IAAF World Indoor Championships
BIRMINGHAM 2018
1–4 MARCH

# BIOMECHANICAL REPORT

FOR THE

IAAF

WORLD INDOOR CHAMPIONSHIPS 2018

## Pole Vault Men


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# INTRODUCTION

The men's pole vault took place on the afternoon of Sunday 4th March. With no qualifying rounds preceding the final, a large field of 15 men took part. World Record holder Renaud Lavillenie won gold with his second attempt at 5.90 m, with Sam Kendricks winning silver on countback from Piotr Lisek. There were personal best performances at 5.80 m for Kurtis Marschall and Emmanouil Karalís, with all athletes clearing at least one height. 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 Men - Final

| RECORDS | RESULT | NAME | COUNTRY | AGE | VENUE | DATE |
|---|---|---|---|---|---|---|
| World Indoor Record WIR | 6.16 | Renaud LAVILLENIE | FRA | 28 | Donetsk (Sport Palace Druzhba) | 15 Feb 2014 |
| Championship Record CR | 6.02 | Renaud LAVILLENIE | FRA | 30 | Portland (Oregon Convention Center), OR | 17 Mar 2016 |
| World Leading WL | 5.93 | Renaud LAVILLENIE | FRA | 32 | Clermont-Ferrand (FRA) | 25 Feb 2018 |
| World Leading WL | 5.93 | Sam KENDRICKS | USA | 26 | Clermont-Ferrand (FRA) | 25 Feb 2018 |

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

4 March 2018 15:01 START TIME
18:24 END TIME

| PLACE | NAME | COUNTRY | DATE of BIRTH | ORDER | RESULT | | 5.45 | 5.60 | 5.70 | 5.80 | 5.85 | 5.90 | 5.95 | 6.00 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Renaud LAVILLENIE | FRA | 18 Sep 86 | 15 | 5.90 | | - | - | O | - | O | XO | - | XXX |
| 2 | Sam KENDRICKS | USA | 7 Sep 92 | 14 | 5.85 | | O | O | O | X- | O | XX- | X | |
| 3 | Piotr LISEK | POL | 16 Aug 92 | 13 | 5.85 | | - | XO | - | X- | O | XXX | | |
| 4 | Kurtis MARSCHALL | AUS | 25 Apr 97 | 8 | 5.80 | PB | XO | O | O | O | X- | XX | | |
| 5 | Raphael HOLZDEPPE | GER | 28 Sep 89 | 10 | 5.80 | | O | XO | XO | O | X- | XX | | |
| 5 | Emmanouíl KARALÍS | GRE | 20 Oct 99 | 5 | 5.80 | PB | XO | O | XO | O | X- | XX | | |
| 7 | Armand DUPLANTIS | SWE | 10 Nov 99 | 12 | 5.70 | | O | XO | O | X- | X- | X | | |
| 7 | Konstadínos FILIPPÍDIS | GRE | 26 Nov 86 | 1 | 5.70 | | XO | O | O | X- | XX | | | |
| 9 | Melker SVÄRD JACOBSSON | SWE | 8 Jan 94 | 4 | 5.70 | | O | XXO | XO | XX- | X | | | |
| 10 | Axel CHAPELLE | FRA | 24 Apr 95 | 7 | 5.60 | | O | O | XXX | | | | | |
| 11 | Changrui XUE | CHN | 31 May 91 | 6 | 5.60 | | O | XO | XXX | | | | | |
| 12 | Thiago BRAZ | BRA | 16 Dec 93 | 11 | 5.60 | | - | XXO | - | XXX | | | | |
| 13 | Scott HOUSTON | USA | 11 Jun 90 | 3 | 5.60 | | XO | XXO | XXX | | | | | |
| 13 | Pawel WOJCIECHOWSKI | POL | 6 Jun 89 | 9 | 5.60 | | XO | XXO | XXX | | | | | |
| 15 | Shawnacy BARBER | CAN | 27 May 94 | 2 | 5.45 | | O | XXX | | | | | | |

Timing and Measurement by SEIKO AT-PV-M-f--A--.RS1..v1 Issued at 18:26 on Sunday, 04 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 men'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.

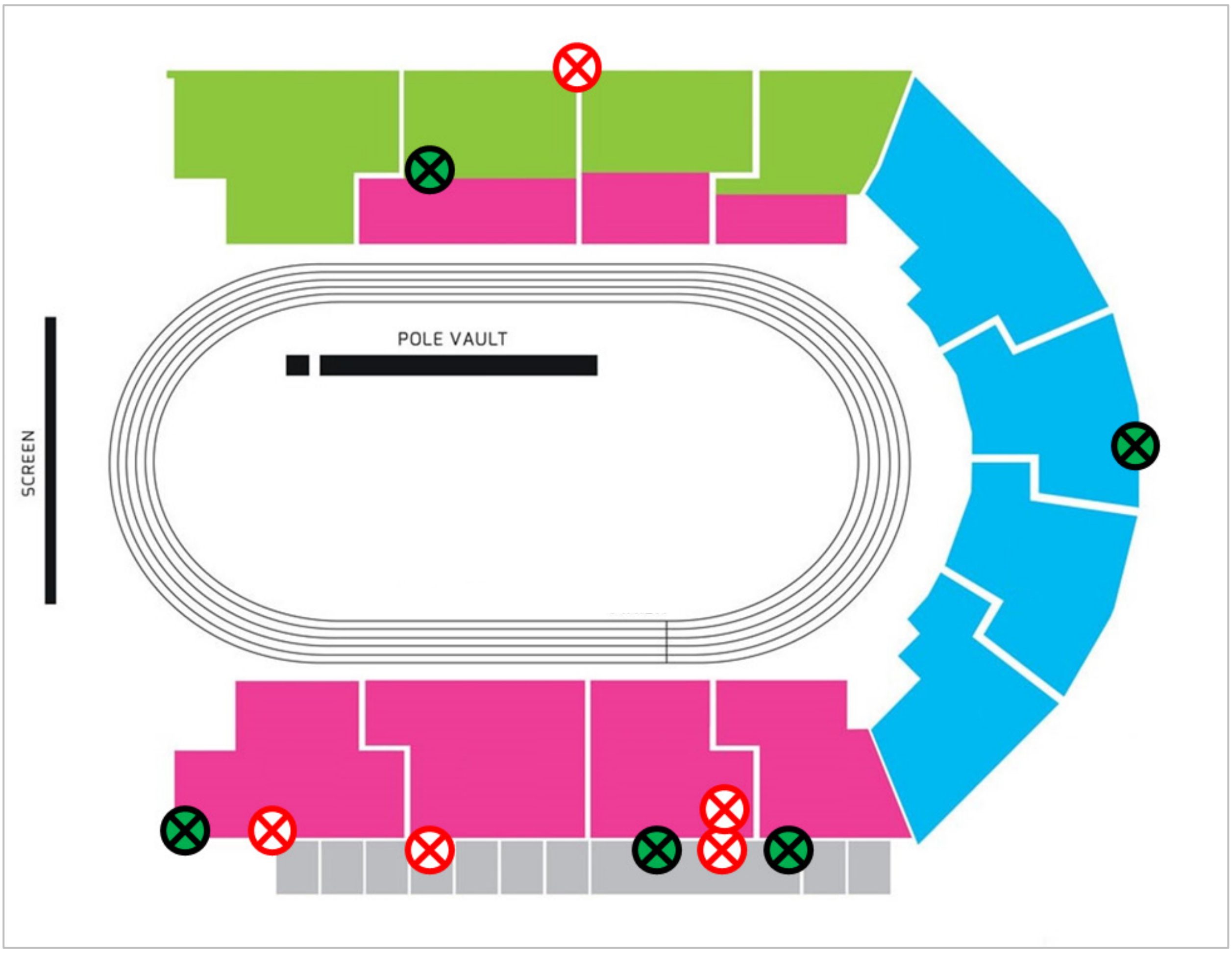


Figure 1. Camera layout for the men's pole vault indicated by green-filled circles.

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 (11-6 m away from the plant box). |
| **3$^{rd}$ 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. |
| **2$^{nd}$ last step length** | The toe-off to toe-off distance of the step immediately before the last step. |
| **2$^{nd}$ last step velocity** | The mean CM horizontal velocity during the step immediately before the last step. |
| **3$^{rd}$ last step length** | The toe-off to toe-off distance of the third last step before take-off. |
| **3$^{rd}$ 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.*

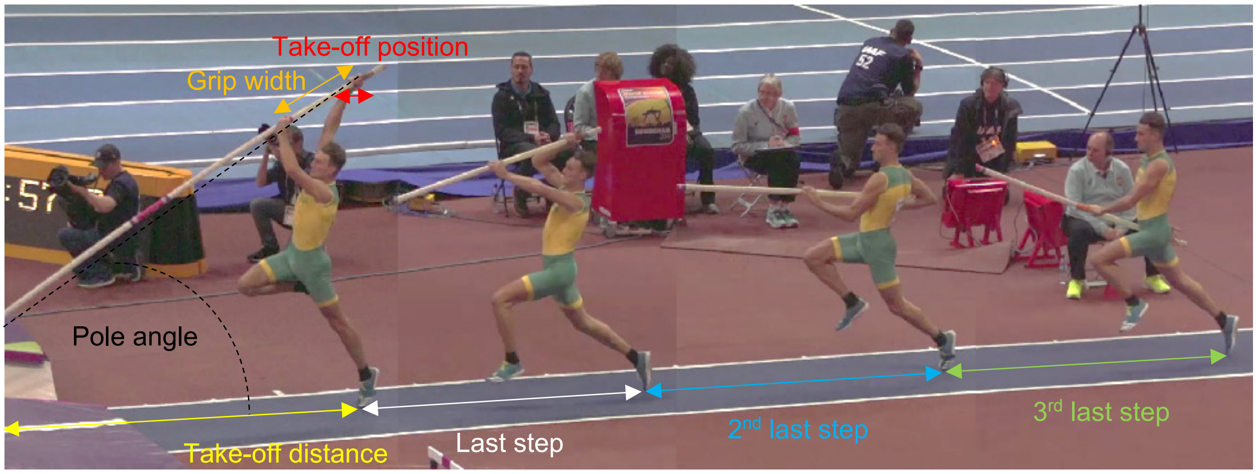

Figure 2. Final three steps in the approach phase of the pole vault with visual definitions of the variables.

# 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 11 and 6 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 nearly all athletes were within 11 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) |
|---|---|---|---|
| **LAVILLENIE** | 21 | 9.23 | 10.93 |
| **KENDRICKS** | 18 | 8.99 | 10.15 |
| **LISEK** | 16 | 8.71 | 10.47 |
| **MARSCHALL** | 18 | 9.05 | 11.05 |
| **HOLZDEPPE** | 18 | 9.59 | 10.92 |
| **KARALÍS** | 20 | 9.05 | 10.53 |
| **DUPLANTIS** | 18 | 9.33 | 10.25 |
| **FILIPPÍDIS** | 20 | 9.35 | 10.43 |
| **SVÄRD JACOBSSON** | 18 | 9.00 | 10.05 |
| **CHAPELLE** | 24 | 8.81 | 10.00 |
| **XUE** | 18 | 9.25 | 10.97 |
| **BRAZ** | 18 | 9.22 | 10.82 |
| **HOUSTON** | 18 | 9.18 | 10.79 |
| **WOJCIECHOWSKI** | - | 9.00 | 10.69 |
| **BARBER** | 20 | 8.98 | 10.18 |

***Note:*** *It was not possible to calculate Wojciechowski's total number of run-up steps.*

Because the results showed that athletes were at different stages of their run-up with 11 m remaining, their run-up velocities have been calculated separately for the 3rd last, 2nd last and last steps in Figures 3-7 below. Figure 8 shows the step lengths for the last three steps, and Figures 9-13 show visually the last two step lengths and take-off distance for each athlete.

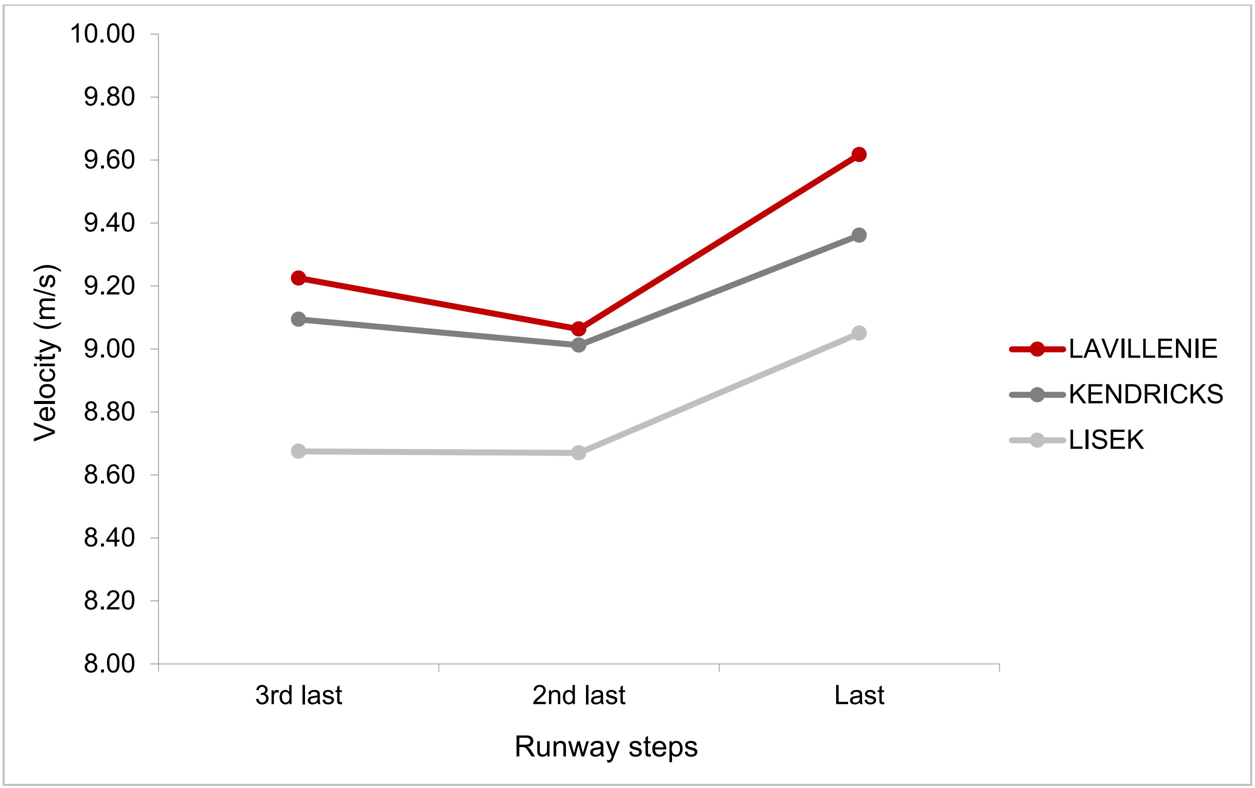


Figure 3. Velocity profiles of the athletes finishing first, second and third during their last three steps.

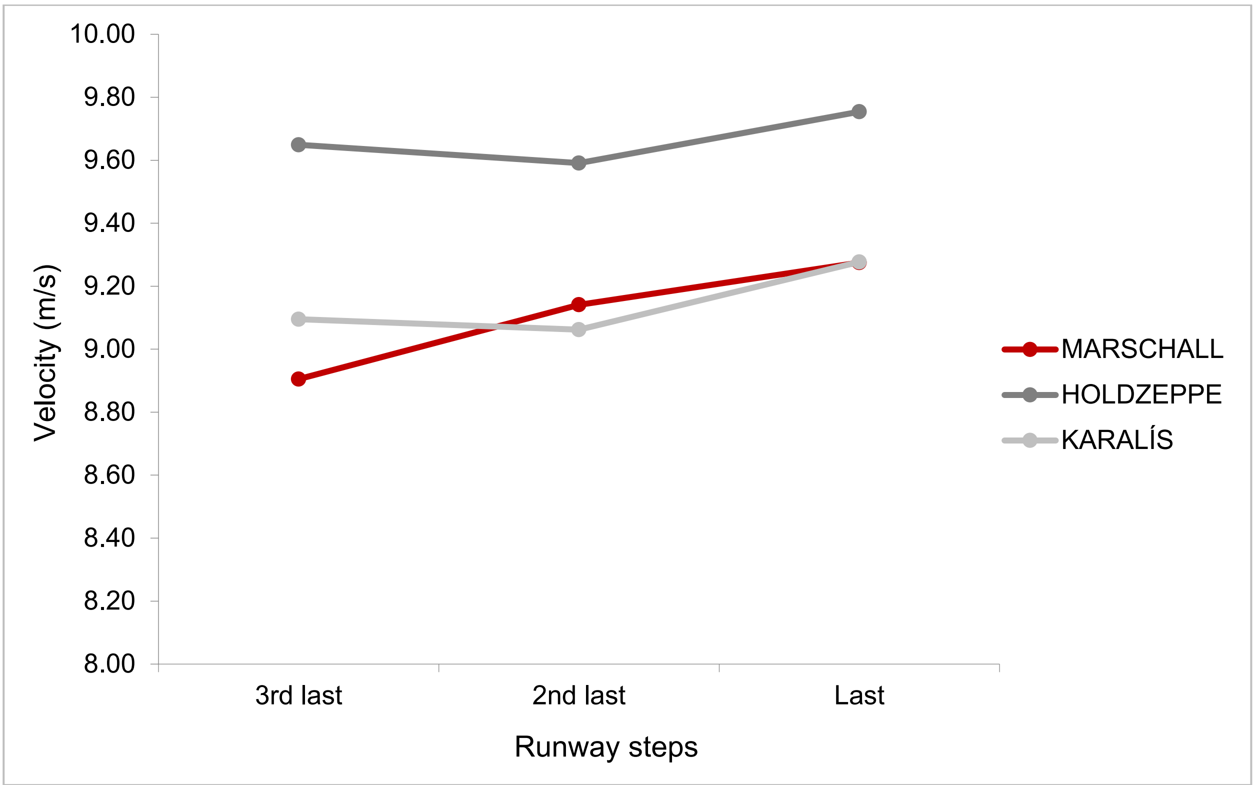


Figure 4. Velocity profiles of the athletes finishing fourth, fifth and sixth during their last three steps.

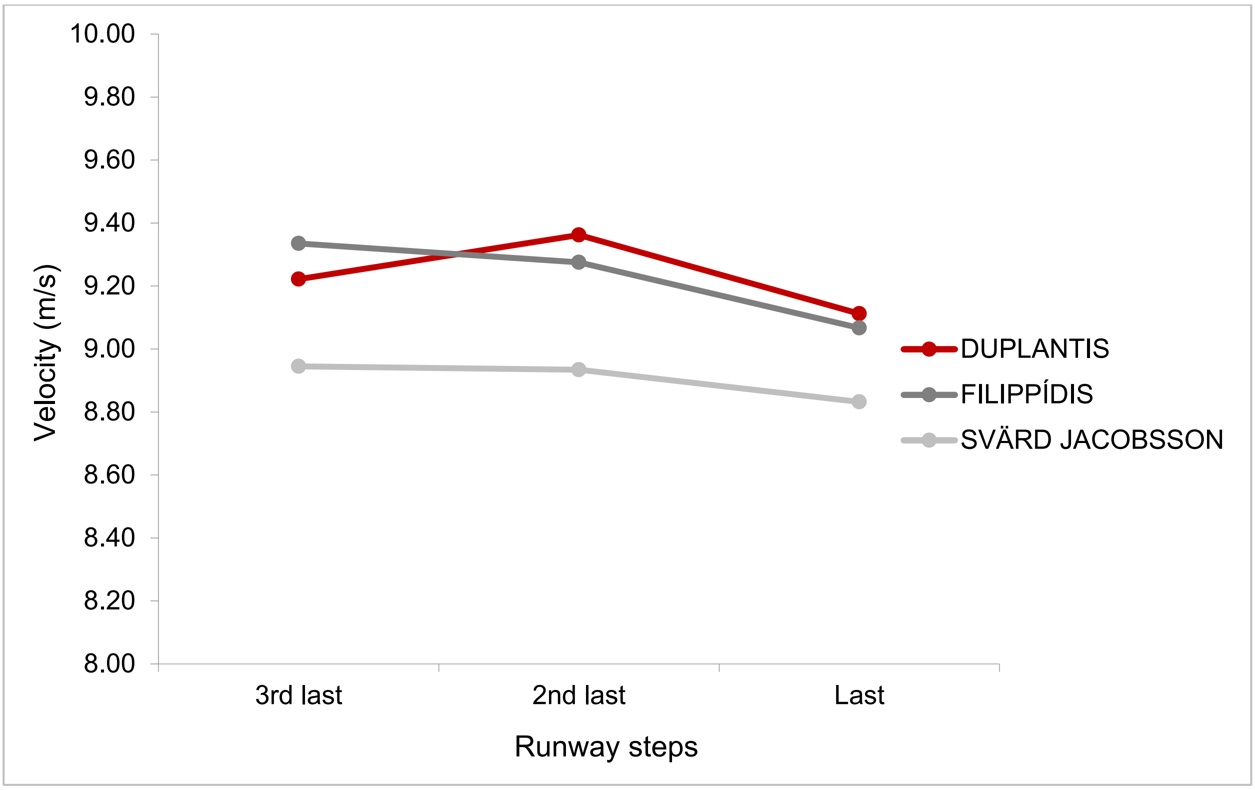


Figure 5. Velocity profiles of the athletes finishing seventh, eighth and ninth during their last three steps.

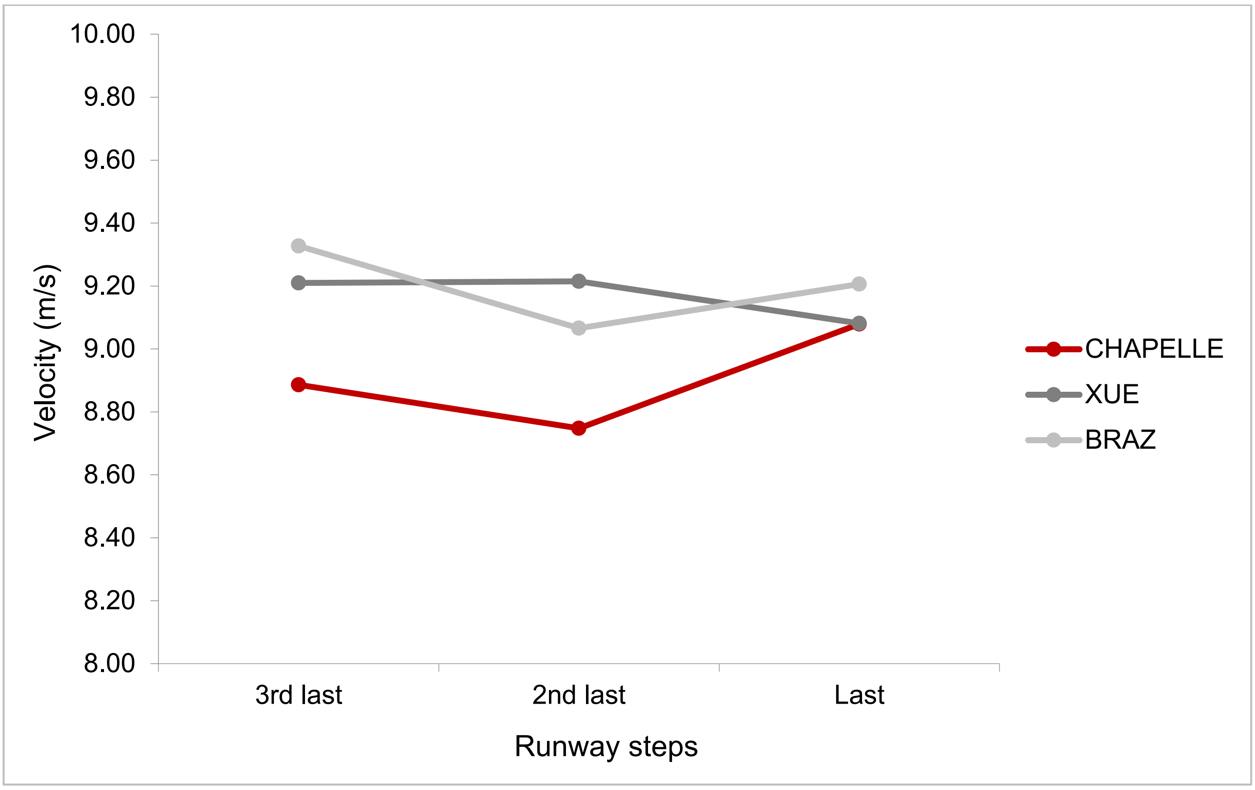


Figure 6. Velocity profiles of the athletes finishing tenth, eleventh and twelfth during their last three steps.

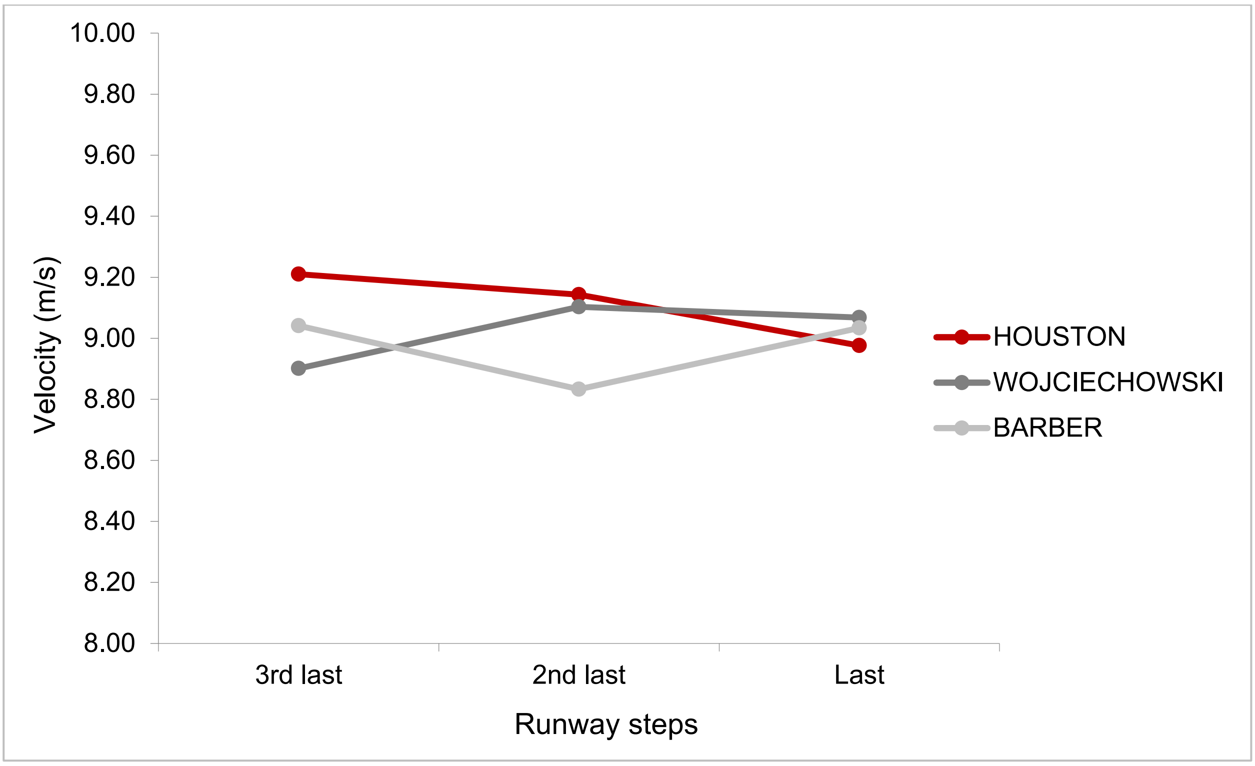


Figure 7. Velocity profiles of the athletes finishing thirteenth, fourteenth and fifteenth during their last three steps.

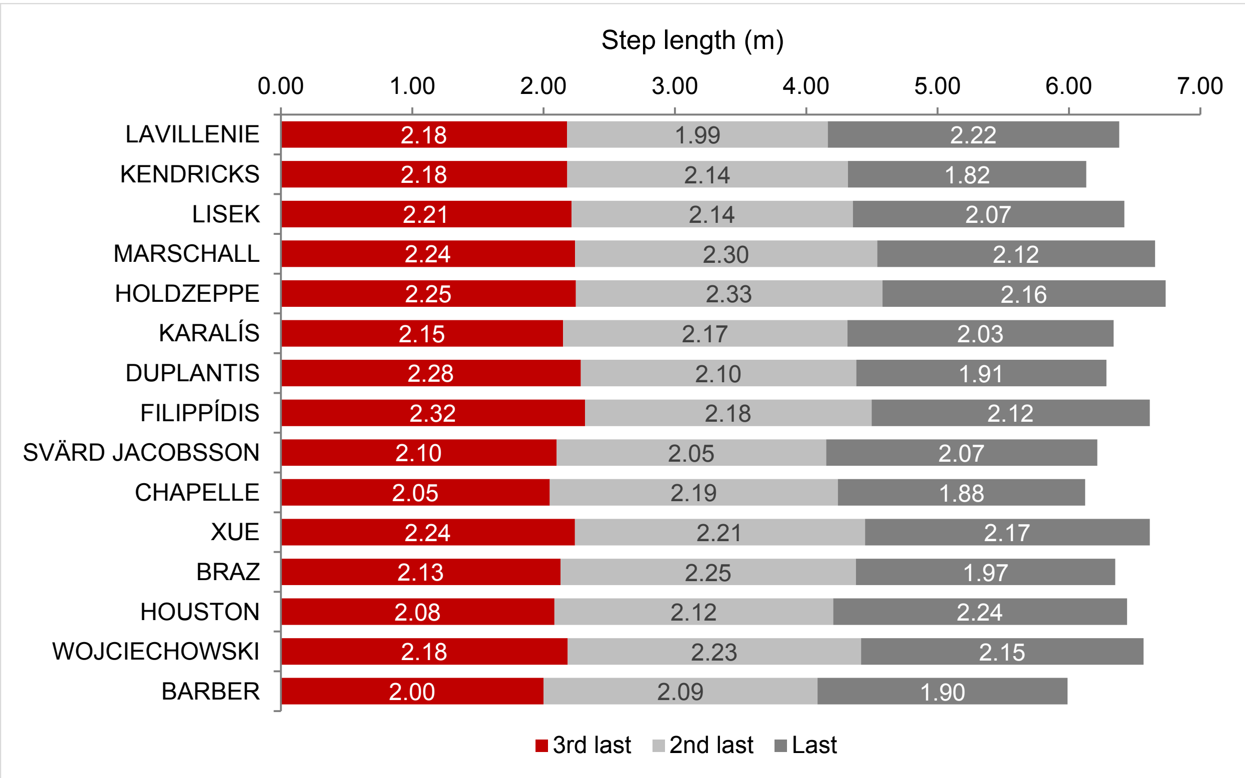


Figure 8. Step lengths of all athletes for the final three steps before take-off.

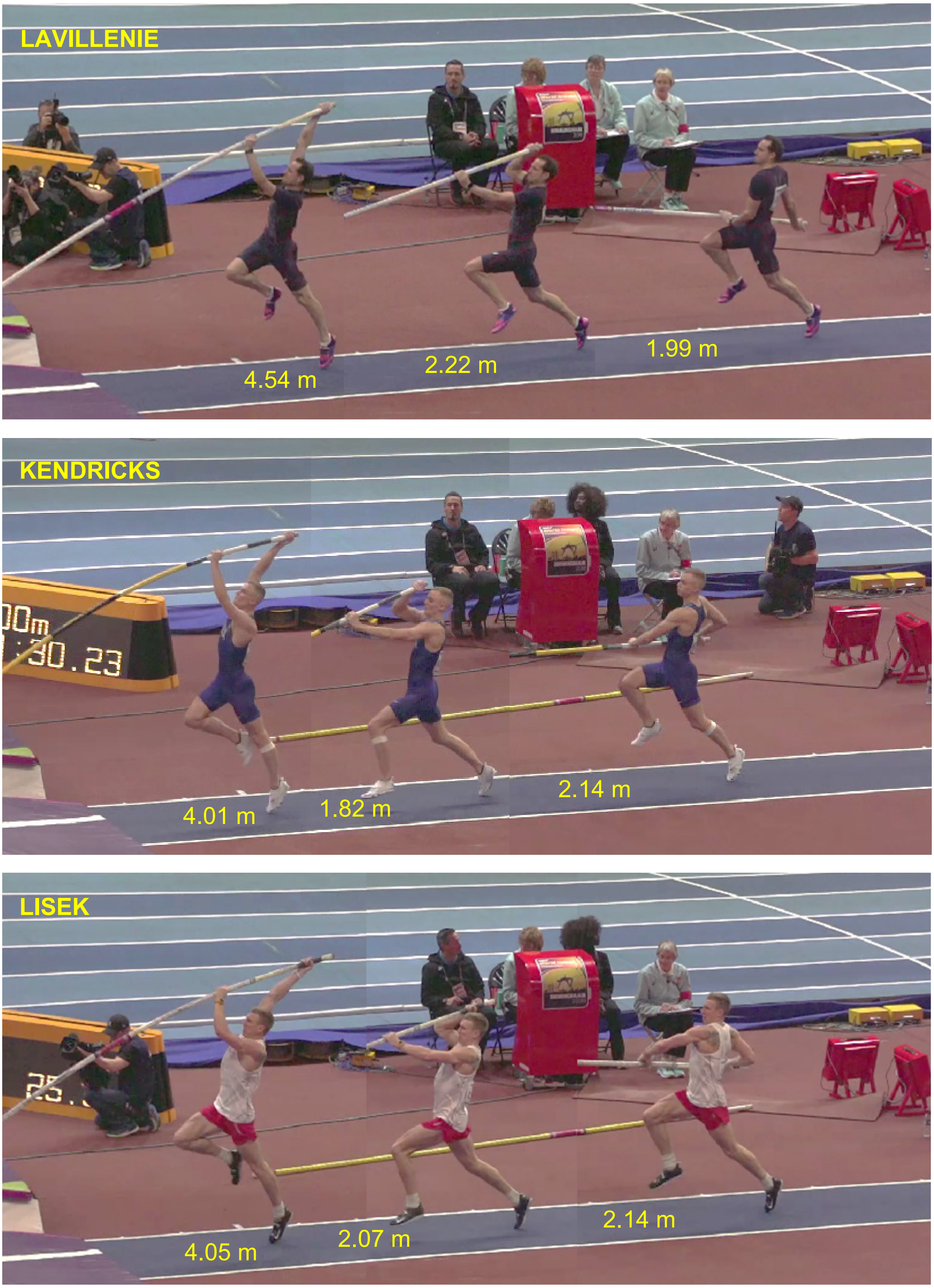


Figure 9. Take-off distance and last two step lengths of the athletes finishing first, second and third.

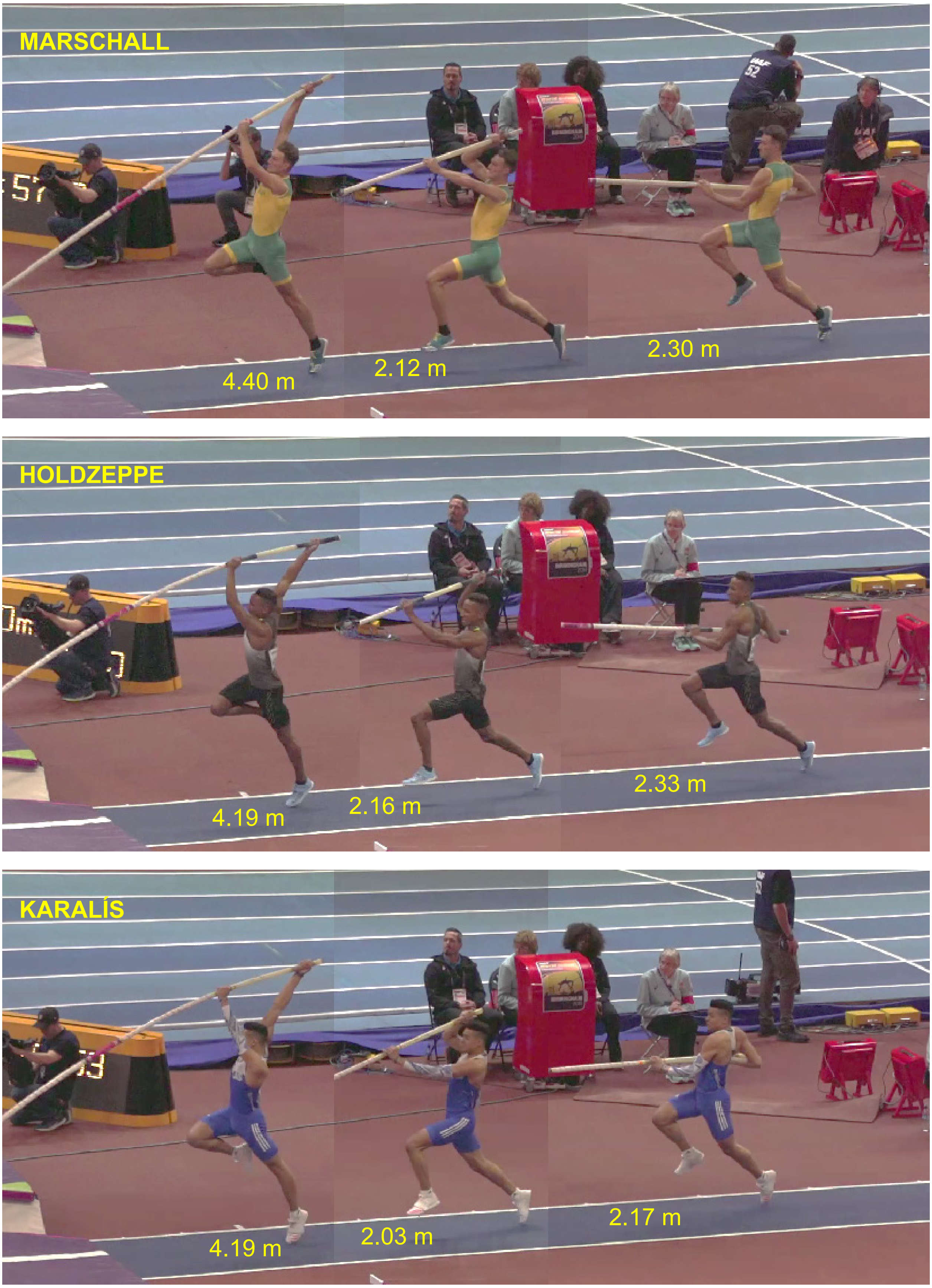


Figure 10. Take-off distance and last two step lengths of the athletes finishing fourth, fifth and sixth.

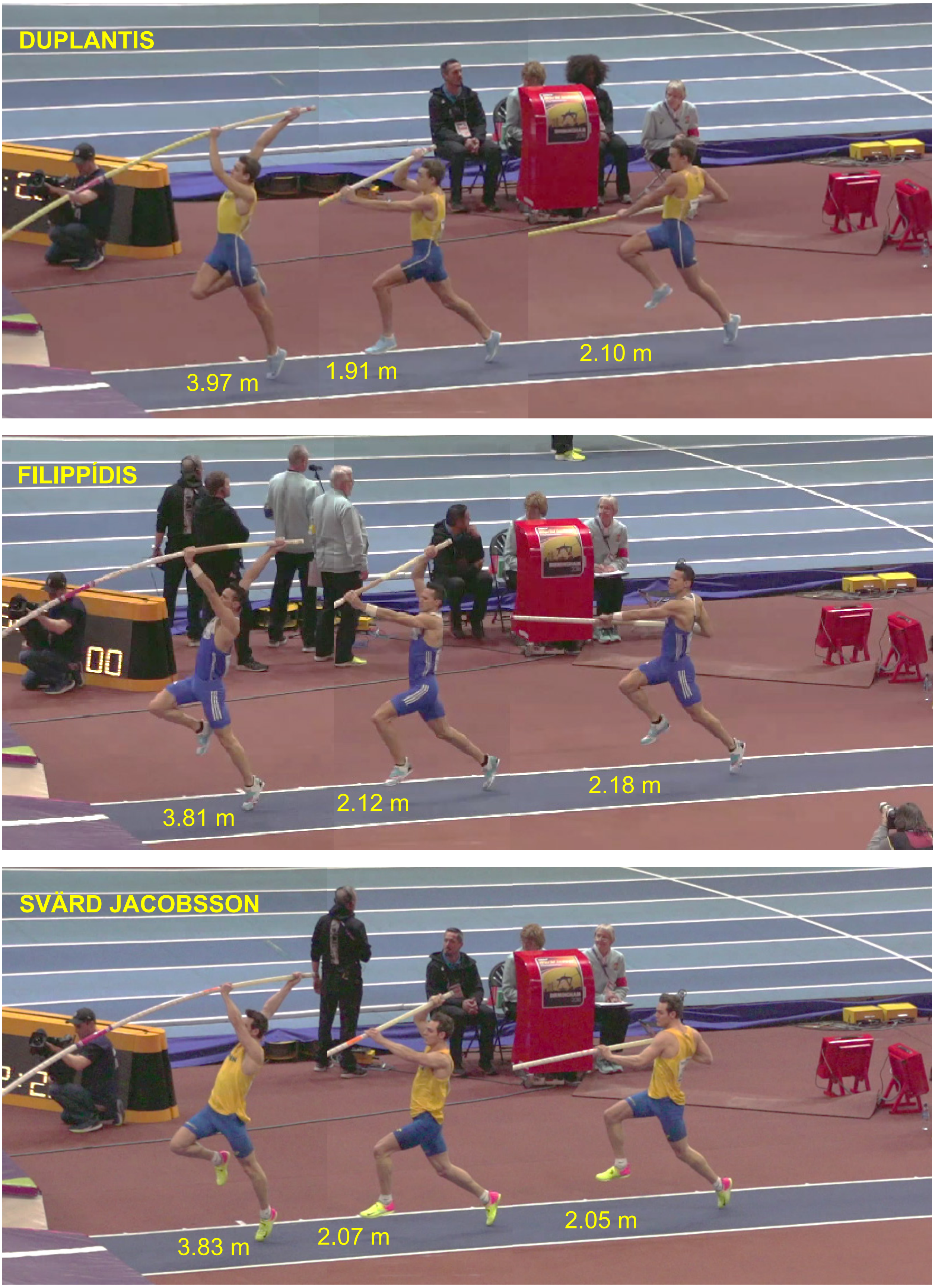


Figure 11. Take-off distance and last two step lengths of the athletes finishing seventh, eighth and ninth.


Figure 12. Take-off distance and last two step lengths of the athletes finishing tenth, eleventh and twelfth.

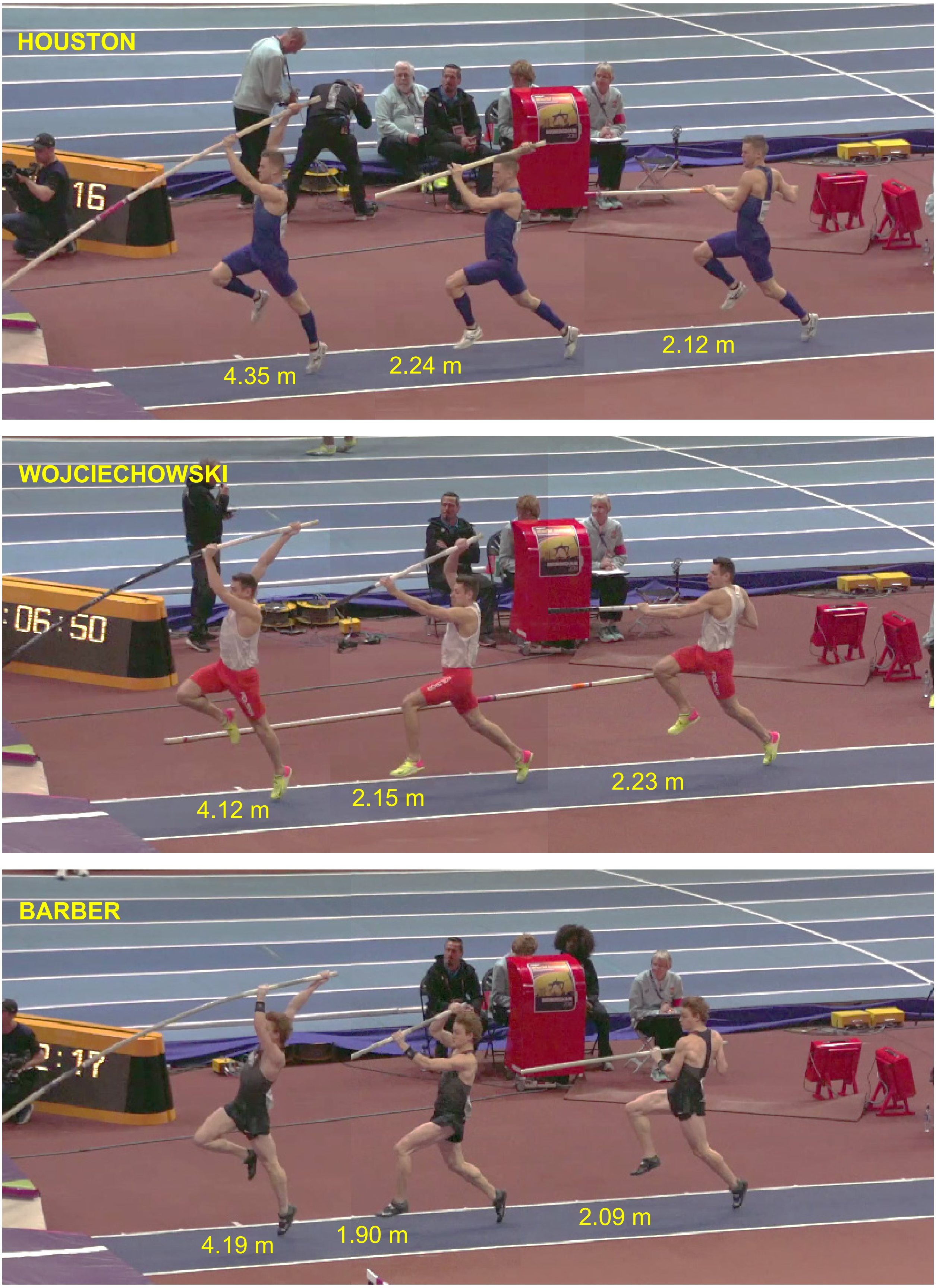


Figure 13. Take-off distance and last two step lengths of the athletes finishing thirteenth, fourteenth and fifteenth.

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) |
|---|---|---|---|
| **LAVILLENIE** | 9.66 | 8.59 | –1.07 |
| **KENDRICKS** | 9.72 | 7.82 | –1.90 |
| **LISEK** | 9.31 | 7.79 | –1.52 |
| **MARSCHALL** | 9.36 | 8.11 | –1.25 |
| **HOLZDEPPE** | 10.10 | 7.88 | –2.22 |
| **KARALÍS** | 9.40 | 7.85 | –1.55 |
| **DUPLANTIS** | 9.37 | 7.68 | –1.69 |
| **FILIPPÍDIS** | 9.54 | 7.50 | –2.04 |
| **SVÄRD JACOBSSON** | 9.11 | 7.74 | –1.37 |
| **CHAPELLE** | 9.26 | 8.11 | –1.15 |
| **XUE** | 9.21 | 8.21 | –1.00 |
| **BRAZ** | 9.35 | 7.95 | –1.40 |
| **HOUSTON** | 9.13 | 7.26 | –1.87 |
| **WOJCIECHOWSKI** | 9.33 | 7.40 | –1.93 |
| **BARBER** | 9.41 | 7.17 | –2.24 |

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) |
|---|---|---|---|
| **LAVILLENIE** | 9.01 | 17.5 | 4.54 |
| **KENDRICKS** | 8.32 | 19.9 | 4.01 |
| **LISEK** | 8.23 | 19.0 | 4.05 |
| **MARSCHALL** | 8.50 | 17.5 | 4.40 |
| **HOLZDEPPE** | 8.40 | 20.2 | 4.19 |
| **KARALÍS** | 8.23 | 17.5 | 4.19 |
| **DUPLANTIS** | 8.10 | 18.4 | 3.97 |
| **FILIPPÍDIS** | 7.89 | 18.1 | 3.81 |
| **SVÄRD JACOBSSON** | 8.31 | 21.2 | 3.83 |
| **CHAPELLE** | 8.43 | 15.8 | 3.87 |
| **XUE** | 8.63 | 17.9 | 4.35 |
| **BRAZ** | 8.49 | 20.5 | 4.47 |
| **HOUSTON** | 7.60 | 17.1 | 4.35 |
| **WOJCIECHOWSKI** | 7.81 | 18.7 | 4.12 |
| **BARBER** | 7.64 | 20.1 | 4.19 |

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 Lavillenie, Svärd Jacobsson and Houston had last steps longer than the second last step. 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) |
|---|---|---|---|
| LAVILLENIE | 1.12 | 1.17 | 0.020 |
| KENDRICKS | 0.85 | 1.24 | 0.075 |
| LISEK | 0.96 | 1.28 | 0.065 |
| MARSCHALL | 0.92 | 1.29 | 0.030 |
| HOLZDEPPE | 0.92 | 1.22 | 0.055 |
| KARALÍS | 0.94 | 1.23 | 0.070 |
| DUPLANTIS | 0.91 | 1.22 | 0.075 |
| FILIPPÍDIS | 0.97 | 1.25 | 0.105 |
| SVÄRD JACOBSSON | 1.01 | 1.23 | 0.090 |
| CHAPELLE | 0.86 | 1.18 | 0.070 |
| XUE | 0.98 | 1.26 | 0.050 |
| BRAZ | 0.88 | 1.26 | 0.040 |
| HOUSTON | 1.05 | 1.22 | 0.040 |
| WOJCIECHOWSKI | 0.96 | 1.28 | 0.075 |
| BARBER | 0.91 | 1.17 | 0.070 |

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 (°) |
|---|---|---|---|---|
| LAVILLENIE | –27.7 | –7.0 | 14.2 | 25.8 |
| KENDRICKS | –7.2 | 1.7 | 21.0 | 29.1 |
| LISEK | –17.6 | –6.1 | 17.6 | 28.2 |
| MARSCHALL | –22.0 | –6.0 | 15.0 | 29.0 |
| HOLZDEPPE | –20.2 | –6.1 | 16.3 | 26.7 |
| KARALÍS | –14.3 | 0.4 | 20.2 | 28.1 |
| DUPLANTIS | –4.0 | 7.6 | 22.5 | 27.6 |
| FILIPPÍDIS | –25.3 | –6.8 | 25.3 | 28.5 |
| SVÄRD JACOBSSON | –2.6 | 6.1 | 19.5 | 27.4 |
| CHAPELLE | –4.4 | 3.1 | 20.8 | 27.6 |
| XUE | –16.8 | –4.0 | 19.8 | 27.6 |
| BRAZ | –8.4 | 3.7 | 17.2 | 27.7 |
| HOUSTON | –15.4 | –2.2 | 14.4 | 28.3 |
| WOJCIECHOWSKI | –19.4 | 1.4 | 22.4 | 28.6 |
| BARBER | –8.1 | 3.7 | 20.7 | 26.3 |

On the following page, Figures 14 and 15 illustrate variables relating to handgrip at take-off. More specifically, Figure 14 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 15 shows the variety of grip widths adopted by the competitors during the final.

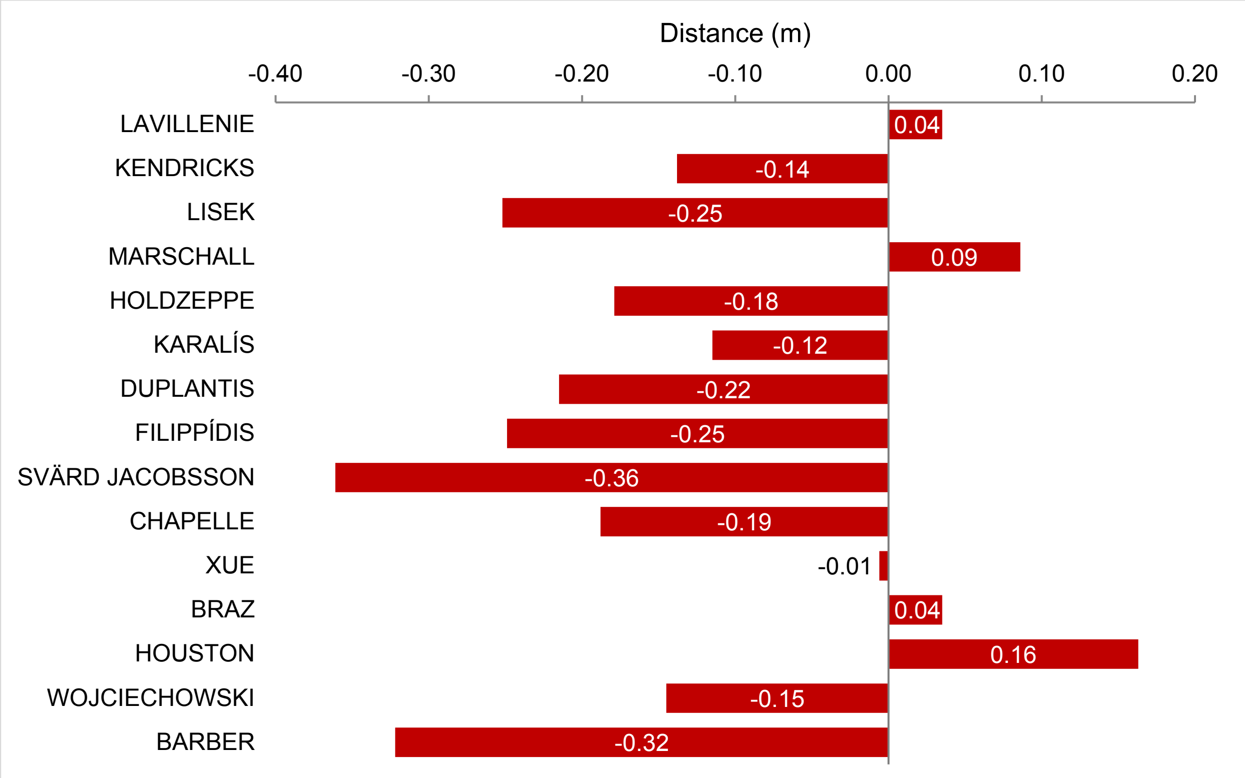


Figure 14. Take-off foot position (relative to upper grip position).

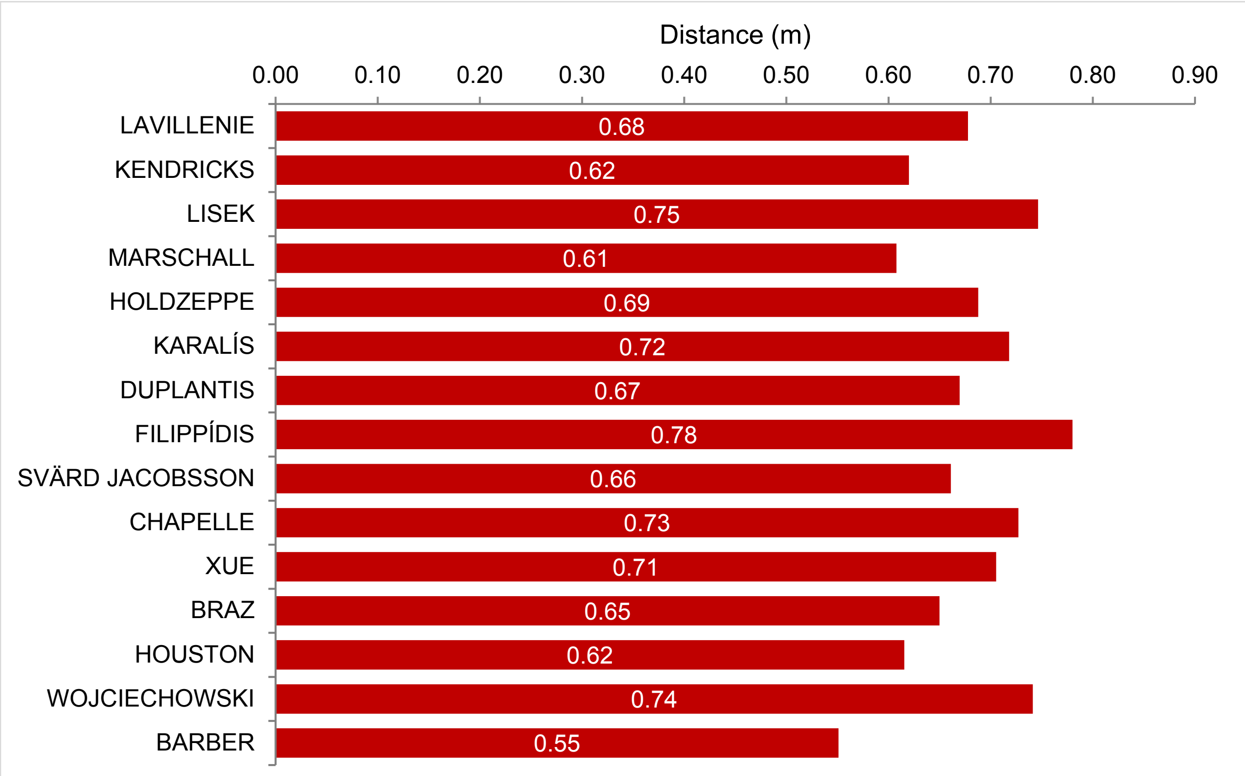


Figure 15. Grip widths for each athlete.

## 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 competition results were at the expected standard, but were possibly a little bit disappointing amongst the medallists in light of the fact that only one week before six athletes from this final cleared between 5.93 m and 5.88 m at an international competition in Clermont-Ferrand, with all of these athletes achieving lower performances in the World Indoor Championships final.

Nevertheless, six athletes jumping 5.80 m or higher created the best performance standard below the medal rankings ever in a World Indoor Championships.

The winner, Renaud Lavillenie, was able to fulfil his role as the most successful pole vaulter of the past ten years and most experienced athlete in the field, beating the 2017 World Champion, Sam Kendricks, and Piotr Lisek. Former Olympic champion Thiago Braz and former World champions Pawel Wojciechowski, Shawn Barber and Raphael Holzdeppe were not able to get into the medal positions, whereas three youngsters, Kurtis Marschall, Emmanouil Karalís and Armand Duplantis made bold appearances in this final, performing personal bests or results close to their PB.

*Approach data*

The approach length median was 18 steps, with only five athletes taking more steps than this. Compared with the situation about 20 years ago this seems to be a regression, when 20 steps were the usual length of a world-class pole vaulter's approach.

Supporting many earlier IAAF biomechanics reports, the results show a strong relationship between speed and performance if you want to be among the "best of the best". With World Indoor Champion Renaud Lavillenie being the third fastest athlete in the field, he was able to maintain a great velocity throughout the whole pole plant and take-off, losing only 1.07 m/s up until take-off. Compare him with Holzdeppe, for instance, who achieved by far the fastest horizontal velocity with a previously unheard of velocity of 10.10 m/s at the moment of pole plant, but who lost 2.22 m/s up until leaving the ground. Similarly, Sam Kendricks, the second fastest athlete at the moment of pole plant, lost 1.9 m/s during that same period and shows that we have to think about where all this kinetic energy went. We have to fear that a considerable amount of the kinetic energy from their approaches was not stored in elastic structures like the bending pole or in muscle-tendon stiffness, but dissipated through ineffective absorption in body structures, caused by ineffective technical details in that part of the jump.

An interesting exception is Lisek. This strong, tall athlete currently takes only 16 steps for his approach, reaching a rather mediocre approach speed that has previously let him jump 6 m, this time scoring 5.85 m. In his case, his tall size allows him a high grip on the pole, and the better overall stability during the jump paid off to win the bronze medal, even without achieving top velocities in his approach.

The development of speed during the last three steps shows clearly that the more successful half of this field of finalists accelerated into the last step, which must be seen as a clear advantage over their competitors. It remains unclear, however, whether these are stable behaviours for these athletes.

*Pole plant and take-off data*

Looking at the speed of the athletes from 11 m to 6 m before the zero-line and comparing these data to the final speed at the pole plant, we can see that there has been a wide spread of different speed developments. This can only be explained by different techniques of preparation of the pole plant and the take-off. Notably, the angle of the pole at the moment of the 3rd last step differed greatly, e.g., from Lavillenie's –27.7° down to –2.6° for Svärd Jacobsson, caused by different timings in the execution of the pole plant and also by different styles of coordinating the necessary movements of the trunk, shoulders, arms and the hands holding the pole.

During the last three steps, the pole angle differences diminish from more than 25° to around 12° while they further shrink to just 2 – 3° during the take-off. We could look at these numbers just as facts, illustrating different individual styles, but we could also ask ourselves whether the technical quality of this part of pole vault technique has degraded during the last 20 years. In the 1990s, more athletes at a World Championships showed an active pole drop using the momentum of the lowering pole, helping a fast forwards-upwards movement throughout pole plant and take-off. Maybe this is also related to the shortening of the approach by using fewer steps during the same time period, as mentioned above.

The differences between the athletes concerning the relationship between the penultimate step and the last step and the take-off cannot be discussed conclusively. We have elongated last steps with a "free take-off", shortened last steps with being "under", and vice versa. It might well be the case that some of these data are just reactions of the athletes to their approach rhythm feelings and their fear of coming too close or too far away at take-off. It would take a lot more data to come to a clear conclusion in this respect.

If we look at these images and numbers, we could search for similar patterns, not only indicating different individual "styles", but also different "techniques" of pole grip, plant and take-off. Some athletes try to achieve a "free take-off" (Lavillenie, Marschall, Braz and Houston actually manage that task, and Xue coming close), using a slightly narrower grip than others, generating a good "swing" momentum up to the pole tip, thus creating additional kinetic energy during the jump. Others, like Lisek, Filippídis and Wojciechowski, seem to go for another extreme, being "under" considerably, using a wider grip and the lower arm to push and move the pole forwards-upwards, not showing much swing momentum, but a "tuck and shoot" technique through the L- and I-positions into bar clearance instead. However, this particular discussion would not be based on much of the available data in this report; it is more of a "philosophical" discussion about different pole vault techniques. Finally, trying to conclude some trends on technique and performance for the men’s pole vault, as far as the available data allows:

- The approach speed still is a very important factor to be in the medal rankings. We can see that speed alone is not sufficient for creating medal performances, but they must be paired with a good technical model.
- The pole planting techniques of these world-class athletes differ greatly. Instead, we find strongly varying pole planting styles in this World Indoor Championships pole vault final.
- The “free take-off” does not seem to be a viable concept in the men’s pole vault community presently.
- Overall, we find a wide variety of technical performances in this World Indoor Championships pole vault final, once again proving the necessity of a well thought-out adaptation of technical concepts to the individual’s resources and properties.

# CONTRIBUTORS

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