mark. Alongside his athletic career, Teddy has been evolving since 2014 as a coach. He founded his training group 'Team T' and coaches a talented group of 8 athletes including Hugues Zango actual world leading performer (17.58 m) and Rouguy Diallo (14.39 m) former world junior champion.