IAAF World Indoor Championships
BIRMINGHAM 2018
1–4 MARCH

BIOMECHANICAL REPORT

FOR THE

IAAF

WORLD INDOOR CHAMPIONSHIPS 2018

Pole Vault Women

Dr Brian Hanley, Helen Gravestock
and Dr Athanassios Bissas
Carnegie School of Sport

Stéphane Merlino
IAAF Project Leader

LEEDS BECKETT UNIVERSITY

IAAF

Correspondence:

Dr Athanassios Bissas

Head of Sport & Exercise Biomechanics, Carnegie School of Sport

Leeds Beckett University

Fairfax Hall, Headingley Campus

Leeds, UK, LS6 3QT

Email: A.Bissas@leedsbeckett.ac.uk

Released:

February 2019

Please cite this report as:

Hanley, B., Gravestock, H. J., Bissas, A. and Merlino, S. (2019). *Biomechanical Report for the IAAF World Indoor Championships 2018: Pole Vault Women.* Birmingham, UK: International Association of Athletics Federations.

Event Directors

Dr Brian Hanley

Helen Gravestock

Project Director

Dr Athanassios Bissas

Project Coordinator

Louise Sutton

Senior Technical and Logistical Support

Liam Gallagher

Aaron Thomas

Liam Thomas

Calibration

Dr Brian Hanley

Report Editors

Josh Walker

Dr Catherine Tucker

Data Management

Nils Jongerius

Josh Walker

Data Analyst

Dr Brian Hanley

Project Team

Dr Tim Bennett

Dr Mark Cooke

Dr Alex Dinsdale

Dr Lysander Pollitt

Dr Gareth Nicholson

Masalela Gaesenngwe

Emily Gregg

Parag Parelkar

Dr Giorgos Paradisis (*National and Kapodistrian University of Athens*)

Scott Bingham

Iain Findlay

Dr Ian Richards

Jessica Thomas

Sarah Walker

Nathan Woodman

Coaching Commentary

Herbert Czingon

Table of Contents

Figures

Tables

INTRODUCTION

The women's pole vault took place on the evening of Saturday 3rd March. Twelve athletes took part, with one achieving no height. Sandi Morris of the USA won gold and recorded a Championship Record with her third attempt at 4.95 m, with Anzhelika Sidorova winning silver with a personal best of 4.90 m. The outdoor World Champion from London 2017, Katerina Stefanídi, finished third. Two of the youngest competitors, Eliza McCartney and Alysha Newman, achieved national records for New Zealand and Canada, respectively. This report focusses on the run-up and take-off phases of the pole vault competition.

IAAF World Indoor Championships

Birmingham (GBR) 1-4 March 2018

RESULTS

Pole Vault Women - Final

RECORDS	RESULT	NAME	COUNTRY	AGE	VENUE	DATE
World Indoor Record WIR	5.02	Jennifer SUHR	USA	31	Albuquerque, NM	2 Mar 2013
Championship Record CR	4.95	Sandi MORRIS	USA	26	Birmingham	3 Mar 2018
World Leading WL	4.95	Sandi MORRIS	USA	26	Birmingham	3 Mar 2018

Area Indoor Record AIR — National Indoor Record NIR — Personal Best PB — Season Best SB

3 March 2018 18:00 START TIME

21:16 END TIME

PLACE	NAME	COUNTRY	DATE of BIRTH	ORDER	RESULT		4.35	4.50	4.60	4.70	4.75	4.80	4.85	4.90	4.95	5.04
1	Sandi MORRIS	USA	8 Jul 92	9	4.95	CR	-	O	O	XO	O	XXO	X-	XO	XXO	XXX
2	Anzhelika SIDOROVA	ANA	28 Jun 91	11	4.90	PB	-	-	O	O	-	O	O	XXO	XXX	
3	Katerina STEFANIDI	GRE	4 Feb 90	10	4.80		-	-	-	O	XO	XXO	X-	XX		
4	Eliza MCCARTNEY	NZL	11 Dec 96	7	4.75	AIR	-	XO	O	XXO	O	XXX				
5	Katie NAGEOTTE	USA	13 Jun 91	12	4.70		-	XO	O	XO	X-	XX				
6	Alysha NEWMAN	CAN	29 Jun 94	1	4.70	NIR	O	O	XXO	XXO	XXX					
7	Yarisley SILVA	CUB	1 Jun 87	8	4.60	SB	O	XO	O	XXX						
8	Nina KENNEDY	AUS	5 Apr 97	2	4.60		XO	XO	O	XXX						
9	Olga MULLINA	ANA	1 Aug 92	5	4.60	PB	O	XO	XXO	XXX						
10	Ninon GUILLON-ROMARIN	FRA	15 Apr 95	4	4.50		O	O	XXX							
11	Angelica BENGTSSON	SWE	8 Jul 93	6	4.50	SB	O	XO	XXX							
	Lisa RYZIH	GER	27 Sep 88	3	NM		-	XXX								

Timing and Measurement by SEIKO — AT-PV-W-f--A--.RS1..v1 — Issued at 21:18 on Saturday, 03 March 2018

Official Partners

METHODS

Five vantage locations for camera placement were identified and secured. Three locations were situated on the home straight, one at the first bend, and a final position was located about two-thirds of the way along the back straight. Four locations housed a Sony PXW-FS5; the final position was occupied by a Canon EOS 700D. All cameras were deployed to record each attempt during the women’s final. The Sony PXW-FS5 cameras operating at 200 Hz (shutter speed: 1/1250; ISO: 2000-4000; FHD: 1920x1080 px) recorded the last section of the runway to take-off. The Canon EOS 700D cameras operating at 60 Hz (shutter speed: 1/1250; ISO: 1600-3600; SHD: 1280x720 px) recorded the entire trial from the start of the runway to take-off and was used to count the number of steps each athlete took during the run-up.

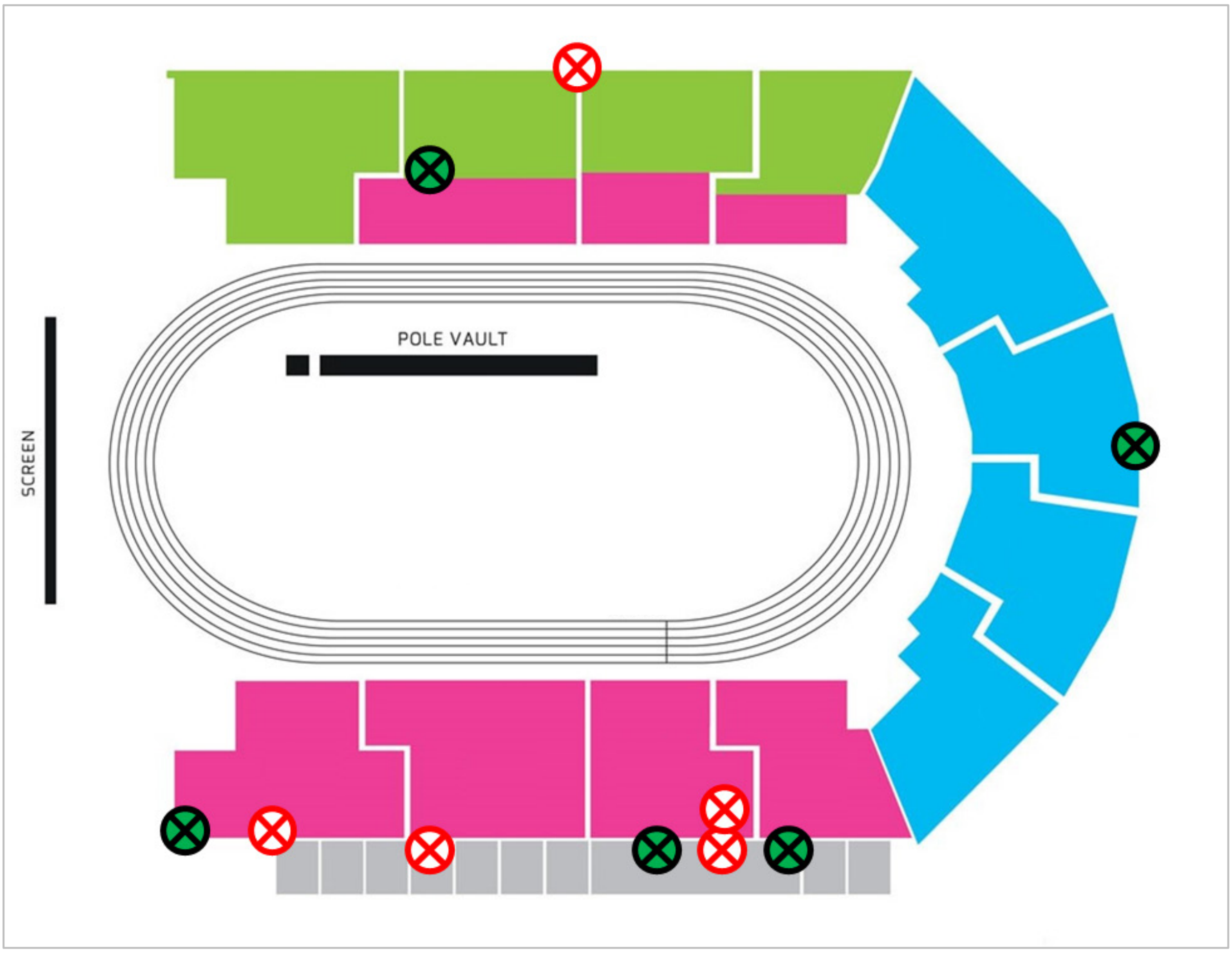

Figure 1. Camera layout for the women's pole vault indicated by green-filled circles.

Calibration procedures were conducted before 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 from. 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.

The best successful trial for each athlete was selected for analysis. 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 and take-off. 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.

Table 1. Variables selected to describe the performance of the athletes.

Variable	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.
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 (10-5 m away from the plant box).
3rd last to pit distance	The distance between the toe-off at the start of the third last step to the end of the plant box.
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.
2nd last step length	The toe-off to toe-off distance of the step immediately before the last step.
2nd last step velocity	The mean CM horizontal velocity during the step immediately before the last step.
3rd last step length	The toe-off to toe-off distance of the third last step before take-off.
3rd last step velocity	The mean CM horizontal velocity during the third last step before take-off.
Horizontal velocity at pole plant	The instantaneous CM horizontal velocity at the moment of pole plant.
Horizontal velocity at take-off	The instantaneous CM horizontal velocity at the moment of take-off.
Change in velocity to take-off	The change in horizontal velocity between pole plant and take-off.
Take-off velocity	The resultant velocity of the CM at the instant of take-off.
Take-off angle	The angle between the path of the CM and the horizontal at take-off.

Take-off distance	The horizontal distance from the plant box to the foot tip at take-off.
SLR [step length ratio]	The ratio of the last step length to the 2nd last step length.
Standing height	The vertical distance between the runway and the CM at take-off.
Time from pole plant to take-off	The time between pole plant and take-off.
Pole angle	The angle between the pole and the ground, measured at toe-off for the 3rd last step, 2nd last step, last step (angle of carry) and take-off (angle of attack). Negative values indicate that the end of the pole held by the vaulter was lower than the pole tip.
Take-off foot position	The horizontal distance between the toe of the take-off leg and the upper grip at the instant of take-off.
Grip width	The distance between the upper and lower grips on the pole.

Note: *CM = centre of mass.*

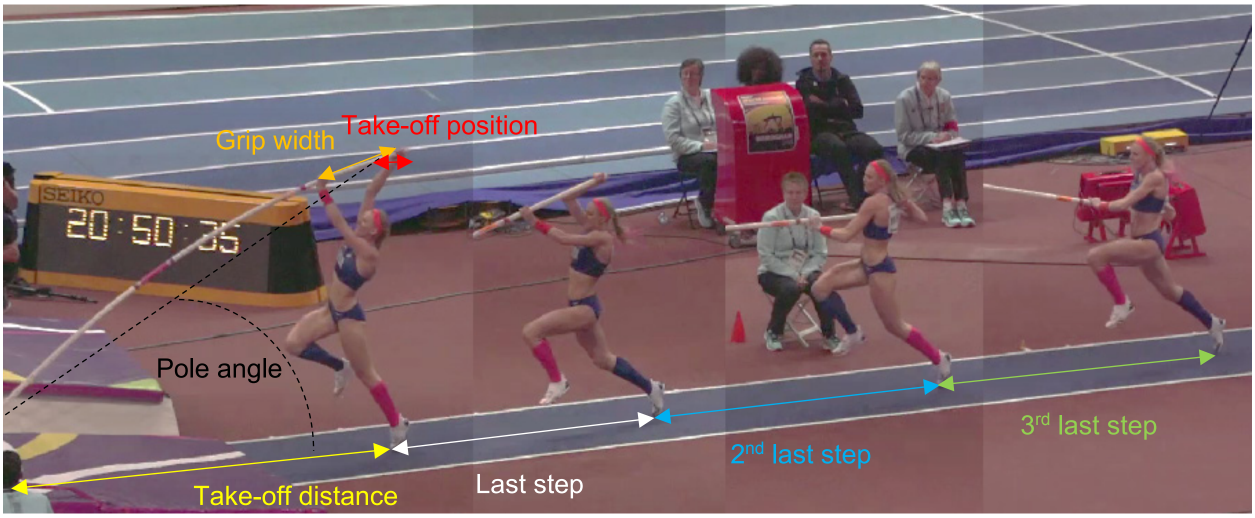

Figure 2. Final three steps in the approach phase of the pole vault with visual definitions of the variables.

RESULTS

Table 2 shows the values for run-up steps (from the beginning of the run-up to take-off), the mean runway velocity between 10 and 5 m to the end of the pit, and the distance from the end of the pit to the toe-off of the 3rd last step. The results show that all athletes were within 10 m of the back of the pit with three steps of their run-up remaining.

Table 2. Runway characteristics.

Athlete	Run-up steps (N)	Runway velocity (m/s)	3rd last to pit distance (m)
MORRIS	14	8.30	9.79
SIDOROVA	16	8.21	9.67
STEFANÍDI	16	8.10	8.75
MCCARTNEY	12	7.70	9.52
NAGEOTTE	16	8.33	9.22
NEWMAN	16	7.80	9.23
SILVA	14	7.81	8.56
KENNEDY	16	7.94	9.58
MULLINA	16	7.82	8.81
GUILLON-ROMARIN	16	7.99	8.90
BENGTSSON	14	7.67	8.57

Because the results showed that athletes were at different stages of their run-up with 10 m remaining, their run-up velocities have been calculated separately for the 3rd last, 2nd last and last steps in Figures 3-6 below. Figure 7 shows the step lengths for the last three steps, and Figures 8-11 show visually the last two step lengths and take-off distance for each athlete.

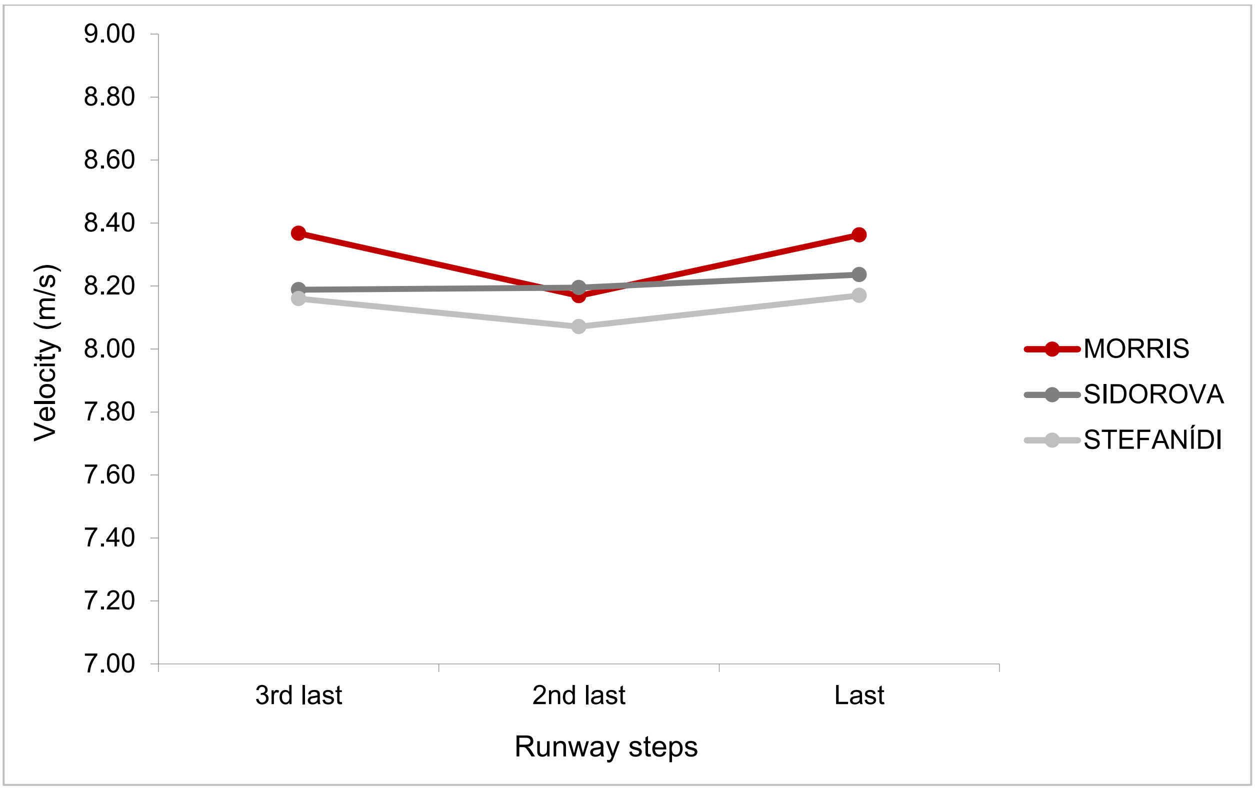

Figure 3. Velocity profiles of the athletes finishing first, second and third during their last three steps.

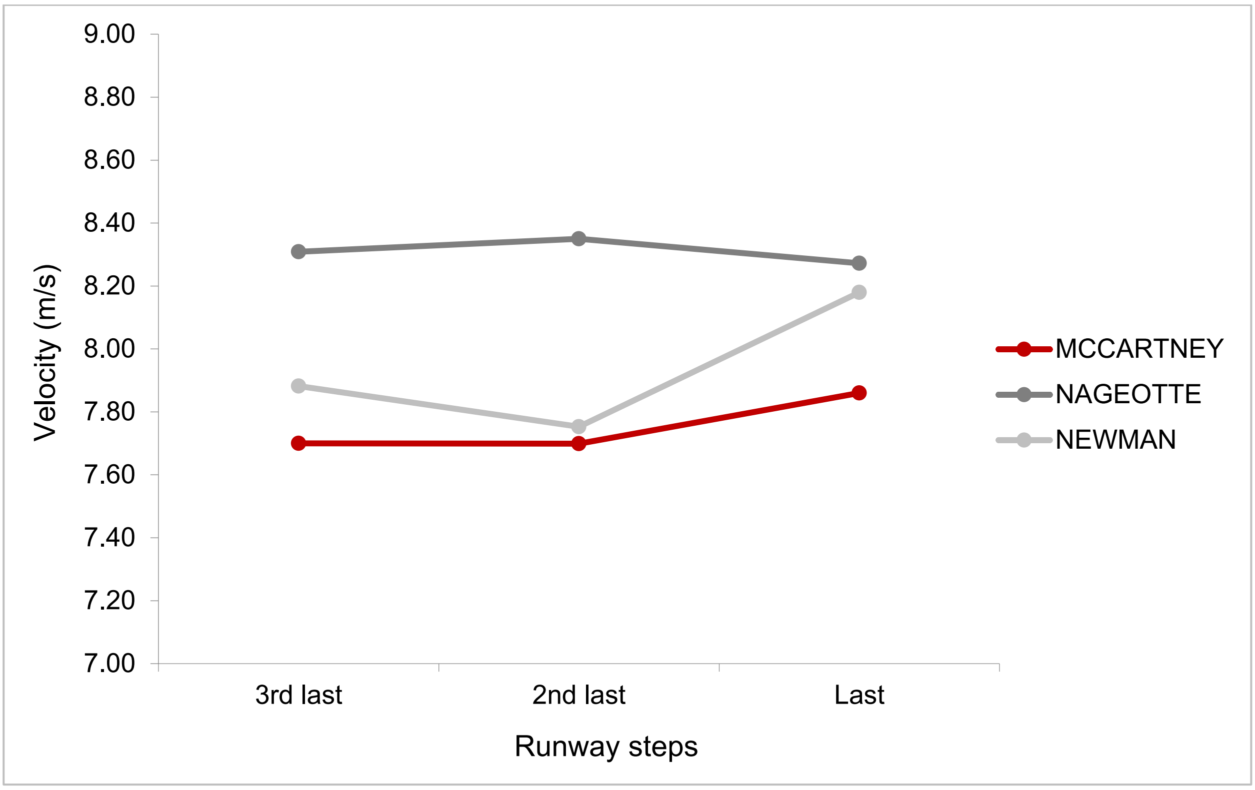

Figure 4. Velocity profiles of the athletes finishing fourth, fifth and sixth during their last three steps.

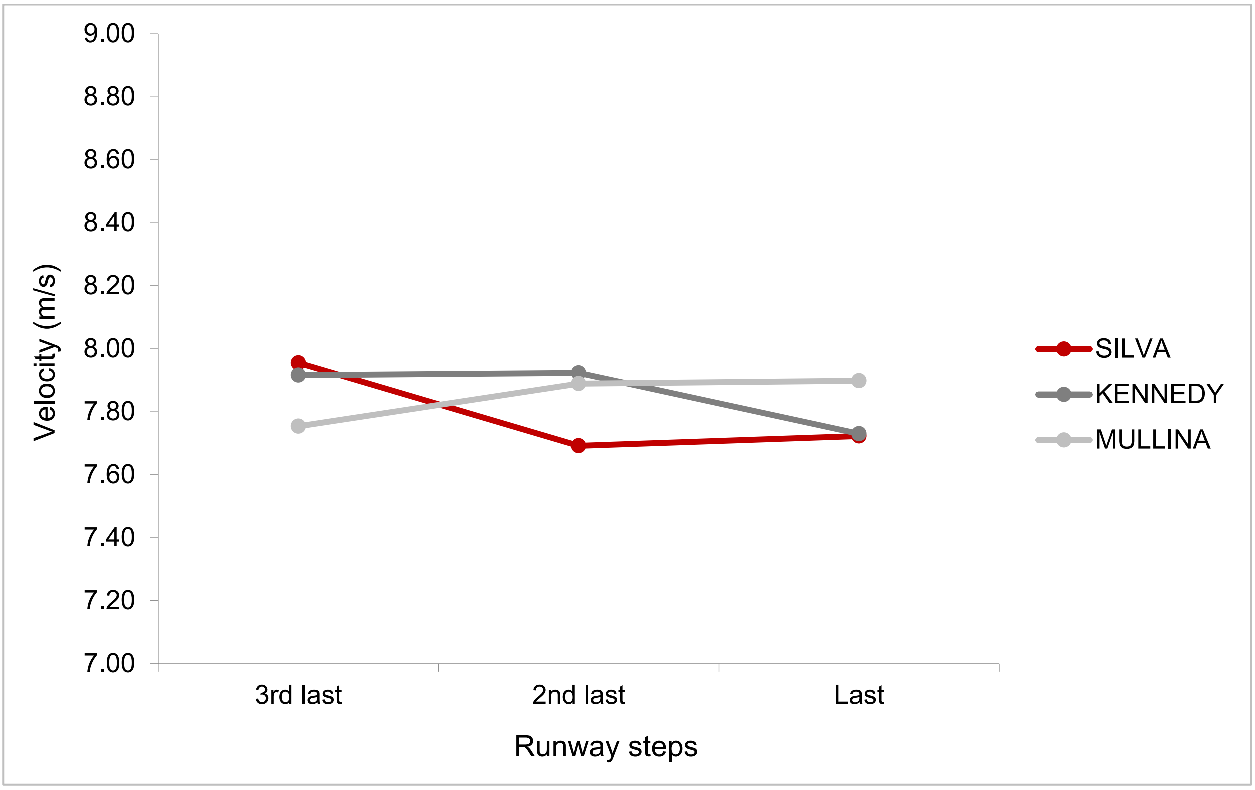

Figure 5. Velocity profiles of the athletes finishing seventh, eighth and ninth during their last three steps.

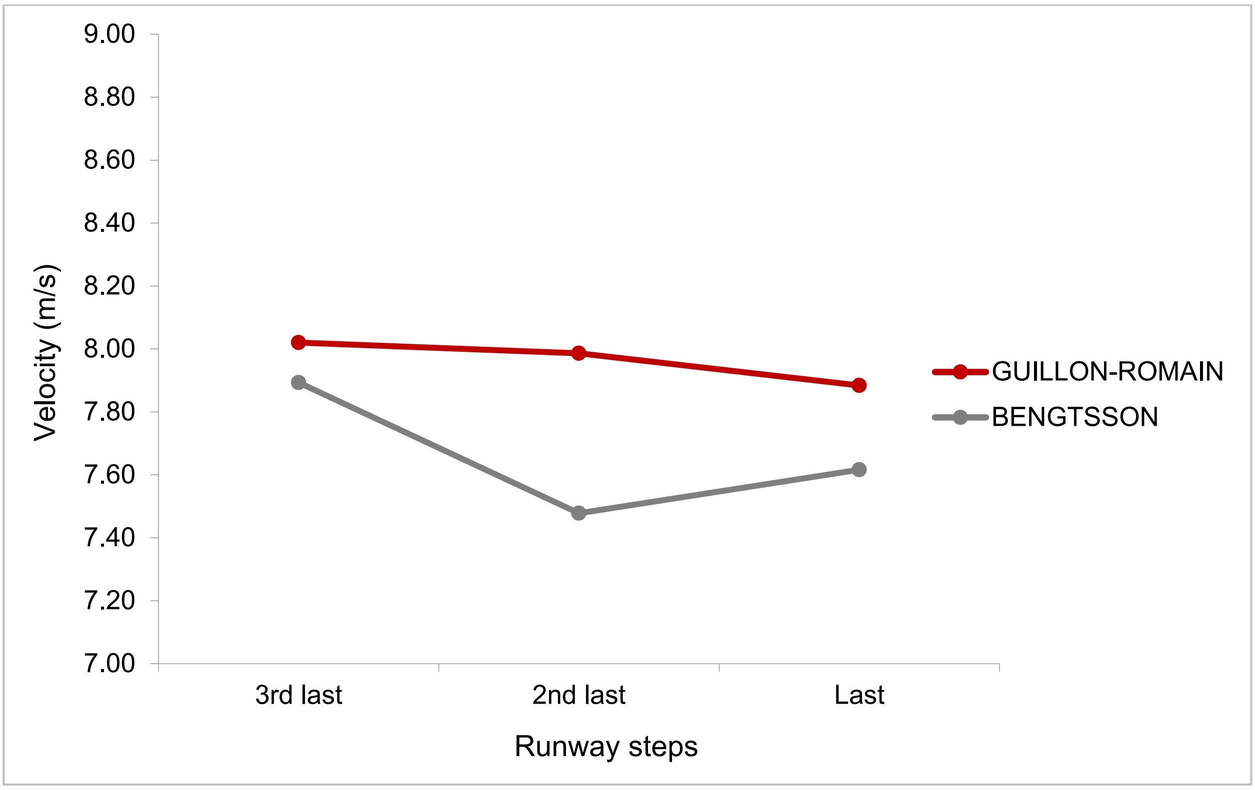

Figure 6. Velocity profiles of the athletes finishing tenth and eleventh during their last three steps.

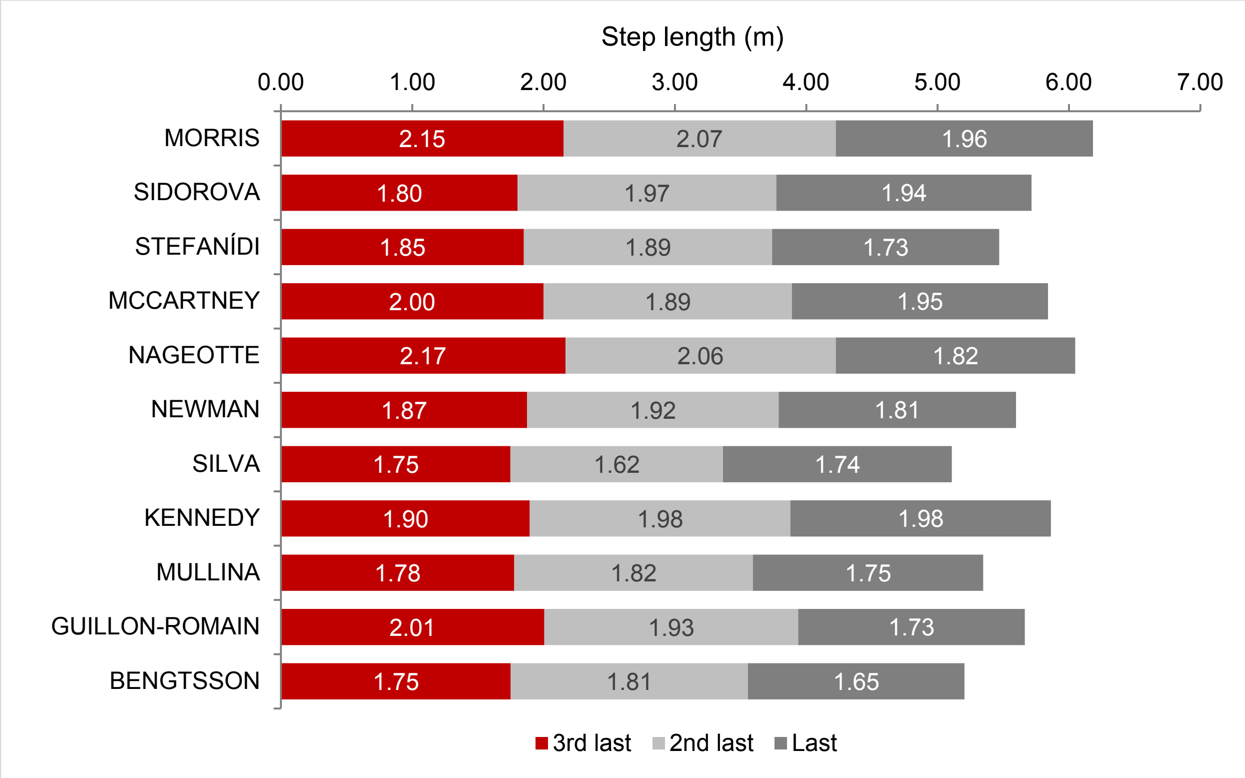

Figure 7. Step lengths of all athletes for the final three steps before take-off.

Figure 8. Take-off distance and last two step lengths of the athletes finishing first, second and third.

Figure 9. Take-off distance and last two step lengths of the athletes finishing fourth, fifth and sixth.

Figure 10. Take-off distance and last two step lengths of the athletes finishing seventh, eighth and ninth.

Figure 11. Take-off distance and last two step lengths of the athletes finishing tenth and eleventh.

Table 3 shows the horizontal velocity of the CM at pole plant and at take-off. Table 3 also shows how much change in velocity occurred between the time when the pole struck the back of the pit and the time of take-off.

Table 3. Characteristics of the last step and pole plant.

Athlete	Horizontal velocity at pole plant (m/s)	Horizontal velocity at take-off (m/s)	Change in velocity to take-off (m/s)
MORRIS	8.50	7.35	–1.15
SIDOROVA	8.25	7.60	–0.65
STEFANÍDI	8.53	6.97	–1.56
MCCARTNEY	8.08	6.79	–1.29
NAGEOTTE	8.48	7.13	–1.35
NEWMAN	8.15	6.31	–1.84
SILVA	7.85	6.74	–1.11
KENNEDY	7.76	6.35	–1.41
MULLINA	8.05	6.87	–1.18
GUILLON-ROMARIN	8.14	6.90	–1.24
BENGTSSON	7.89	6.64	–1.25

Table 4 shows the take-off parameters for each athlete. The take-off velocity shown is the resultant of the horizontal and vertical velocities at take-off, with the take-off angle calculated using those two values. Take-off distance was measured from the back of the pit to the toe of the take-off foot (this was the left foot for all athletes).

Table 4. Take-off characteristics.

Athlete	Take-off velocity (m/s)	Take-off angle (°)	Take-off distance (m)
MORRIS	7.75	18.6	3.61
SIDOROVA	8.02	18.5	3.95
STEFANÍDI	7.36	18.7	3.28
MCCARTNEY	7.13	17.8	3.68
NAGEOTTE	7.49	17.8	3.18
NEWMAN	6.85	22.9	3.64
SILVA	7.18	20.1	3.46
KENNEDY	6.73	19.3	3.71
MULLINA	7.19	17.2	3.47
GUILLON-ROMARIN	7.21	16.8	3.24
BENGTSSON	7.03	19.2	3.36

Table 5 shows the step length ratio (SLR) of the last two steps, where values below 1.0 indicate that the 2nd last step was longer than the last step. Only McCartney and Silva had last steps longer than the 2nd last step (Kennedy's were identical). The athletes' standing heights and the time from pole plant to take-off are also shown.

Table 5. Further characteristics of the take-off phase.

Athlete	SLR	Standing height (m)	Time from pole plant to take-off (s)
MORRIS	0.95	1.10	0.070
SIDOROVA	0.99	1.07	0.035
STEFANÍDI	0.92	1.09	0.085
MCCARTNEY	1.03	1.16	0.070
NAGEOTTE	0.89	1.09	0.120
NEWMAN	0.94	1.15	0.075
SILVA	1.08	1.07	0.045
KENNEDY	1.00	1.09	0.020
MULLINA	0.97	1.04	0.045
GUILLON-ROMARIN	0.89	1.07	0.085
BENGTSSON	0.91	1.06	0.060

Table 6 shows the angle of the pole during the last three steps (angle of carry) and at take-off (angle of attack), where negative values indicate that the end of the pole held by the vaulter was lower than the pole tip.

Table 6. Pole angles during the last three steps and at take-off.

Athlete	3rd last step pole angle (°)	2nd last step pole angle (°)	Last step pole angle (°)	Take-off pole angle (°)
MORRIS	–14.5	–1.7	19.2	28.7
SIDOROVA	–24.1	–9.8	13.4	27.9
STEFANÍDI	–3.9	4.0	22.4	29.0
MCCARTNEY	–17.0	–5.3	12.6	29.6
NAGEOTTE	–15.2	–4.0	23.3	28.5
NEWMAN	–14.3	1.5	21.6	30.3
SILVA	–5.0	2.8	18.7	30.2
KENNEDY	–12.3	–2.1	15.4	29.7
MULLINA	–18.6	–5.7	17.7	28.9
GUILLON-ROMARIN	–20.1	–9.4	19.8	27.6
BENGTSSON	–25.6	–6.3	20.5	28.9

On the following page, Figures 12 and 13 illustrate variables relating to handgrip at take-off. More specifically, Figure 12 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 13 shows the variety of grip widths adopted by the competitors during the final.

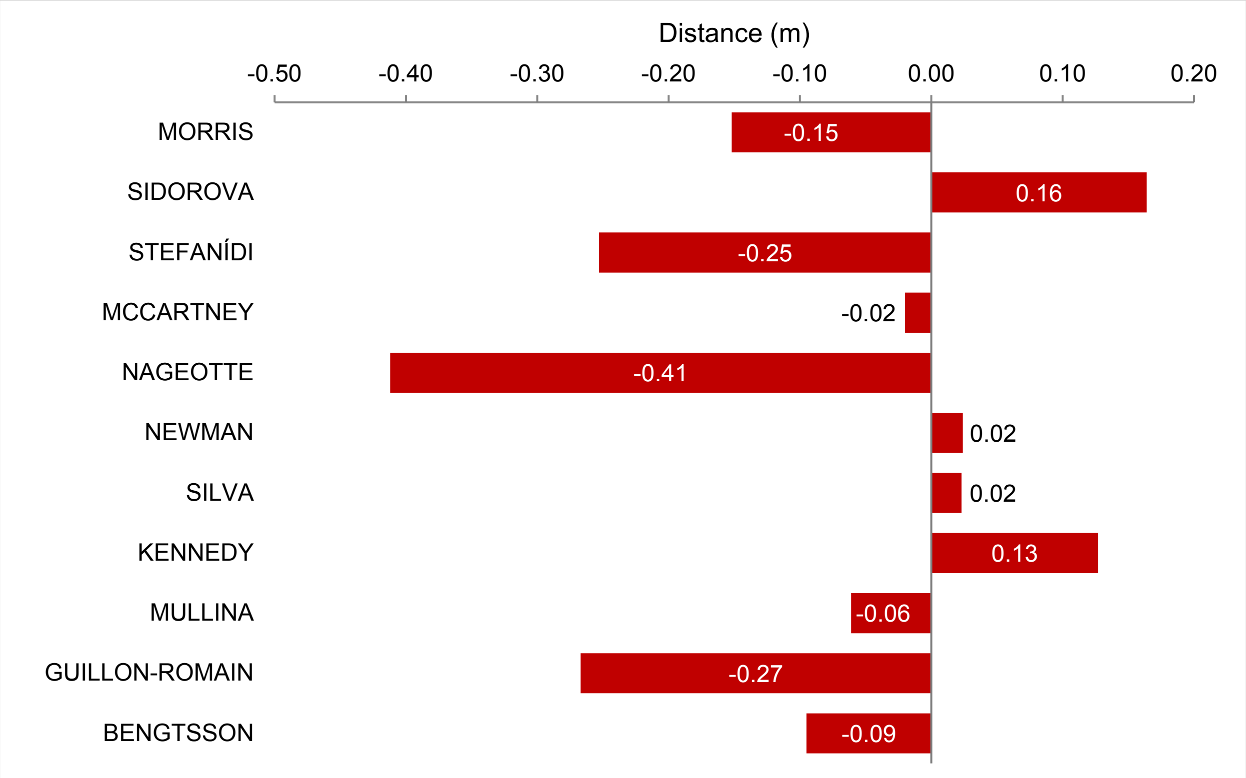

Figure 12. Take-off foot position (relative to upper grip position).

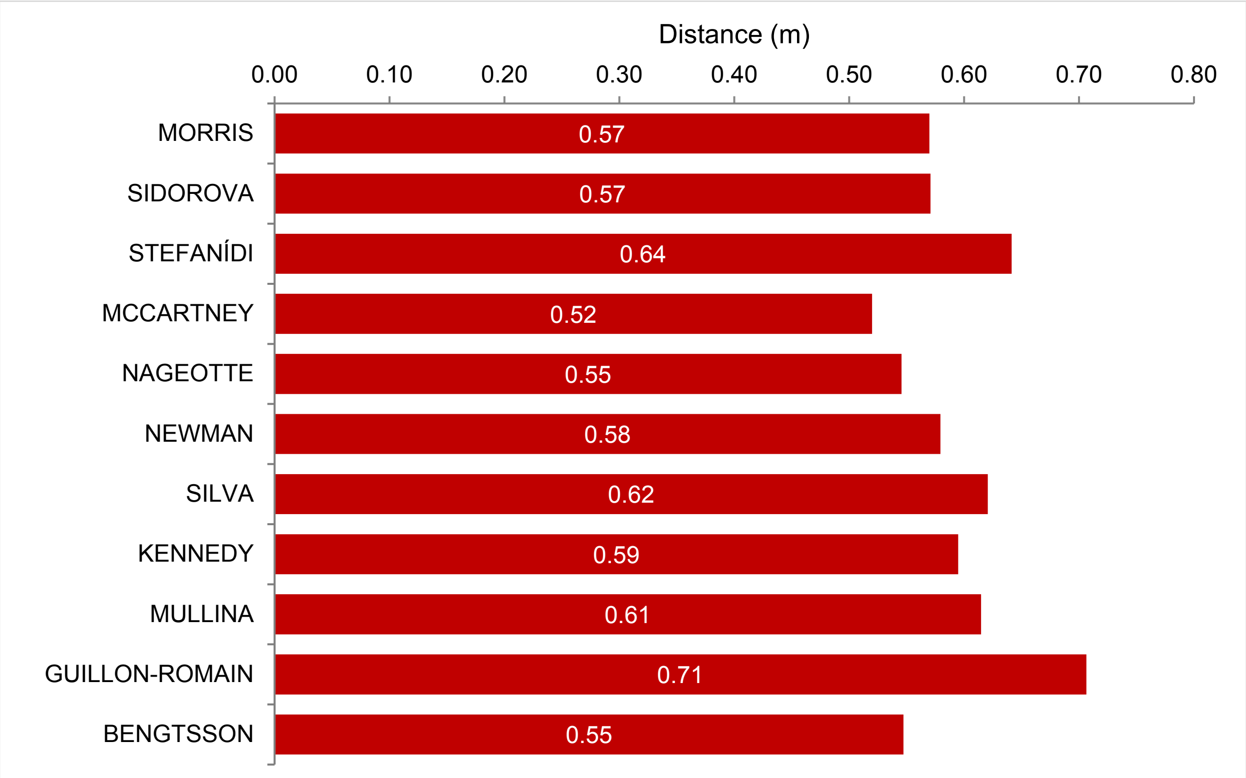

Figure 13. Grip widths for each athlete.

COACH'S COMMENTARY

The pole vault is one of the most spectacular field events in athletics. It combines typical athletic demands like sprinting and jumping with gymnastics and acrobatics. It is very helpful to have biomechanists at hand to learn from their results and findings to improve the performances of our athletes. What can we coaches learn from the results of biomechanics research, in this particular case to improve our athletes' performances?

To create a framework for this discussion, I would like to sketch a basic biomechanical concept for the pole vault. In a nutshell: mechanically, the pole vault requires the transformation of most kinetic energy (i.e., generated in the approach, during take-off and swing up, extension into inversion, turn and push off) into potential (location) energy (heightening of the centre of mass (CM) of an athlete) while still keeping enough horizontal energy to allow him or her to successfully clear the crossbar.

After the approach run, starting with the take-off from the ground and the planting of the pole in the box, this energy transformation process is practised in part directly (e.g., by swinging the body upwards and thus heightening the CM, the athlete is gaining potential location energy but losing kinetic energy accordingly), and in part indirectly, storing elastic energy in the bending pole and regaining it during the pole recoil.

However, not only is the pole storing and returning energy, the athlete's body itself is being used for short-time energy storage throughout the jump. For instance, in the so-called C-position shortly after take-off, some kinetic energy is not converted directly into location energy through heightening of the CM, but it is briefly stored in the athlete's body, straining the shoulder and trunk structures, using the stiffness properties of the muscle-tendon-ligament system, before being transformed into kinetic energy again as soon as the athlete is swinging the hips and legs forwards and upwards, finally creating the height needed for a good performance.

Although we know that energy storage in the modern glass fibre pole is quite efficient, returning around 95% of the initially stored energy, it is a very open question (and certainly related to the quality of the athlete's technical abilities) as to how much of the initially created energy might be lost because of mechanically ineffective technical behaviour, or might be gained because of optimised technical behaviour.

From former scientific projects, we have learned three conclusions in this respect:

- First, most athletes at the international performance standard are able to create a net gain of energy during their jumps within the range of 1 to 5 J/kg of bodyweight. However, athletes with very good technical abilities are able to create up to 8 J/kg of bodyweight and even more!
- Second, interestingly, most of the fastest pole vaulters are not able to come close to these numbers, as sometimes even medallists at the global level create a net loss of energy during their jumps! It seems that we have to conclude that it is very hard for the fastest pole vaulters (men > 9.5 m/s, women > 8.5 m/s) to work mechanically as effectively as slower pole vaulters.
- Third, these findings are similar for male and female athletes.

Coming back to our initial question, what can we learn from the specific results at the World Indoor Championships 2018 in Birmingham?

As we do not have data concerning the upper jump phases for this competition (after the take-off until the highest point of the jump), we cannot discuss the complete mechanical efficiency of the athletes and their techniques. Instead, we have to concentrate on the data for their approach, pole plant and take-off.

This gives us the opportunity to look at the findings related to the approach, especially in the last part, the various pole planting and take-off styles. As these phases are considered by most coaches and athletes to be the most fundamental, and which decide the success of the vault, this report gives us a good insight into the technical development standards and trends at this time. We have to keep in mind, however, that these results just reflect the athletes' behaviours in their best jump within this competition. One single jump might not reflect the typical technique of an athlete, e.g., he might have been adapting stride patterns based on the competition conditions.

One particular aspect of interest is the concept of the "free take-off", developed by the late Soviet school of pole vaulting during the 1980s as a requirement for outstanding results. It proposes that the planting of the pole into the box should take place towards the end of the take-off support phase, thus giving good mechanical conditions for a successful take-off with an immediate start of the bending of the pole.

Pole Vault Final, World Indoor Championships

The women's pole vault, being less than 20 years as part of a global athletics championship, showed some interesting developments. That six women jumped 4.70 m or higher, and a new Championship Record was achieved, were proof of an ongoing dynamic development in the women's pole vault. It remains to be discussed, however, how "mature" the female pole vault is at this time. Some 14 years ago, a woman first achieved 5 m and many coaches thought this would be the beginning of a real wave of 5 m results. As we know by now, this has not happened yet: medals at World Championships are still won with heights well below 5 m.

Over the last 30 years, it seemed that the women's pole vault would attract a new female athletic type to our sport: not as tall as a thrower or heptathlete, nor as fast as a sprinter or long jumper, but able to integrate sufficient speed, strength and gymnastic abilities into strong performances, close to or even higher than 5 m. At least two athletes from this final, the winner Sandi Morris and fifth-placed Katie Nageotte, both from the USA, seem to present a new type of female pole vaulter: taller, stronger and faster than most of their rivals, with lots of technical reserves for further improvement!

Approach data

Similar to the men's pole vault, once again approach velocity proved to be a necessary ingredient for a medal in the women's pole vault at this World Indoor Championships. The four fastest athletes were ranked among the top five placed athletes in this competition, only allowing Olympic bronze medallist Eliza McCartney, who used only 12 steps in her approach, to finish amongst them. Most athletes used 16 steps, with no one taking more than 16, but Eliza McCartney seems especially to follow a long-term strategy of building up a solid technique, based on her strong physical qualities, being 1.80 m tall and having a solid gymnastics background. As soon as she extends her approach to 14 or 16 steps, she will be able to come close to the World Record.

Similar to the men's pole vault, there are interesting relationships between the different speed marks from "runway velocity" to "pole plant velocity" and "take-off velocity". The least velocity loss was produced by Anzhelika Sidorova, an Authorised Neutral Athlete with her roots deeply in the successful Russian pole vault tradition, winning the silver medal. She follows very closely the "Russian school" of pole vault technique, combining an "active pole drop" with a "free take-off", being a remarkable 15 cm "out". This gives her a very powerful swing after take-off (thus producing more kinetic energy through the "upper" part of the jump compared with "tuck and shoot") and the ability to successfully compete against athletes with considerably better physical abilities (e.g., reaching height, speed).

The female pole vaulters seemed to lose less kinetic energy during take-off than the men, as a comparison of Table 3 in this report with the same data in the men's report shows clearly. The reason for this is not quite clear; it might be related to their lower velocities in general, but also to relatively lower grips on relatively softer poles, compared with the men.

For the reigning World Champion, Katerina Stefanídi, the speed loss during her take-off was bigger than in the outdoor World Championships the year before, and might have caused her not to win this time. As the data cover only one jump, it remains unclear whether this was a trend in her development or just a “spike” in this particular jump in this particular competition.

Pole plant and take-off data

The pole angles during the last steps until the take-off show a similar pattern to the men’s competition. The spread is not quite as big, though, in the 3rd last step. Interestingly, for the women the pole angles at take-off are higher than for the men. This could be seen as an indicator that for the relatively “young” women’s pole vault, the development of important technical criteria like grip height (relative to reaching height and approach speed) is not mature yet.

The profiles of the development of velocities during the last three steps does not show a clear picture here, related to the performances in this competition. We can say that the medal-winning athletes show some acceleration into the last step that is not as clear for athletes ranking below them. Sometimes, however, this was managed only after a slight deceleration in the penultimate step.

As the development of step length during the last three steps cannot be discussed in depth, it is not possible to find a clear performance related pattern here. All in all, the two fastest athletes in this competition, Nageotte and Morris, have considerably longer last steps than in the penultimate steps that might be a sign of a technical deficit, caused by the high speed they generate in their approach.

Similar to the men’s pole vault, there seems to be a clear relationship between grip width and take-off position, allowing athletes with a take-off farther away to use a narrower grip than for athletes with closer take-off spots. Further through the jump, this narrower grip might help a more powerful swing on the pole, producing more additional energy during this phase than compared with the “tuck-and-shoot” technique. It would be very interesting to further discuss these data in the context of a more complete biomechanical overview than is possible here.

Development trends:

- The women’s pole vault is still developing faster than the men’s pole vault. There is still room for new athletic types with gymnastics backgrounds as well as for more heptathlon-type athletes like Nageotte or Morris.
- The future might be for taller, but still light-weight and faster athletes, than most of the female athletic base at the moment, but only for those who master the technical and athletic demands more completely than at the moment.

In particular, the ability to develop better approach velocities and the ability to transform this kinetic energy base into a sound technique on the pole requires better technical skills and special strength properties than many of the current female pole vaulters are able to deliver.

CONTRIBUTORS

Dr Brian Hanley is a Senior Lecturer in Sport and Exercise Biomechanics. Brian's particular research interests are in the area of elite athletics, especially race walking and distance running, as well as the pacing profiles adopted by endurance athletes. He is also interested in musculotendon profiling of athletes to appreciate internal limiting and contributing factors affecting performance, in addition to longitudinal studies measuring the technical development of junior athletes as they progress to become senior athletes.

Helen Gravestock is a Lecturer in Sport and Exercise Biomechanics at Leeds Beckett University, and is a BASES probationary sport and exercise scientist in biomechanics. Helen has a First Class Honours degree in BSc Sport and Exercise Science, and an MSc in Applied Sport Science from the University of Worcester. Helen's research interests include the biomechanics of race walking, gait and 3D motion capture. Previously, Helen has provided applied biomechanical support to British Athletics and British Gymnastics during competition.

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 he team he has produced over 100 research outputs and he is actively involved in research projects with institutions across Europe.

Herbert Czingon is the National Coach for Pole Vault for Switzerland, coaching (among others) Angelica Moser, the U20 World Champion in 2016 and the U23 European Champion in 2017, who has a PB of 4.61 m. He has previously been the National Pole Vault Coach for Germany and the Head of DLV Coaches Education, and since 2004 has organised and lectured at every European Pole Vault Symposium, held in Cologne. Herbert is also an IAAF Coaches Education and Certification System Lecturer in Jumps and Combined Events.