IAAF World Championships LONDON 2017

BIOMECHANICAL REPORT

FOR THE

IAAF World Championships

LONDON 2017

Pole Vault Women's

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INTRODUCTION

The women's pole vault final took place on the night of August 6th in good weather conditions. There was great excitement coming into the event given the thrilling Olympic final between Kateríni Stefanídi and Sandi Morris the previous year. Despite this, and entering the competition with the highest personal best, Morris only took the silver medal with 4.75 m. Stefanídi progressed her own world-leading and national records, which secured her the gold medal with a height of 4.91 m. A national record was also achieved for Robeilys Peinado who shared the bronze medal with Yarisley Silva at 4.65 m.

IAAF World Championships

London 4-13 August 2017

RESULTS

Pole Vault Women - Final

RECORDS	RESULT	NAME	COUNTRY	AGE	VENUE	DATE
World Record WR	5.06	Elena ISINBAEVA	RUS	27	Zürich (Letzigrund)	28 Aug 2009
Championships Record CR	5.01	Elena ISINBAEVA	RUS	23	Helsinki (Olympic Stadium)	12 Aug 2005
World Leading WL	4.91	Ekateríni STEFANÍDI	GRE	27	London	6 Aug 2017

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

6 August 2017 — 19:01 START TIME — 19° C TEMPERATURE — 56 % HUMIDITY

21:24 END TIME — 19° C — 56 %

PLACE	NAME	COUNTRY	DATE of BIRTH	ORDER	RESULT		4.30	4.45	4.55	4.65	4.75	4.82	4.89	4.91	5.02
1	Ekateríni STEFANÍDI	GRE	4 Feb 90	5	4.91	WL	-	-	-	O	O	O	X-	O	XXX
2	Sandi MORRIS	USA	8 Jul 92	4	4.75		-	O	O	O	O	X-	XX		
3	Robeilys PEINADO	VEN	26 Nov 97	11	4.65	NR	O	O	O	XO	XXX				
3	Yarisley SILVA	CUB	1 Jun 87	12	4.65		-	O	O	XO	XXX				
5	Lisa RYZIH	GER	27 Sep 88	9	4.65		-	XO	O	XO	XXX				
6	Holly BRADSHAW	GBR	2 Nov 91	8	4.65		-	-	O	XXO	XXX				
7	Alysha NEWMAN	CAN	29 Jun 94	1	4.65		XO	O	O	XXO	XXX				
8	Olga MULLINA	ANA	1 Aug 92	7	4.55		XO	O	O	XXX					
9	Eliza MCCARTNEY	NZL	11 Dec 96	2	4.55		-	O	XO	XXX					
10	Angelica BENGTSSON	SWE	8 Jul 93	3	4.55		XO	O	XO	XXX					
11	Nicole BÜCHLER	SUI	17 Dec 83	10	4.45		-	O	XXX						
12	Anicka NEWELL	CAN	5 Aug 93	6	4.45		XO	XO	XXX						

Timing and Measurement by SEIKO — AT-PV-W-f--A--.RS1..v1 — Issued at 21:29 on Sunday, 06 August 2017

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METHODS

Four vantage locations for camera placement were identified and secured. Each location had the capacity to accommodate two adjacent cameras placed on tripods. Two locations were situated on the broadcasting balcony along the home straight, one at the south media platform, and a final position was located at the end of the back straight. Three locations housed a Sony PXW-FS5 and a Canon EOS 700D. The final position was occupied by an additional Canon EOS 700D. All cameras were deployed to record each attempt during the women's pole vault final. The Sony PXW-FS5 cameras operating at 200 Hz (shutter speed: 1/1250; ISO: 2000; FHD: 1920x1080 px) recorded the last section of the runway to bar clearance. The Canon EOS 700D cameras operating at 60 Hz (shutter speed: 1/1250; ISO: 3200; SHD: 1280x720 px) recorded the entire trial from the start of the runway to landing.

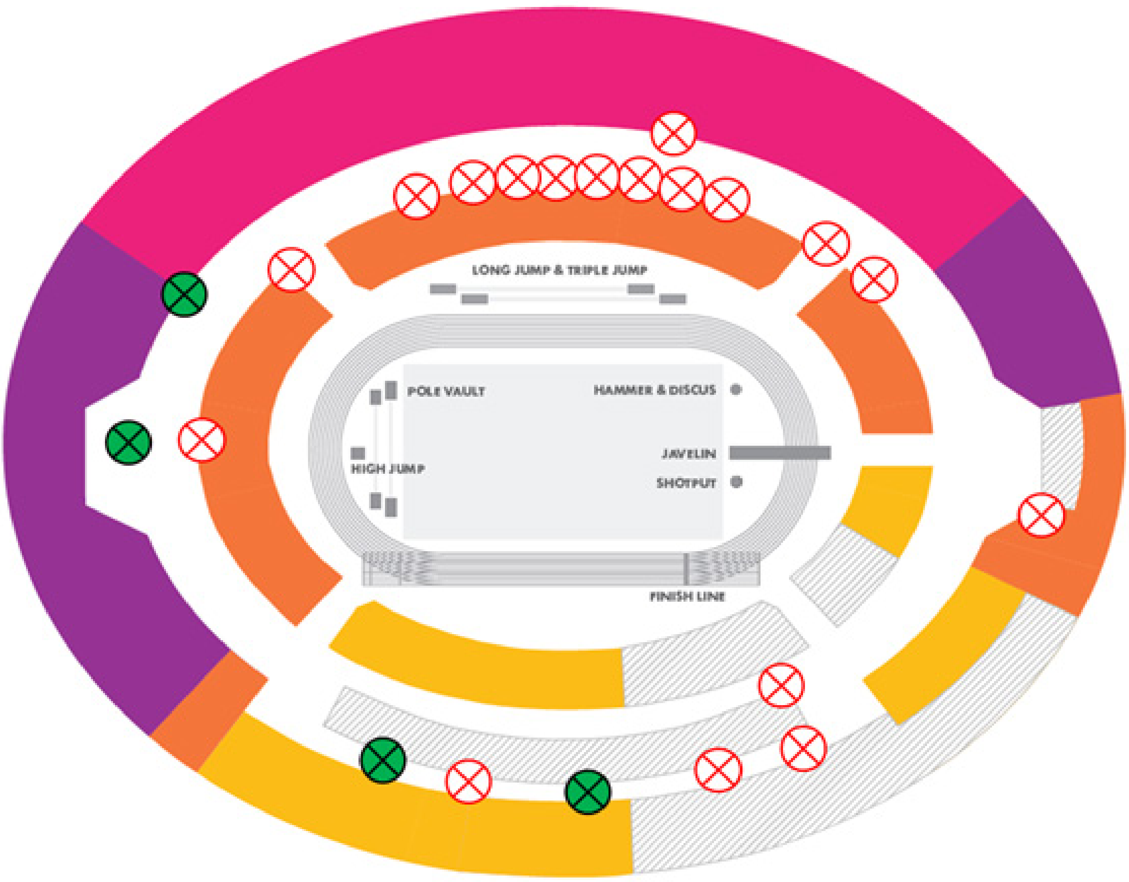


Figure 1. Camera positions for the women's pole vault final (shown in green).

Two separate calibration procedures were conducted after the competition. First, a rigid cuboid calibration frame was positioned on the runway over the plant box. This frame was then moved to a second position, away from the plant box to ensure an accurately defined volume that athletes would take off and clear the crossbar in. This approach produced a large number of non-coplanar control points per individual calibrated volume and facilitated the construction of a specific global coordinate system. A further calibration was completed using vertical poles to accurately measure horizontal runway sections.

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

The best successful trial for each athlete was selected for analysis. Technical issues meant that the second best successful performance was used in analysis for Alysha Newman (4.55 m). The video files were imported into SIMI Motion (SIMI Motion version 9.2.2, Simi Reality Motion Systems GmbH, Germany) for full body manual digitising. All digitising was completed 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 took place during the approach, take-off and clearance. This commenced 15 frames before and finished 15 frames after various events of these phases to provide sufficient data for subsequent 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 take-off 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. 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.

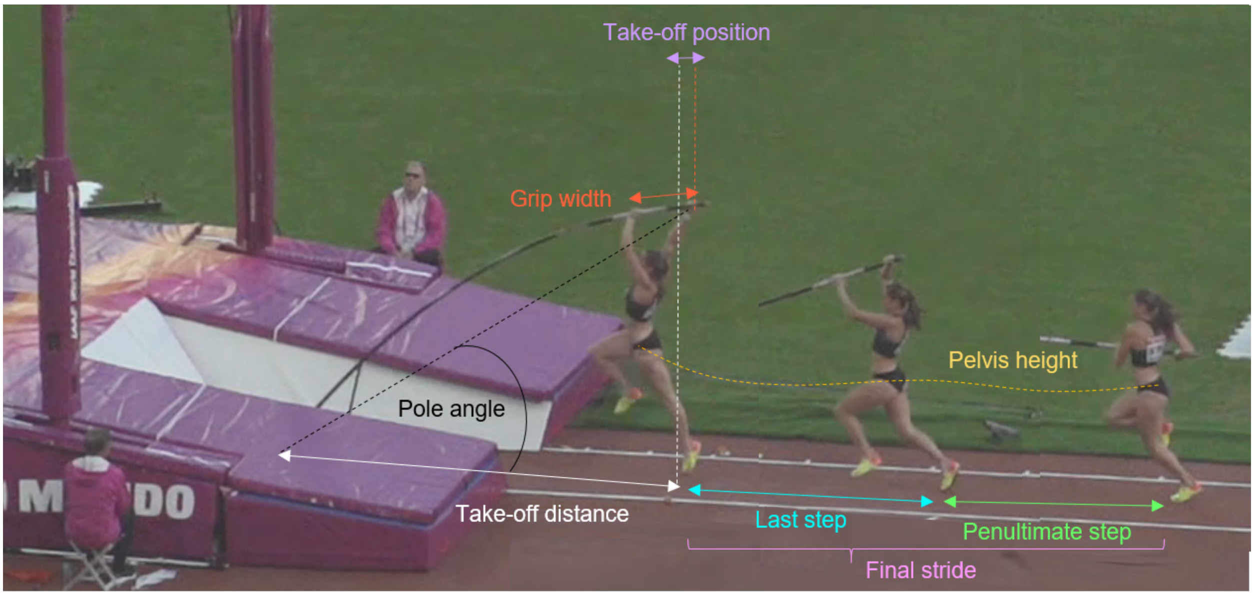


Figure 3. Final stride in the approach phase of the pole vault with visual definitions of the variables.

Table 1. Events selected to analyse the performance of the athletes.

Event	Definition
Take-off	The last point of contact when the foot leaves the runway.
Pole plant	The time instant when the pole makes contact with the box.
Pole release	The time instant when the upper grip releases the pole.

Table 2. Variables selected to describe the performance of the athletes.

Variable	Definition
Run up steps	The total number of steps completed on the runway to take-off, excluding any preparatory action.
Runway velocity	The mean horizontal velocity achieved during the mid-section of the runway (11-6 m away from the plant box).
Penultimate step length	The toe-off to toe-off distance of the step immediately before the last step.
Penultimate step velocity	The mean CM horizontal velocity during the step immediately before the last step.
Last step length	The toe-off to toe-off distance of the step immediately before take-off.
Last step velocity	The mean CM horizontal velocity during the step immediately before take-off.
Final stride length	The distance between the toe-off at the start of the penultimate step to the instant of take-off.
Take-off distance	The horizontal distance from the plant box to the foot tip at take-off.
Grip height	The distance between the lower tip of the pole and the athlete's upper grip.
Grip width	The distance between the upper and lower grip on the pole.
Take-off foot position	The horizontal distance between foot tip of the take-off leg and upper grip at the instant of take-off.
Take-off velocity	The resultant velocity of the CM at the instant of take-off.
Direction of travel	The angle between CM and horizontal at take-off and 5 frames after.

Pole angle	The angle between the pole chord and ground at take-off.
Ankle angle	The angle between the lower leg and foot segments.
Knee angle	The angle between the thigh and lower leg segments and considered to be 180° in the anatomical standing position.
Hip angle	The angle between the trunk and thigh segments and considered to be 180° in the anatomical standing position. Values greater than 180° indicates hyperextension.
Elbow angle	The angle between the upper and lower arm segments.
Shoulder angle	The angle between the upper arm and trunk segments and to be considered to be 0° in the anatomical standing position. Values greater than 180° indicates hyperextension.
Time on pole	The time between take-off and pole release.
Standing height	The vertical distance between the runway and the CM at take-off.
Swing height	The vertical distance between the CM at take-off and at pole release.
Push height	The vertical distance between the CM height at pole release and peak height.
CM clearance height	The vertical distance between the competition height and peak CM height.
Pelvis clearance height	The vertical distance between the competition height and pelvis height.
Pelvis horizontal distance	The horizontal distance from the cross bar to the pelvis at peak vertical height.
Vertical pelvis displacement	The vertical distance between the runway and the mid-point of the pelvis.
Shank angle	The angle of the shank segment relative to the runway.

Note: *CM = centre of mass.*

Please note that the results from this report supersede the results contained within the fast report published in August 2017. The results presented here have been derived from data extracted from all cameras involved in the recording and digitised fully to provide a more accurate analysis of performance.

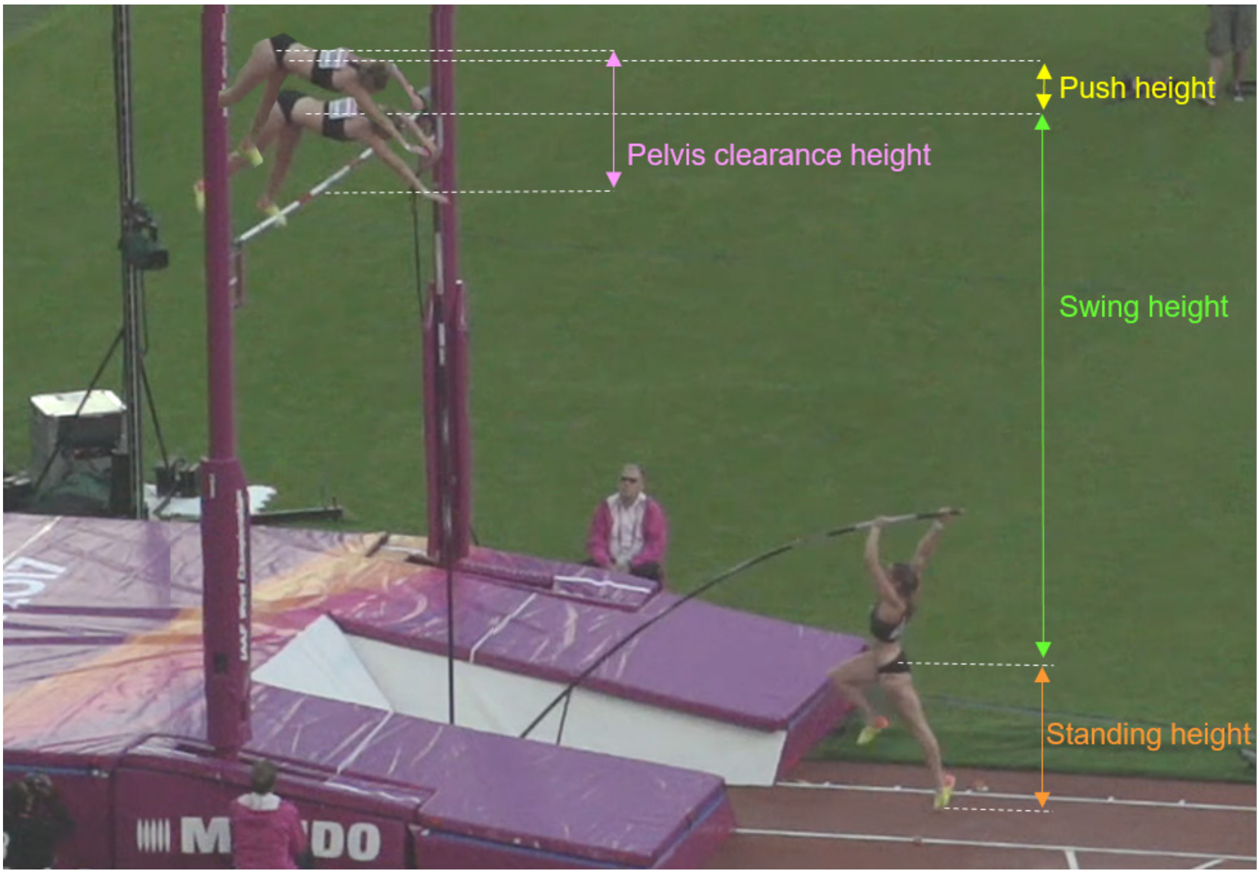


Figure 4. Visual definitions for partial height variables.

RESULTS

The mean age of the finalists was 25 yrs (Table 3). This is younger compared to the mean age of the finalists in Daegu 2011 (28 yrs) and Berlin 2009 (27 yrs). The mean vault height for the finalists in London 2017 was greater than the mean competition height in Berlin 2009 (4.58 m) but less than the mean heights achieved in Daegu 2011 (4.72 m).

Table 3. Descriptive statistics for all finalists of the women's pole vault (mean ± SD).

Age (yrs)	Stature (m)	Mass (kg)
25 ± 4	1.69 ± 0.07	61.75 ± 4.79

Table 4. Competition results in relation to 2017 season's best (before the World Championships).

	Rank	SB 2017 (m)	Official height (m)	Difference (%)
STEFANÍDI	1	4.85	4.91	+1.24
MORRIS	2	4.84	4.75	−1.86
PEINADO	3	4.65	4.65	0.00
SILVA	3	4.82	4.65	−3.53
RYZIH	5	4.75	4.65	−2.11
BRADSHAW	6	4.81	4.65	−3.33
NEWMAN	7	4.71	4.65	−1.27
MULLINA	8	4.67	4.55	−2.57
MCCARTNEY	9	4.83	4.55	−5.80
BENGTSSON	10	4.65	4.55	−2.15
BÜCHLER	11	4.73	4.45	−5.92
NEWELL	12	4.65	4.45	−4.30

Table 5 shows the results for number of steps, runway velocity (m/s) and take-off distance (m). Mean runway velocity (7.82 m/s) was 0.41 m/s slower compared to mean runway velocities achieved in Daegu (8.23 m/s) and Berlin (8.23 m/s). The mean take-off distance was 0.22 m shorter than both Daegu (3.62 m) and Berlin (3.62 m).

Table 5. Number of run-up steps, runway velocity in section 10-5 m and take-off distance.

	Steps	Runway velocity (m/s)	Take-off distance (m)
STEFANÍDI	16	8.13	3.29
MORRIS	15	8.33	3.29
PEINADO	16	7.63	3.34
SILVA	16	7.87	3.36
RYZIH	14	7.69	3.48
BRADSHAW	17	7.94	3.59
NEWMAN	16	7.75	3.45
MULLINA	16	8.00	3.39
MCCARTNEY	13	7.52	3.41
BENGTSSON	17	7.87	3.49
BÜCHLER	14	7.94	3.66
NEWELL	15	7.81	3.07

Presented above are traditionally reported variables for analysing pole vault performance. The next page provides a more detailed analysis of the final steps on the runway. This includes mean velocity during the step, and the step length.

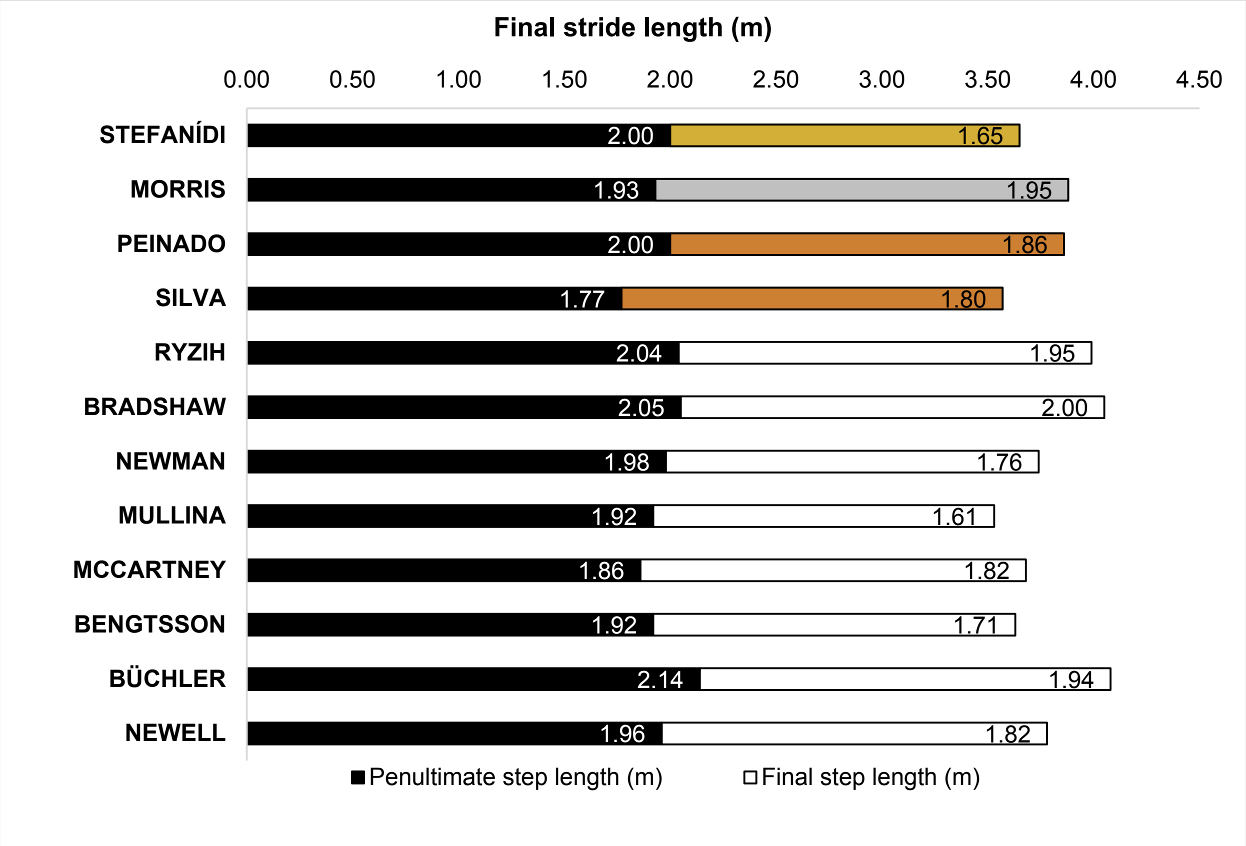


Figure 5. Contribution of the last two steps to final stride length.

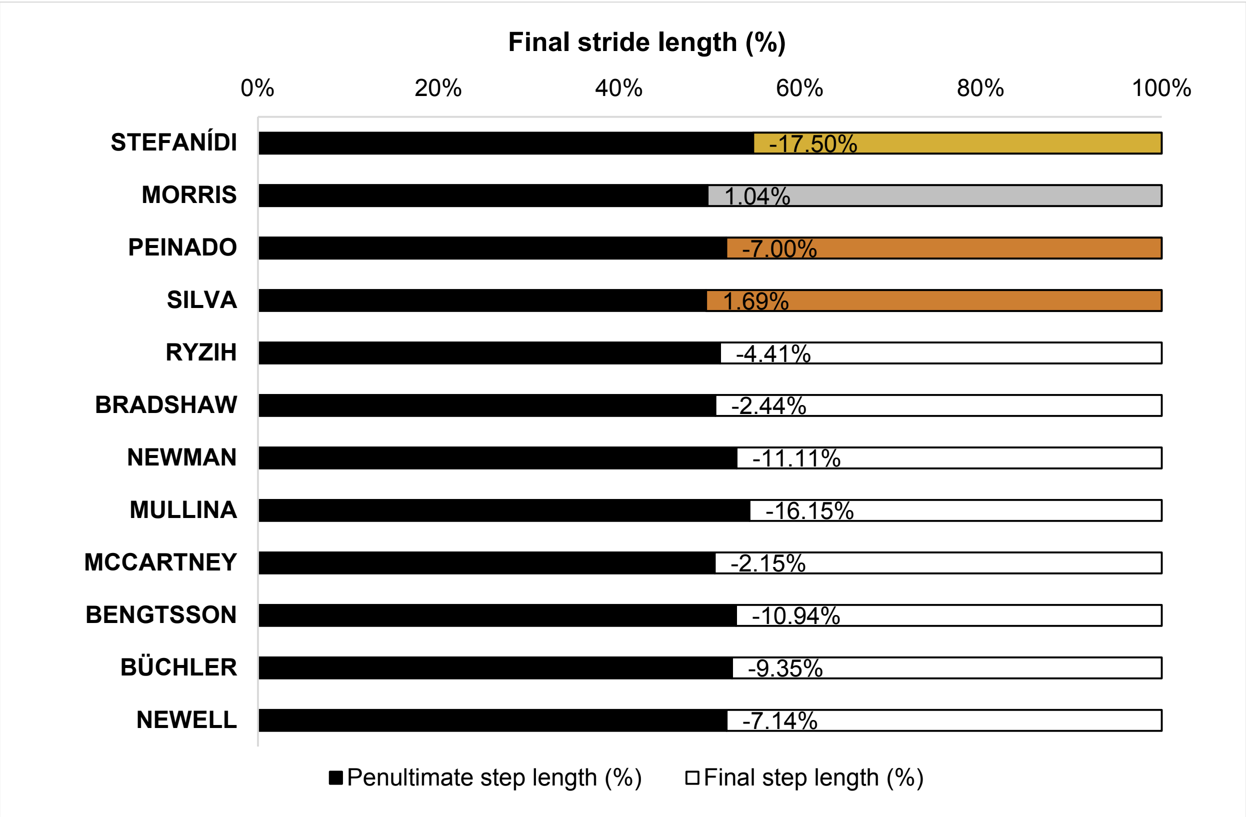
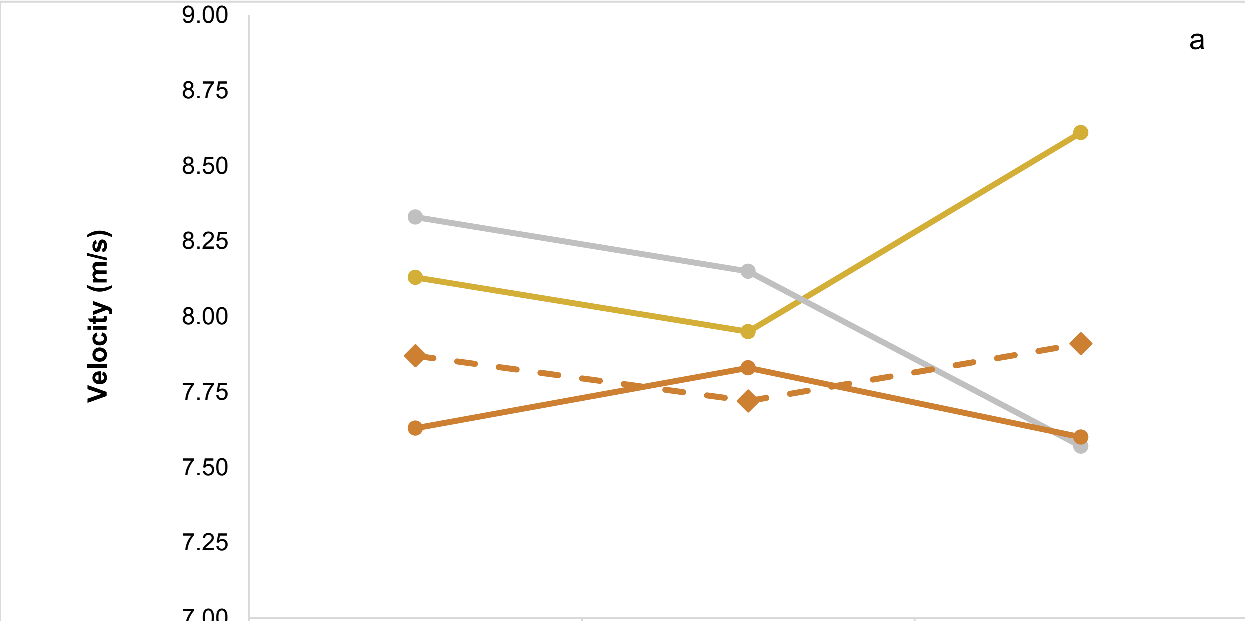
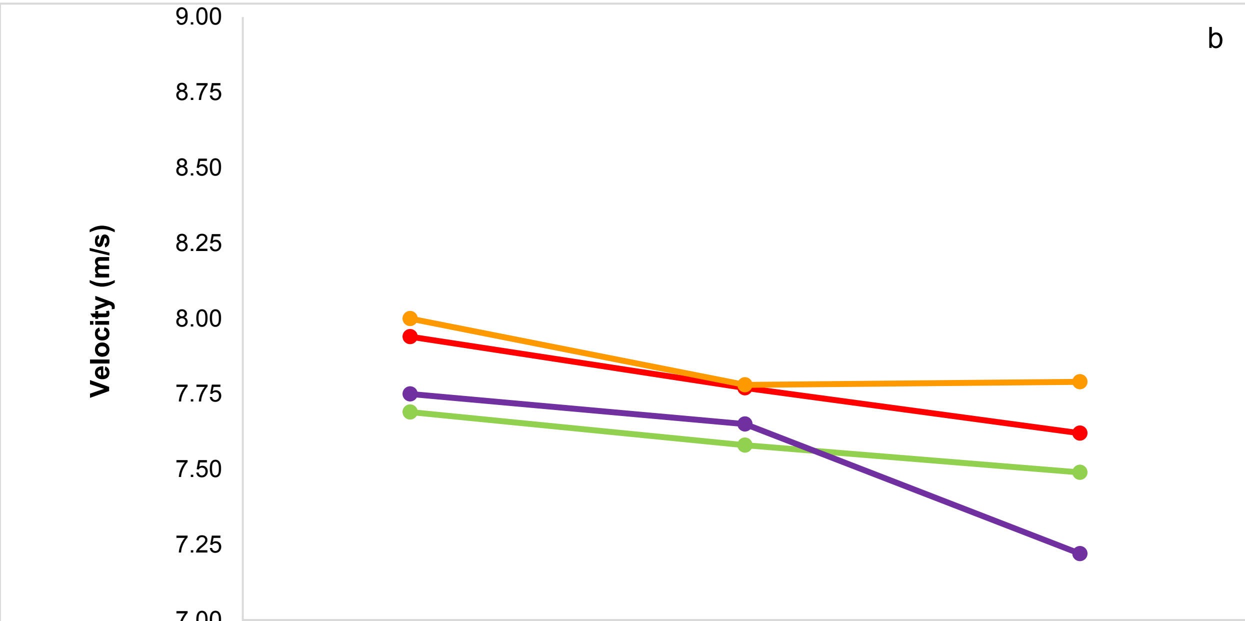


Figure 6. Relative contribution of the last two steps to final stride length. The percentage change is also displayed. A negative number indicates that the final step was shorter than the penultimate step.

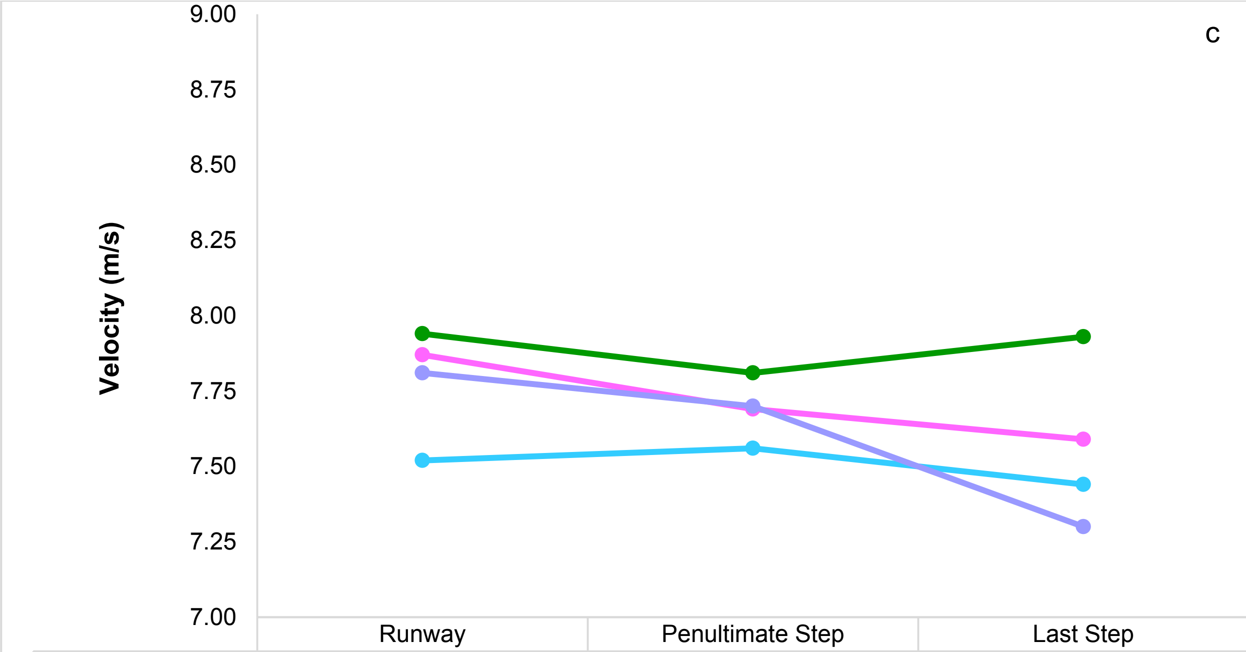
The following three graphs depict velocity profiles for each of the women finalists. Mean horizontal velocity on the runway (10-5 m), during the penultimate, and last steps is presented.



	Runway	Penultimate Step	Last Step
STEFANÍDI	8.13	7.95	8.61
MORRIS	8.33	8.15	7.57
PEINADO	7.63	7.83	7.60
SILVA	7.87	7.72	7.91



	Runway	Penultimate Step	Last Step
RYZIH	7.69	7.58	7.49
BRADSHAW	7.94	7.77	7.62
NEWMAN	7.75	7.65	7.22
MULLINA	8.00	7.78	7.79



	Runway	Penultimate Step	Last Step
MCCARTNEY	7.52	7.56	7.44
BENGTSSON	7.87	7.69	7.59
BÜCHLER	7.94	7.81	7.93
NEWELL	7.81	7.7	7.30

Figure 7 a, b, c. Velocity profiles of all athletes.

On the following pages, Figures 8 and 9 illustrate variables relating to handgrip at take-off. More specifically, Figure 8 illustrates the position of the take-off foot with respect to upper grip position. Negative values indicate the foot was in front of the upper grip (under), and positive values indicate the foot was behind (out). Figure 9 shows the variety of grip widths and grip heights adopted by the competitors during the final.

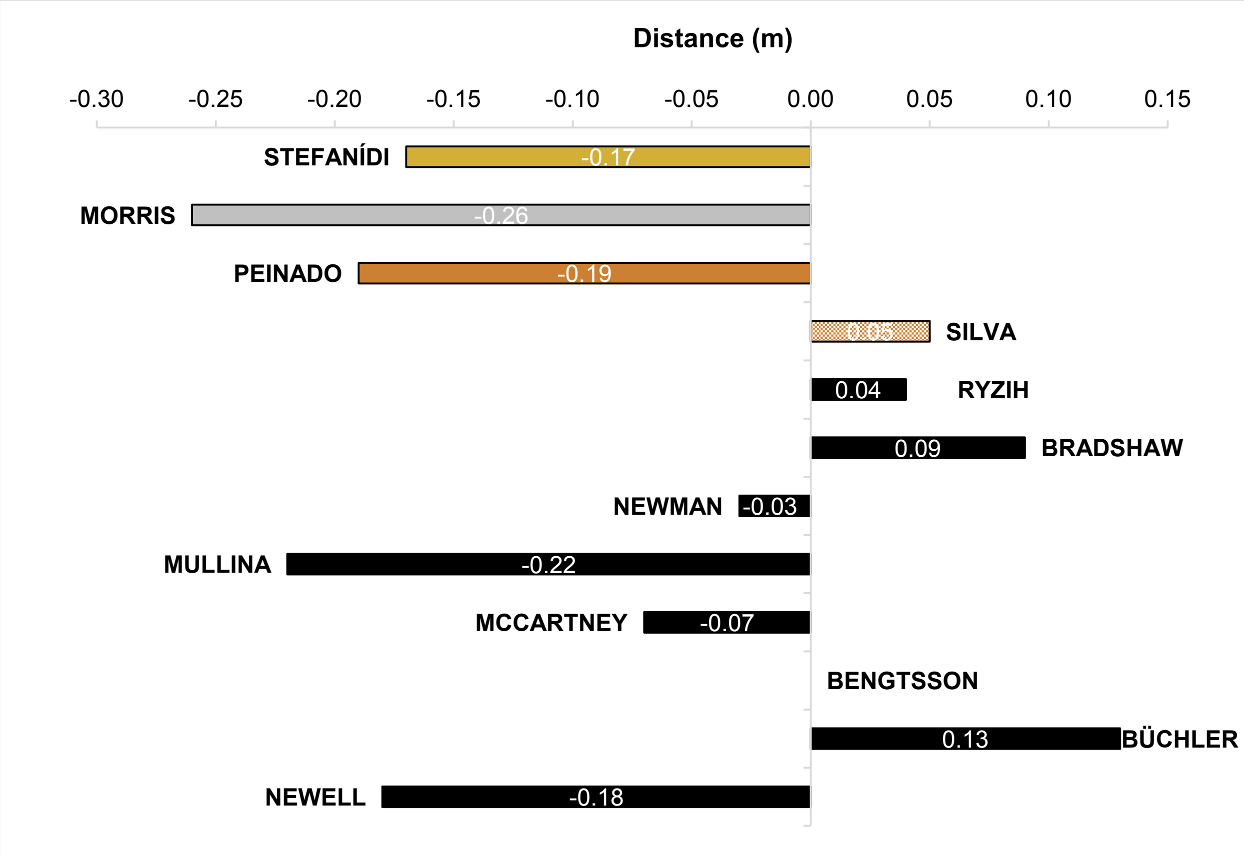


Figure 8. Take-off foot position (relative to upper grip position).

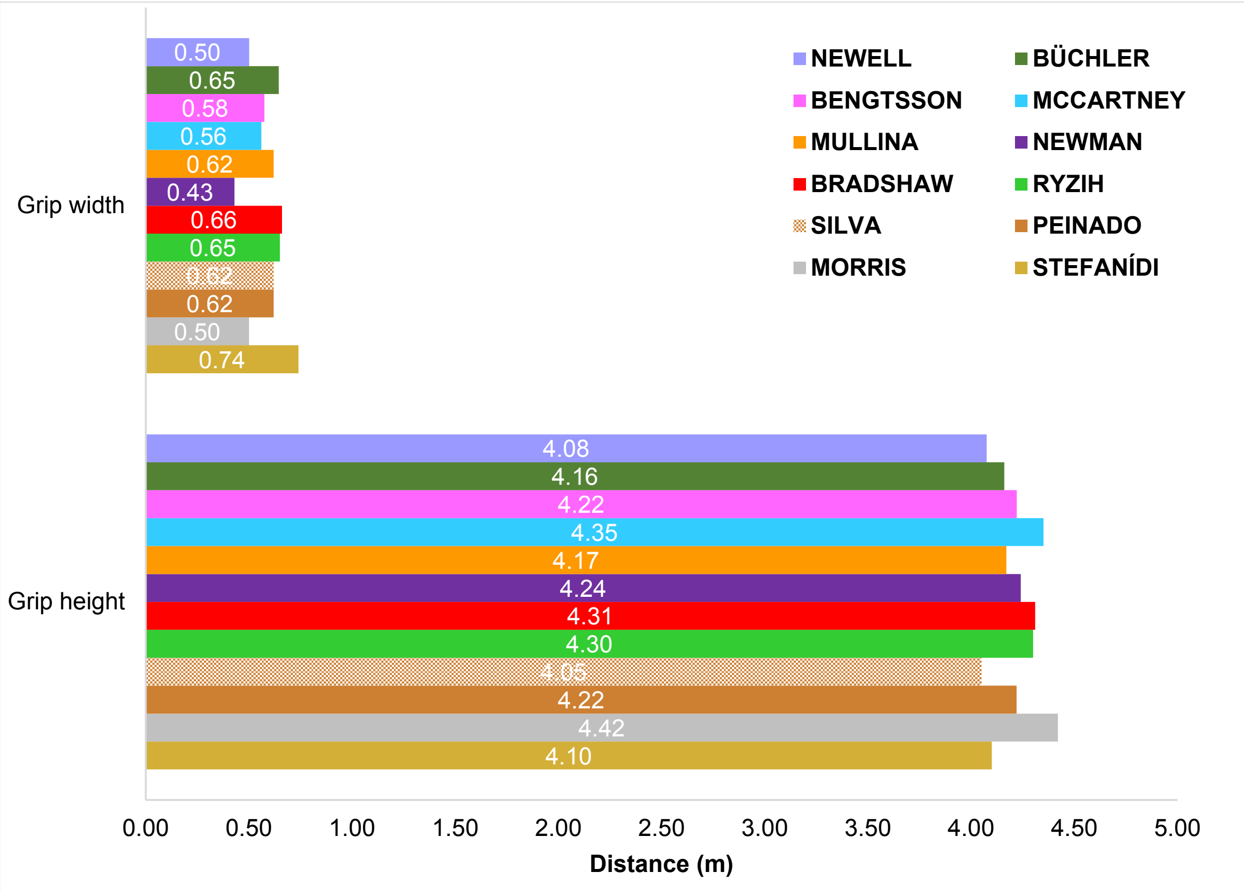


Figure 9. Grip positions for each of the finalists.

The parameters in Table 6 below describe the resultant velocity, direction of travel and the angle between the pole chord and runway at take-off. The following two pages describe joint angles at take-off for both the left and right sides of the body.

Table 6. Take-off parameters.

	Resultant take-off velocity (m/s)	Direction of travel (°)	Pole angle (°)
STEFANÍDI	7.35	23	31
MORRIS	7.68	21	32
PEINADO	6.92	21	31
SILVA	7.41	15	31
RYZIH	6.87	14	32
BRADSHAW	7.13	15	31
NEWMAN	5.96	16	32
MULLINA	7.07	26	30
MCCARTNEY	6.00	23	32
BENGTSSON	7.18	17	30
BÜCHLER	7.30	22	29
NEWELL	6.93	22	34

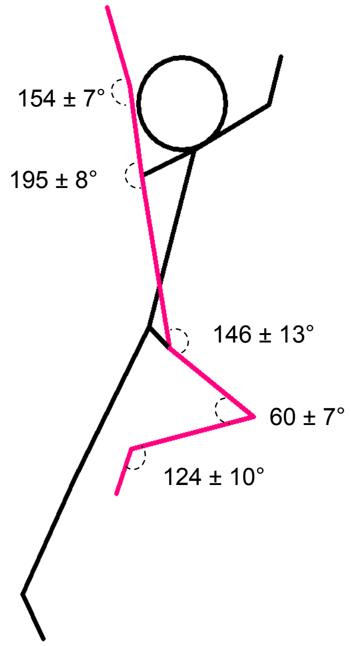


Figure 10. Mean ± standard deviation joint angles at take-off for the right hand side.

All of the athletes in the final used their right leg to drive, and right arm for upper grip (pink). The joint angles for the individual athletes are displayed in Table 7. For illustration purposes Figure 10 displays the take-off posture for one of the athletes, with mean and standard deviation angles for all of the finalists.

Table 7. Details of joint angles of the drive leg and upper grip arm at the instant of take-off.

	Right ankle (°)	Right knee (°)	Right hip (°)	Right elbow (°)	Right shoulder (°)
STEFANÍDI	131	43	147	160	182
MORRIS	116	57	161	149	194
PEINADO	138	58	155	153	183
SILVA	134	72	128	151	191
RYZIH	122	50	138	156	187
BRADSHAW	126	57	133	145	200
NEWMAN	107	68	135	159	198
MULLINA	116	54	167	149	203
MCCARTNEY	141	55	150	163	185
BENGTSSON	121	60	156	169	196
BÜCHLER	120	59	138	149	209
NEWELL	123	68	148	151	196

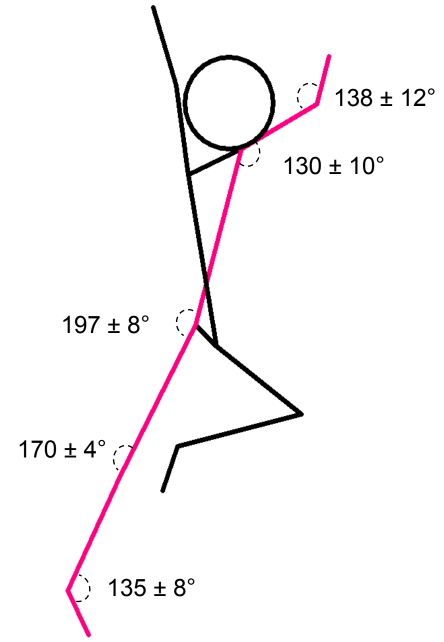


Figure 11. Mean ± standard deviation joint angles at take-off for the left hand side.

All of the athletes in the final used their left leg for take-off, and left arm for lower grip (pink). The joint angles for the individual athletes are displayed in Table 8. For illustration purposes Figure 11 displays the take-off posture for one of the athletes, with mean and standard deviation angles for all of the finalists.

Table 8. Details of joint angles of the take-off leg and lower grip arm at the instant of take-off.

	Left ankle (°)	Left knee (°)	Left hip (°)	Left elbow (°)	Left shoulder (°)
STEFANÍDI	134	173	194	143	130
MORRIS	146	163	204	133	128
PEINADO	132	175	213	112	122
SILVA	137	166	184	131	129
RYZIH	125	173	193	134	127
BRADSHAW	151	168	192	140	123
NEWMAN	133	176	199	141	141
MULLINA	137	173	197	136	127
MCCARTNEY	135	172	202	142	154
BENGTSSON	126	169	194	157	128
BÜCHLER	133	166	191	152	120
NEWELL	142	171	214	154	132

Table 9. Absolute contributions to height in the pole vault. H_s represents swing height; H_p represents push height; H_{cc} represents CM clearance height and H_{pc} represents pelvis clearance height.

	Standing height (m)	Official height (m)	Time on pole (s)	Height (m)	
STEFANÍDI	1.11	4.91	1.31	H_s H_p H_{cc} H_{pc}	3.79 0.04 0.00 0.21
MORRIS	1.18	4.75	1.44	H_s H_p H_{cc} H_{pc}	3.69 0.01 0.12 0.29
PEINADO	1.10	4.65	1.48	H_s H_p H_{cc} H_{pc}	3.65 0.00 0.11 0.28
SILVA	1.11	4.65	1.27	H_s H_p H_{cc} H_{pc}	3.58 0.07 0.10 0.22
RYZIH	1.20	4.65	1.73	H_s H_p H_{cc} H_{pc}	3.47 0.08 0.09 0.33
BRADSHAW	1.21	4.65	1.55	H_s H_p H_{cc} H_{pc}	3.52 0.03 0.10 0.27
NEWMAN	1.17	4.55	1.58	H_s H_p H_{cc} H_{pc}	3.45 0.03 0.10 0.30
MULLINA	1.08	4.55	1.48	H_s H_p H_{cc} H_{pc}	3.65 0.01 0.19 0.34
MCCARTNEY	1.18	4.55	1.59	H_s H_p H_{cc} H_{pc}	3.67 0.00 0.30 0.46
BENGTSSON	1.08	4.55	1.41	H_s H_p H_{cc} H_{pc}	3.64 0.06 0.22 0.41
BÜCHLER	1.10	4.45	1.48	H_s H_p H_{cc} H_{pc}	3.66 0.00 0.31 0.49
NEWELL	1.15	4.45	1.47	H_s H_p H_{cc} H_{pc}	3.42 0.04 0.15 0.36

On the previous page, Table 9 provides the absolute contributions to height in the women's final. The relative contributions to height are provided in Figure 12 below, where 100 % indicates official bar height.

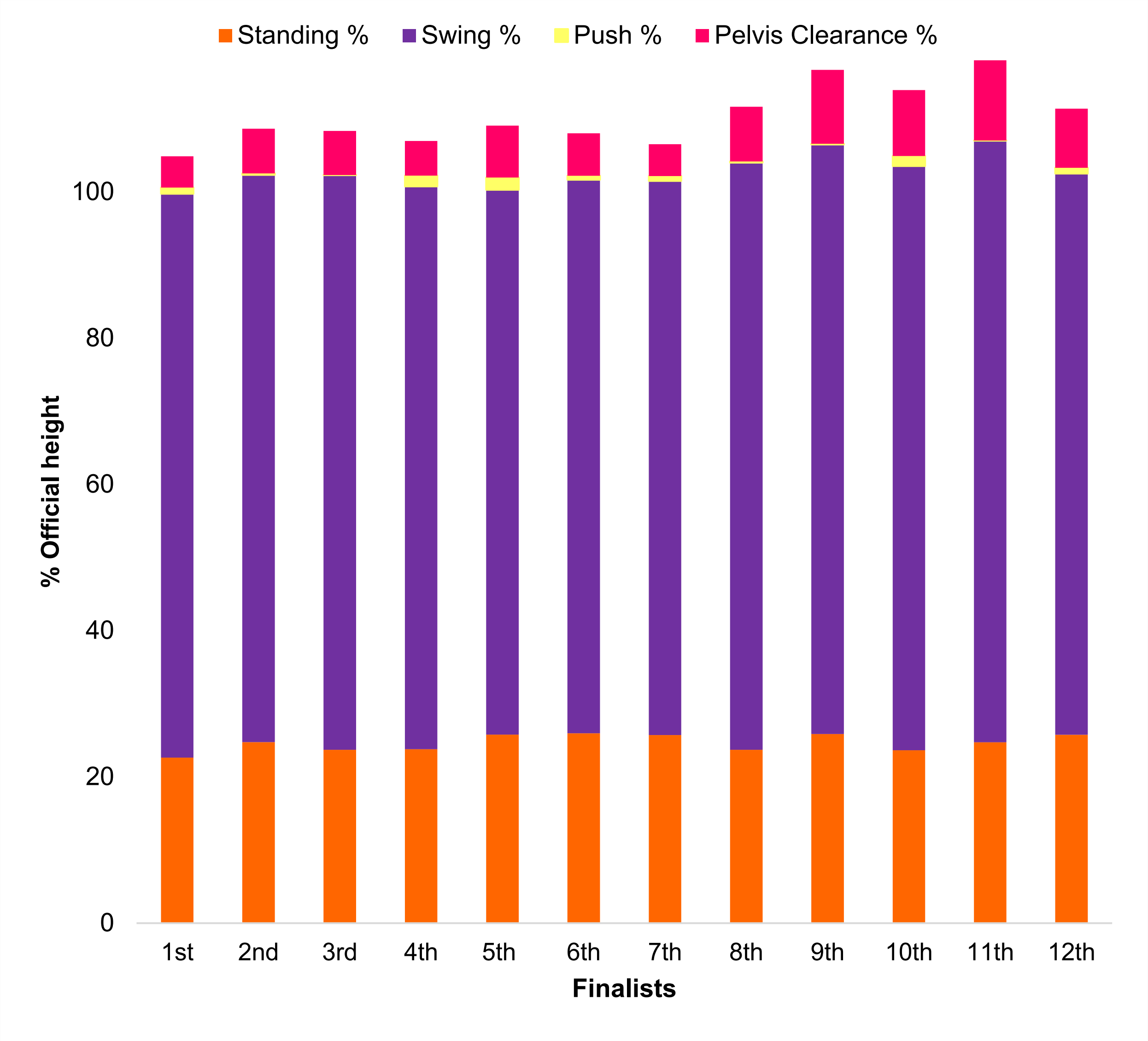


Figure 12. Relative contributions to height in the pole vault expressed as a percentage of the official bar height.

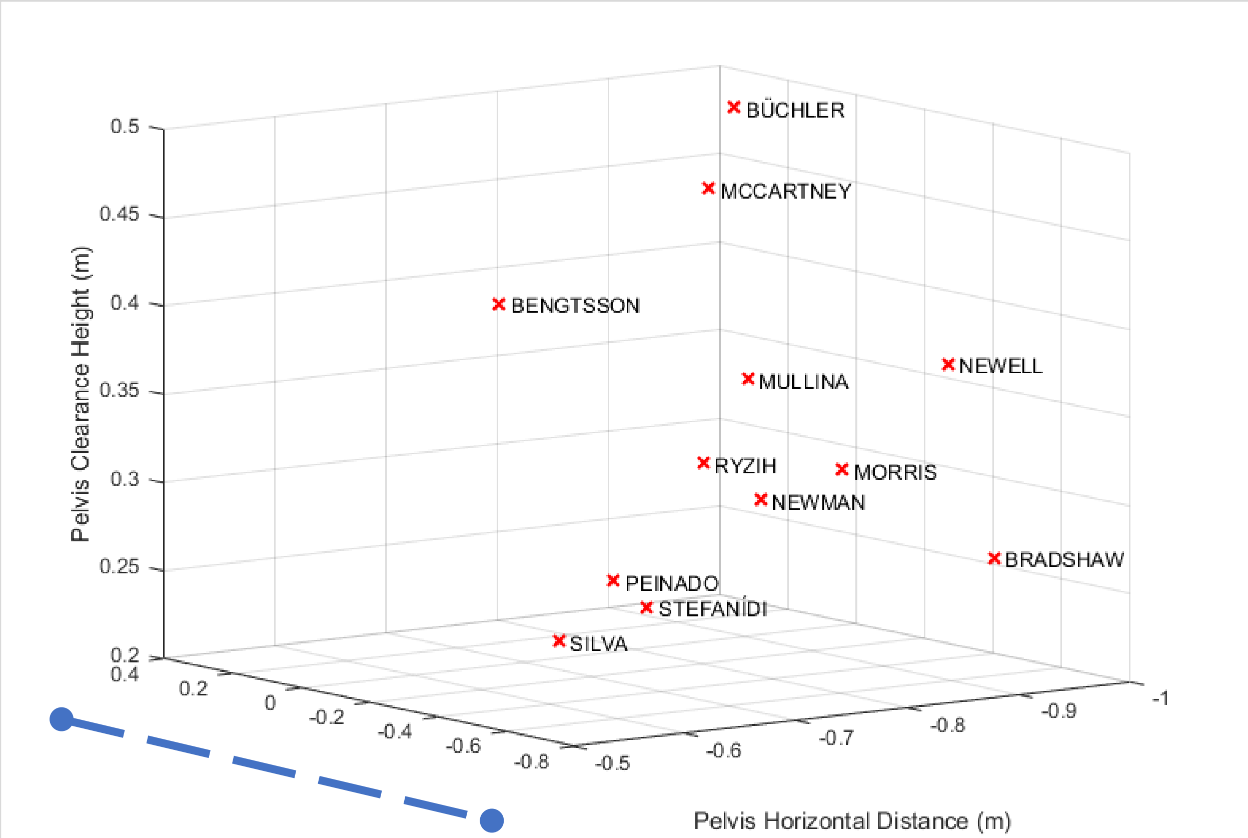


Figure 13. A 3D scatter graph to illustrate peak pelvis position in relation to the competition crossbar.

Figure 13 shows the vertical clearance height and corresponding horizontal positions of the pelvis at the apex of the vault. A visual representation of the crossbar has been included for reference (blue dashed line), where the centre of the crossbar is the origin of the three axes. The pelvis horizontal distance shows the penetration towards the pit, whilst the axis parallel to the crossbar shows the mediolateral location. The red crosses represent the position of the pelvis relative to the individual competition bar height for each of the finalists. This ranged between 4.45 – 4.91 m.

Further key variables

Through discussion with the coaching collaborator and trying to better understand the techniques employed, the following two variables were chosen for analysis within the medallists. The first variable (Figure 14) shows the path of the pelvis throughout the last three steps to appreciate the running technique in these steps and provide an indication of how much bounce the running pattern had. In this graph time has been normalised to 100% and pelvis height has been standardised to its height at the beginning of the third last step. Table 10 displays the lower leg position (shank angle) during the approach at three instants (touchdown, pole plant and take-off) to indicate how the take-off leg was oriented.

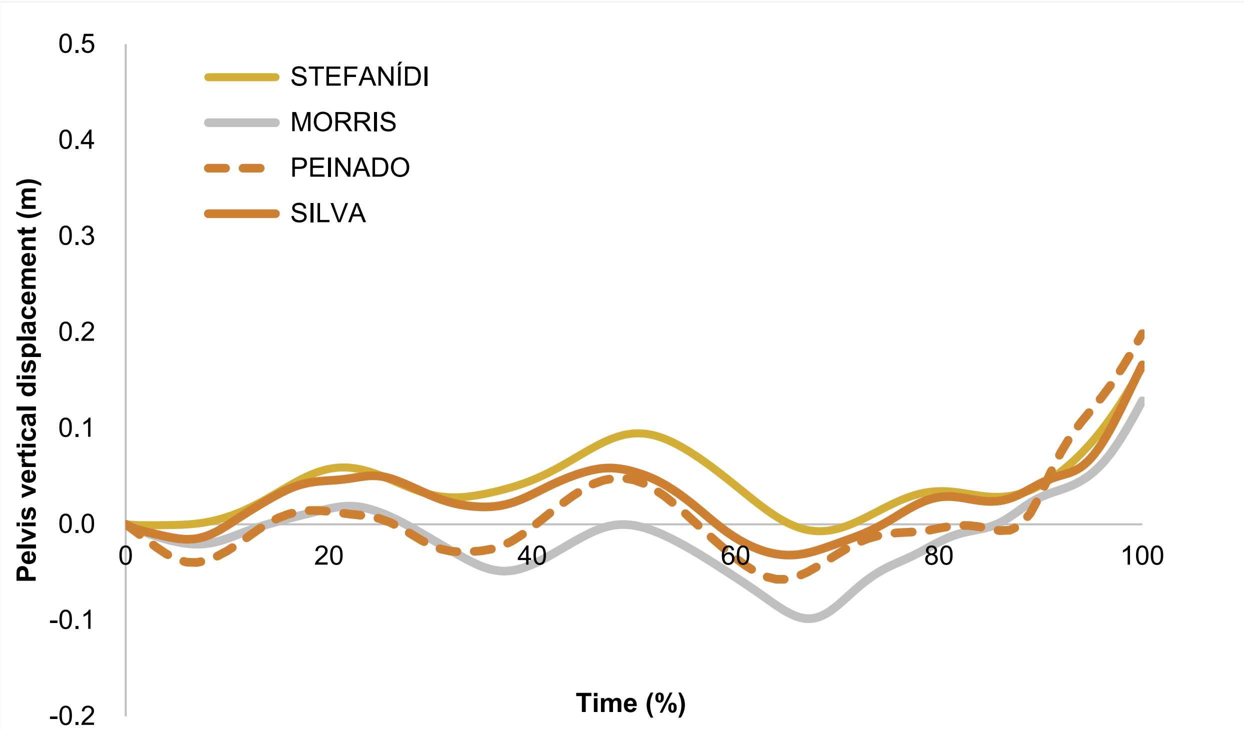


Figure 14. Fluctuations in pelvis height during the last 3 steps for the medallists.

Table 10. Shank angle of the take-off leg at touchdown, pole plant and take-off relative to the ground for the medallists.

	Touchdown (°)	Pole plant (°)	Take-off (°)
STEFANÍDI	101	78	68
MORRIS	108	76	68
PEINADO	113	68	65
SILVA	102	63	62

COACH'S COMMENTARY

In an event as technically complex as the pole vault, there are many factors that can contribute to the potential height of the vaulter. Often, in other events, one key performance indicator is possessed by most of the competitors in the field. However, this is not the case for the pole vault, and this is supported by the data presented.

Having said that, some data did stand out between the medallists of the women's competition. Firstly, Stefanídi did not have the fastest velocity between 10-5 m of the runway, but she did have the fastest velocity into the last step. Her last step was also shorter compared with the penultimate step, and the difference between the two was greater compared with the other finalists. Stefanídi also had one of the smallest clearance heights and horizontal distances of the pelvis at the peak. This shows the apex of the gold medal vault was not only well placed vertically, but also horizontally.

Stefanídi also had the widest handgrip in the field, whereas Morris had one of the narrowest. Variation in grip height and take-off position can also be seen between the women finalists. This highlights the importance of a personalised technique that best suits the individual athlete. I do think there is an optimum model for pole vault performance, but I also think that not every athlete can have the same model. To some extent, the model should be modified to the athlete.

In addition to these observations, I noticed some values that do not necessarily result in a higher performance but are of interest. Runway velocity did not correlate strongly with performance ($r = 0.47$). This is consistent with the last three major championships, and applicable for both men and women.

In recent years, great emphasis on pure velocity has been placed on our event. Speed is not everything in the pole vault. I was happy to see the data supported my personal theory: that velocity of the last step holds more importance to performance than runway velocity. For this to be achieved the athlete must possess not only speed and power, but most importantly good posture, proper running mechanics, and a pole drop that is conducive to the transfer of energy we are trying to make from horizontal to vertical. These data should ideally be used by the individual athletes and coaches to assess if, and how, the implemented changes made throughout the year are transferring into the vault.

CONTRIBUTORS

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Mitchell Krier is the coach of Olympic and world champion, Katerina Stefanídi. He studied exercise science and spent many years pole vaulting under the guidance of Cranston Hysong, father and coach of Olympic champion Nick Hysong. He also spent three additional years training and coaching under Nick Hysong. After coaching Stefanídi to an undefeated season in 2017, he was named International coach of the year in the pole vault at the national pole vault summit.