



BIOMECHANICAL REPORT

FOR THE

IAAF™

WORLD INDOOR CHAMPIONSHIPS 2018

60 Metres Hurdles Women

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Table of Contents

INTRODUCTION	1
METHODS	2
RESULTS	8
Temporal and kinematic characteristics of block clearance	8
Temporal characteristics of the sprint start	17
Kinematic characteristics of the sprint start	21
Hurdle split time analysis	31
COACH'S COMMENTARY	33
CONTRIBUTORS	38

Figures




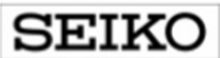

Figure 1.	Camera layout for the women's 60 m hurdles indicated by green-filled circles.	2
Figure 2.	The calibration frame was constructed and filmed before and after the competition.	3
Figure 3.	The block start of the women's 60 m hurdles final.	4
Figure 4.	Relative duration of block phases, displayed relative to total block time for each finalist.	9
Figure 5.	Block clearance distance (horizontal distance between start line and point of initial ground contact) for each of the finalists.	10
Figure 6.	Block flight time (from block clearance to initial ground contact) for each of the finalists.	11
Figure 7.	Body schematic denoting joint and segment angles measured in the set position.	12
Figure 8.	Body schematic denoting joint and segment angles measured at block exit.	13
Figure 9.	Trunk-trailing shank angle of incidence ($\alpha-\theta$) at block exit for each of the finalists.	14
Figure 10.	CM position (relative to the start line) for each finalist at the instant of block exit.	16
Figure 11.	CM projection angle from set position to block exit for each finalist.	16
Figure 12.	Change in ground contact time throughout the first three steps (1-2, 1-3) of the race for all (first contact is used as zero reference point for the other two contacts).	17
Figure 13.	Change in flight time throughout the first three steps (1-2, 1-3) of the race for all finalists (first flight is used as zero reference point for the other two flights).	18
Figure 14.	Change in step time throughout the first three steps (1-2, 1-3) of the race for all finalists (first step is used as zero reference point for the other two steps).	19
Figure 15.	Step velocity for the first three steps of the race for each of the finalists.	22
Figure 16.	Body schematic denoting joint and segment angles measured at touchdown.	23
Figure 17.	Body schematic denoting joint and segment angles measured at toe-off.	25
Figure 18.	Change in trunk angle at toe-off throughout the first three steps (1-2, 1-3) of the race for all finalists (first toe-off is used as zero reference point for the other two toe-offs).	27
Figure 19.	Vertical projection of the CM pathway throughout multiple key events during the sprint start for the medallists only.	30
Figure 20.	Vertical projection of the CM pathway throughout multiple key events during the sprint start for the remaining four finalists.	30
Figure 21.	Athlete ranking at each hurdle throughout the final.	32

Tables

Table 1.	Definitions of variables.	5
Table 2.	Temporal characteristics of block clearance for each of the finalists.	8
Table 3.	Athlete rankings of key events around the sprint start. Rankings based on times.	9
Table 4.	Joint and segment kinematics in the set position of the sprint start for all finalists.	12
Table 5.	Joint and segment kinematics at the instant of block exit for all finalists.	13
Table 6.	Height and setback position of the centre of mass whilst in the set position for each finalist.	15
Table 7.	Contact times of the first three steps of the race for each finalist.	17
Table 8.	Flight times of the first three steps of the race for each finalist.	18
Table 9.	Step times of the first three steps of the race for each finalist.	19
Table 10.	Athlete ranking for second, third and fourth touchdowns (TD).	20
Table 11.	Step lengths and step frequencies of the first three steps for each of the finalists.	21
Table 12.	Joint and segment angles at touchdown for the three medallists.	23
Table 13.	Joint and segment angles at touchdown for the remaining finalists.	24
Table 14.	Joint and segment angles at toe-off for the three medallists.	25
Table 15.	Joint and segment angles at toe-off for the remaining finalists.	26
Table 16.	Trunk-shank angle of incidence at touchdown for the first three steps for each of the finalists.	28
Table 17.	Trunk-shank angle of incidence at toe-off for the first three steps for each of the finalists.	28
Table 18.	Anteroposterior distance to the centre of mass (DCM) at touchdown (TD) for the first three step for each of the finalists.	29
Table 19.	Anteroposterior distance to the centre of mass (DCM) at toe-off (TO) for the first three step for each of the finalists.	29
Table 20.	Athlete split times between the start line and hurdle 1 (H1), between each hurdle (H1 – H5) and between H5 and the finish line.	31
Table 21.	Time to each hurdle and the finishing time for each of the finalists.	32

INTRODUCTION

The women's 60 m hurdles took place on the evening of Saturday 3rd March. In the lead up to the event, Sharika Nelvis (United States) was the likely favourite following her time of 7.70 s in Albuquerque (USA) only two weeks previously, a time that was enough to place her third on the all-time indoor list with the fastest time for over ten years. Kendra Harrison and Christina Manning (both United States) were also likely favourites given their incredibly fast times throughout the season. The race was ultimately dominated by Kendra Harrison, who joined Sharika Nelvis as the third fastest all-time with a time of 7.70 s, breaking the Championship Record along the way. Nelvis herself could only manage fourth place, as Christina Manning and Nadine Visser (The Netherlands) claimed the silver and bronze medals, respectively.

IAAF		Birmingham (GBR)		IAAF World Indoor Championships			
World Indoor Championships		1-4 March 2018					
RESULTS							
60 Metres Hurdles Women - Final							
							
RECORDS	RESULT	NAME	COUNTRY	AGE	VENUE DATE		
World Indoor Record WIR	7.68	Susanna KALLUR	SWE	27	Karlsruhe 10 Feb 2008		
Championship Record CR	7.70	Kendra HARRISON	USA	26	Birmingham 3 Mar 2018		
World Leading WL	7.70	Sharika NELVIS	USA	28	Albuquerque (USA) 18 Feb 2018		
Area Indoor Record AIR		National Indoor Record NIIR		Personal Best PB	Season Best SB		
3 March 2018 20:56 START TIME							
PLACE	NAME	COUNTRY	DATE of BIRTH	LANE	RESULT	REACTION	Fin
1	Kendra HARRISON	USA	18 Sep 92	5	7.70	CR 0.168	
2	Christina MANNING	USA	29 May 90	6	7.79	0.137	
3	Nadine VISSER	NED	9 Feb 96	4	7.84	0.153	
4	Sharika NELVIS	USA	10 May 90	3	7.86	0.163	
5	Cindy ROLEDER	GER	21 Aug 89	7	7.87	0.141	
6	Isabelle PEDERSEN	NOR	27 Jan 92	2	7.94	0.168	
7	Oluwatobiloba AMUSAN	NGR	23 Apr 97	1	8.05	0.149	
8	Devynne CHARLTON	BAH	26 Nov 96	8	8.18	0.158	
Timing and Measurement by SEIKO			AT-60H-W-f--1--RS1..v1		Issued at 21:02 on Saturday, 03 March 2018		
Official Partners							
							

METHODS

Five vantage locations for camera placement were identified and secured. Each location had the capacity to accommodate multiple cameras placed on tripods. Three locations were situated on broadcasting platforms around the stadium whilst one was located in the VIP boxes to capture footage around the starting blocks and first 5 m (Figure 1). One further broadcasting platform was secured parallel to the first 10 m of the 60 m track (Figure 1).

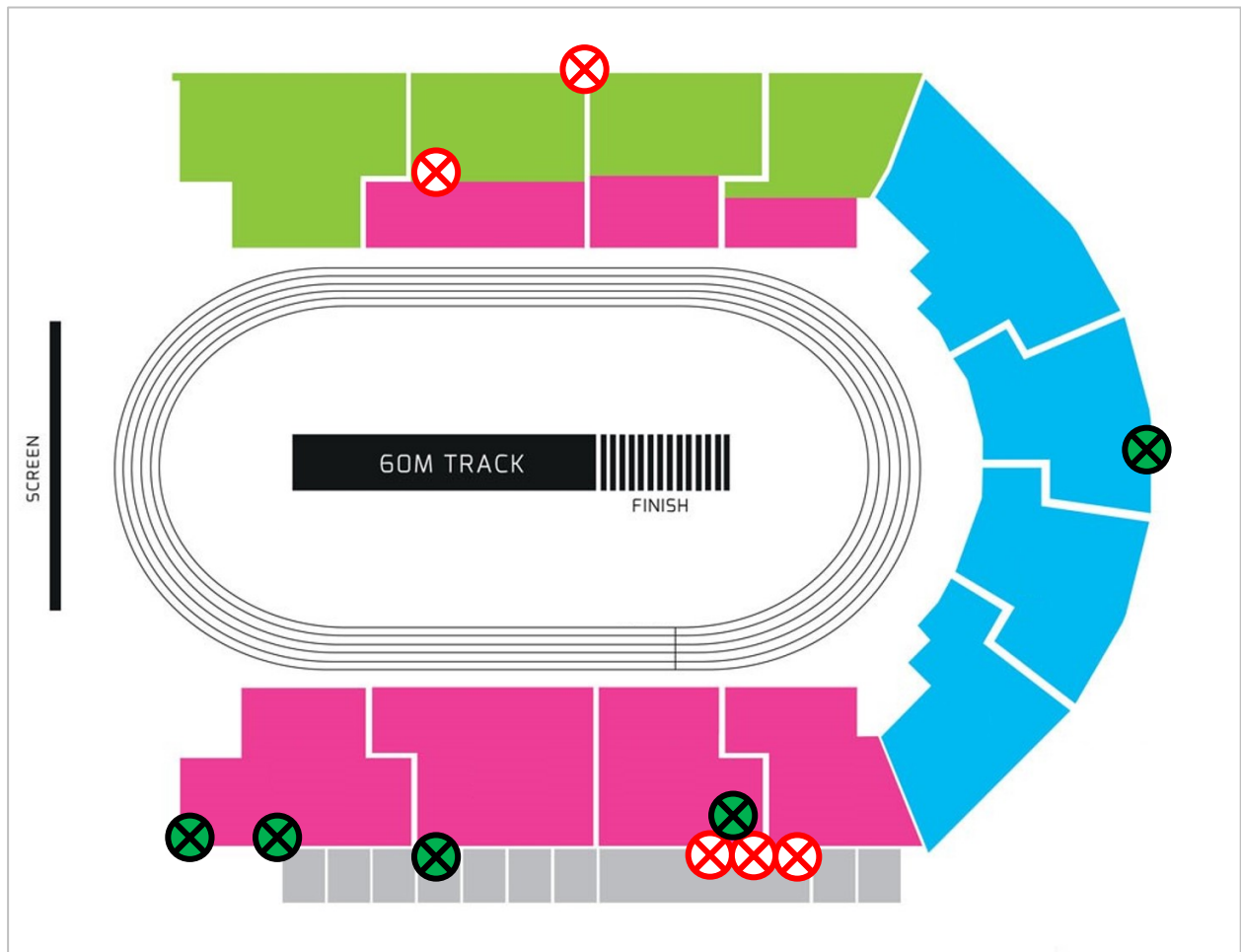


Figure 1. Camera layout for the women's 60 m hurdles indicated by green-filled circles.

A calibration procedure was conducted before and after the event. A rigid cuboid calibration frame was positioned on the running surface from one metre behind the starting line to five metres beyond the start line (Figure 2). This was repeated multiple times over discrete predefined areas along and across the track to ensure an accurate definition of a volume within which athletes were in the starting blocks and would complete three steps of the race. This approach produced a large number of non-coplanar control points per individual calibrated volume and facilitated the construction of bi-lane specific coordinate systems.



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

In total, 11 high-speed cameras were employed to record the action during the 60 m hurdles final. One Sony PXW-FS5 camera operating at 200 Hz (shutter speed: 1/1250; ISO: 2000-4000; FHD: 1920x1080 px) was positioned strategically with its optical axis perpendicular to the running direction covering the start line to the first hurdle in order to capture motion in the sagittal plane and provide footage for the analysis of the first hurdle time. Two Sony RX10 M3 cameras operating at 100 Hz (shutter speed: 1/1250; ISO: 2000-3600; FHD: 1920x1080 px) were used in a similar way to provide further split times between the other hurdles and the final hurdle and the finish line. Four Sony PXW-FS7 cameras operating at 150 Hz (shutter speed: 1/1250; ISO: 2000-4000; FHD: 1920x1080 px) were used to capture motion of athletes within the calibrated volume around block exit and the sprint start. Each of the four Sony PXW-FS7 cameras was paired with an additional Sony RX10 M3 camera operating at 100 Hz as a precaution against the unlikely event of data capture loss.



Figure 3. The block start of the women's 60 m hurdles final.

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. The digitising was centred upon critical events of the sprint start (e.g., set position, block exit, touchdown and toe-off) to provide key kinematic information of each athlete's sprint start performance. Each file was digitised frame by frame and upon completion, adjustments were made as necessary using the points over frame method. 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 repeating the process for randomly selected athletes 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 and for key body segments of interest. 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. Split times and temporal kinematic characteristics were processed through SIMI Motion by using the 200 Hz, 100 Hz and 150 Hz footage respectively.

Definition of a step: the table below (Table 1) contains definitions of the variables in this report. However, it may first be beneficial to outline the definition of a step. The reason for this is that, typically in coaching, the movement from block exit to initial touchdown is coined as the first step of the race. However, here we define a step as being from touchdown of the ipsilateral leg to touchdown of the contralateral leg (see step length; Table 1). As the block exit does not have an 'ipsilateral touchdown' in the first case, it cannot be defined as a step. Therefore, the movement from block exit to first touchdown has been defined as the 'block clearance distance' (Table 1), and the step succeeding this movement has been defined as the first step.

Table 1. Definitions of variables.

Variable	Definition
Double-leg push time	The time between the initial movement in the starting blocks and the first foot leaving the starting block (after reaction time).
Single-leg push time	The time between the first foot and the second foot pushing away from the starting blocks.
Total push time	The total time spent in the block phase from initial movement to block exit. Calculated as double-leg push time + single-leg push time.
Total block time	The total time spent in the block phase from the starting gun to block exit. Calculated as official reaction time (provided by Seiko) + total push time.
Block clearance distance	The anteroposterior distance between the start line and the point of ground contact at initial touchdown after block exit.
Block flight time	Time between the point of block exit and the instant of initial ground contact.
Trunk angle (α)	The angle of the trunk relative to the horizontal and considered to be 90° in the upright position.
Hip angle (γ)	The angle between the trunk and the thigh and in considered to be 180° in the anatomical standing position.
Knee angle (β)	The angle between the thigh and the lower leg and is considered to be 180° in the anatomical standing position.

Shank angle (θ)	The angle of the lower leg relative to the running surface and is considered to be 90° when the shank is perpendicular to the running surface.
Swing thigh angle (δ)	The angle between the thigh of the swing leg and the vertical.
Ankle angle (ι)	The angle between the lower leg and foot and is considered to be 90° in the anatomical standing position.
Trunk-shank angle of incidence	The difference between the trunk angle (α) and the shank angle (θ) at key events.
CM height	The vertical distance between the body's CM and running surface.
CM setback position	The anteroposterior distance between the start line and the body's CM when in the set position.
CM anteroposterior position	The anteroposterior distance between the start line and the body's CM at block exit.
CM projection angle	The sagittal plane angle of projection of the body's CM, relative to the horizontal, from the set position to the point of block exit.
Contact time	The time that the foot is in contact with the ground.
Flight time	The time from toe-off of one foot to touchdown of the other foot.
Step time	Contact time + flight time.
Step length	The distance covered from touchdown on one foot to touchdown on the other foot (foot tips).
Step frequency	The number of steps per second (Hz). Calculated as $1 / \text{step time}$.
Step velocity*	Step length divided by step time.
DCM TD	The anteroposterior distance between the ground contact point (foot tip) at touchdown and the body's CM.
DCM TO	The anteroposterior distance between the ground contact point (foot tip) at toe-off and the body's CM.

Hurdle split times[#]	Duration between each hurdle, between the start line and the first hurdle, and between the final hurdle and the finish line. Identified as the point at which the athlete's chest crosses directly above the hurdle.
Time to hurdle	Time taken to cross each hurdle from start of the race. Cumulative hurdle split times.
Athlete ranking	Ranking of each athlete at each hurdle. Determined by the hurdle split time, as described above.

Note: CM = centre of mass.

Step velocity calculation: please note that step velocity (marked in Table 1 with *) has been specifically chosen for coaching purposes. Although we feel a fully tracked CM horizontal velocity to be the most accurate method of presenting the velocity of movement, the method of presenting step velocity (step length divided by step time) is the most reproducible in a coaching setting due to equipment and time constraints, as well as being most commonly used when analysing maximal velocity sprinting. Step velocity has previously been compared against digitised CM velocity and the two methodologies show good levels of agreement and consistency, even though the values are changing substantially at this stage of the race. We therefore provide this variable in this way to provide concise yet accurate velocity data.

Hurdle split time calculation: please note that the hurdle split times in this report (marked in Table 1 with #) have been determined by the point at which the athlete's chest crosses directly above the hurdle. Although the typical method employed by coaches is to determine a hurdle split by the time that the athlete touches down beyond the hurdle. However, this method may not be the most appropriate in this setting, as determining the exact frame of take-off and touchdown can be difficult due to athletes being blocked by other athletes. Further, the method in this report also corroborates more closely with the method used for the official timings recorded at the finish line.

Temporal rankings: throughout this report, there are tables showing the rankings of each athlete for certain temporal variables at key events in the race. Apart from the athlete ranking at each hurdle (Table 1), these rankings do not indicate the athletes' actual positions in the race, but which athlete ranked first in this specific variable (e.g., time to first touchdown). These rankings are based on the cumulative times seen throughout the report, including the reaction time provided by Seiko.

RESULTS

Temporal and kinematic characteristics of block clearance

The following section of results provides temporal and kinematic characteristics of the set position and block clearance for each of the seven finishers in the final. It is worth noting that all athletes took eight steps to the first hurdle (including the 'block clearance distance') during the women's final.

Table 2. Temporal characteristics of block clearance for each of the finalists.

Athlete	Double-leg push time (s)	Single-leg push time (s)	Total push time (s)	Total block time (s)
HARRISON	0.160	0.167	0.327	0.495
MANNING	0.155	0.167	0.322	0.459
VISSER	0.177	0.153	0.330	0.483
NELVIS	0.178	0.173	0.351	0.514
ROLEDER	0.128	0.193	0.321	0.462
PEDERSEN	0.153	0.167	0.320	0.488
AMUSAN	0.177	0.160	0.337	0.486
CHARLTON	0.145	0.160	0.305	0.463

Table 2 (above) shows the time each athlete spent in the different phases that make up block exit. Total push time is the sum of double-leg push time and single-leg push time, whilst total block time is the sum of the official reaction time (data provided by Seiko) and total push time. The first thing to note is that Cindy Roleder pushed off with her back leg from the starting block before both hands came off the floor. This was the only occasion this happened across the four 60 m finals at these World Indoor Championships. This is shown in the double-leg push time. Eighth placed Devynne Charlton showed the shortest total push time of all finalists (0.305 s). This potentially explained why Charlton was the one of the first athletes to leave the blocks, despite being ranked fifth in reaction time (Table 3). Figure 4 (below) shows the different phases of block exit as a percentage of total block time.

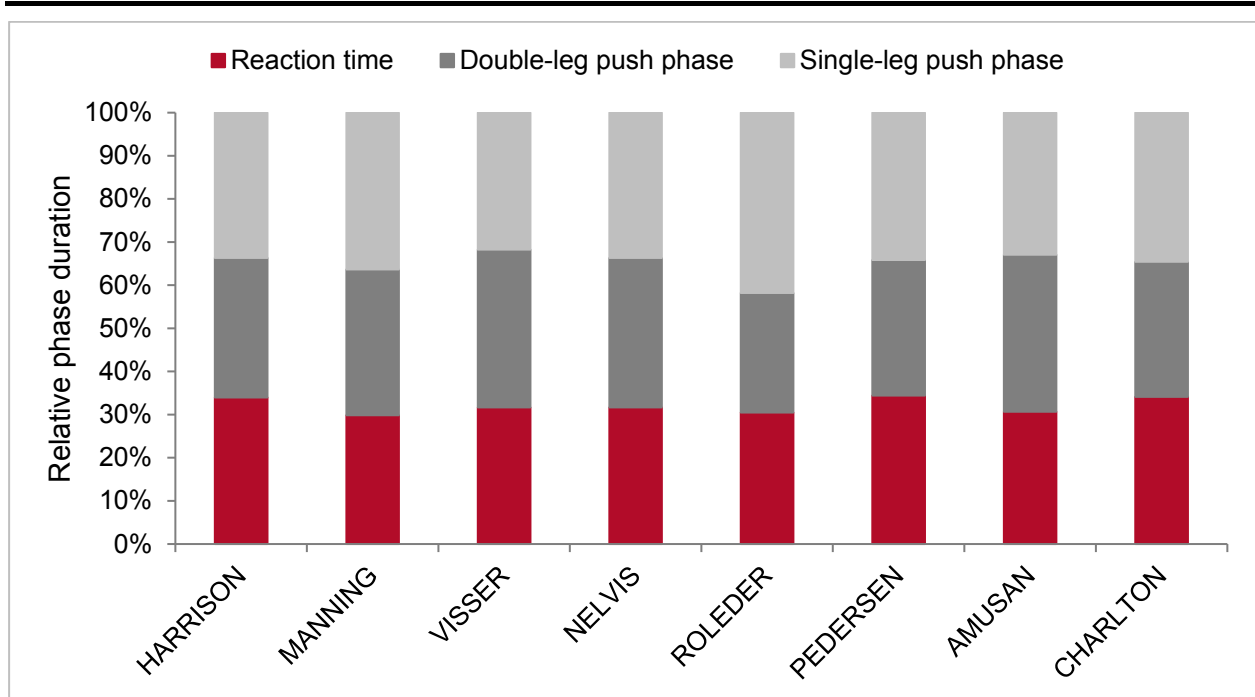


Figure 4. Relative duration of block phases, displayed relative to total block time for each finalist.

Table 3. Athlete rankings of key events around the sprint start. Rankings based on times.

Athlete	Ranking		
	Reaction time	Time to block exit	Time to first touchdown
HARRISON	=7	7	5
MANNING	1	1	1
VISSER	4	4	7
NELVIS	6	8	4
ROLEDER	2	2	2
PEDERSEN	=7	6	3
AMUSAN	3	5	8
CHARLTON	5	3	6

Figure 5 (below) shows the distance of block clearance (beyond the start line) for each athlete. Figure 6 (following page) shows the block flight time, which is the time taken from block exit to the first ground contact. As can be seen in Figure 5, Christina Manning touched down furthest from the start line (0.72 m), whereas Cindy Roleder touched down closest to the start line (0.31 m). Figure 6 shows that Sharika Nelvis clearly had the shortest block flight time (0.047 s), whereas 7th and 8th placed Amusan and Charlton showed the longest block flight time (0.100 s). This could explain some of the rankings seen in Table 3, such as Nelvis' climb and Charlton's fall in the rankings from block exit to initial touchdown.

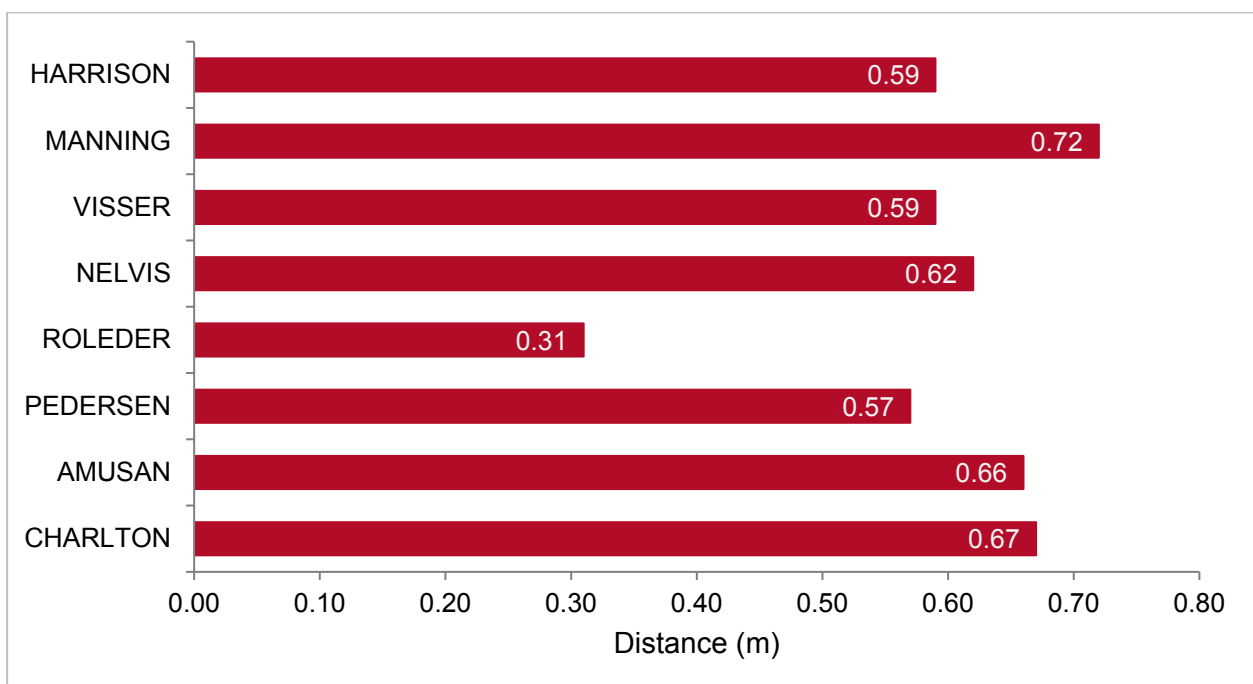


Figure 5. Block clearance distance (horizontal distance between start line and point of initial ground contact) for each of the finalists.

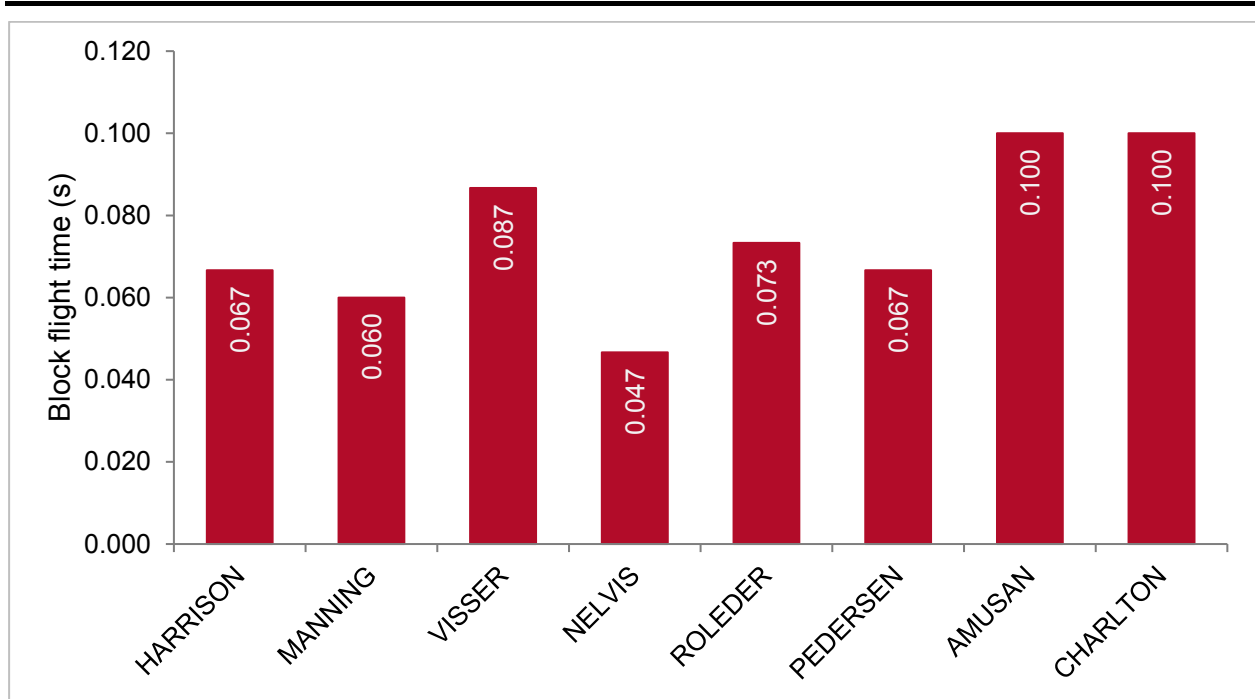


Figure 6. Block flight time (from block clearance to initial ground contact) for each of the finalists.

The following pages display the postural characteristics of each athletes' block set position. Figure 7 is designed to display a typical set position, and does not accurately represent any athlete in the field.

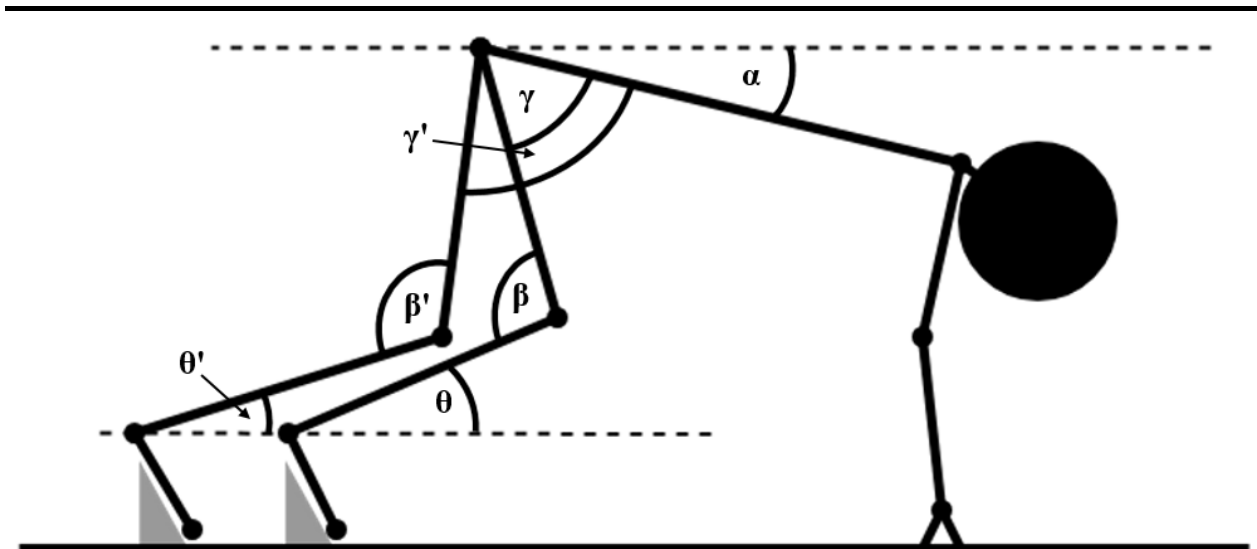


Figure 7. Body schematic denoting joint and segment angles measured in the set position.

Table 4. Joint and segment kinematics in the set position of the sprint start for all finalists.

Athlete	Joint angle (°)						
	α	γ	γ'	β	β'	θ	θ'
HARRISON	-17.3	50.2	92.9	99.4	135.7	30.5	26.4
MANNING	-20.0	37.7	72.9	91.5	126.5	32.6	32.8
VISSER	-17.2	39.7	66.7	85.0	106.8	28.9	21.9
NELVIS	-10.3	34.8	77.5	70.5	102.6	26.8	13.9
ROLEDER	-20.4	51.1	74.3	93.0	114.4	23.4	18.3
PEDERSEN	-16.0	43.4	91.1	91.5	129.4	32.3	16.5
AMUSAN	-21.9	40.2	60.3	95.7	111.0	35.3	26.7
CHARLTON	-15.3	47.1	83	91.3	121.8	30.8	21.6

Note: A negative trunk angle indicates the trunk is angled downwards (the shoulders are below the hips).

As can be seen from Table 4, all athletes showed a negative trunk angle in the set position. This makes sense, although no clear trend can be seen within the field for any joint angle in the set position. The shank angle for the front (angle θ) and rear (angle θ') legs were very similar for Christina Manning. There is a potential connection between these types of postural characteristics and her rankings around the block start (Table 3). The following page displays postural characteristics for each finalist at the point of block exit. As was the case with Figure 7, Figure 8 is designed to display a typical block exit, and does not accurately represent any athlete in the field.

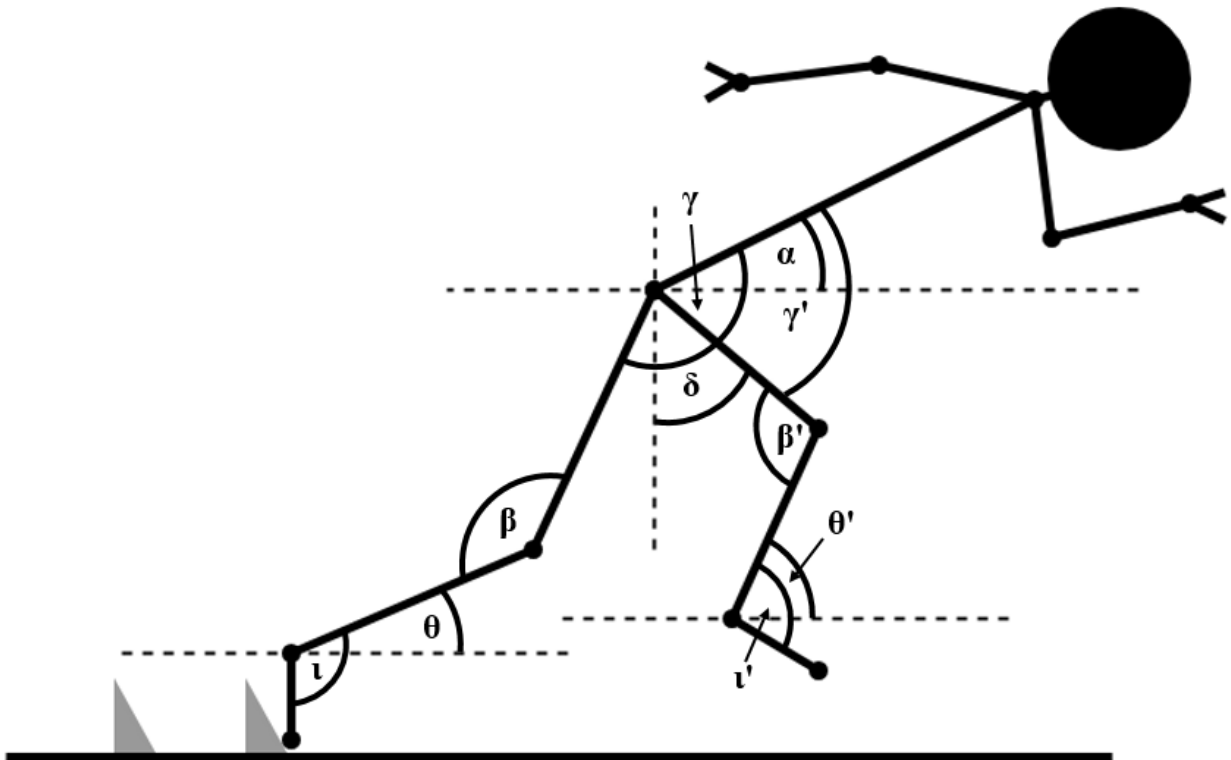


Figure 8. Body schematic denoting joint and segment angles measured at block exit.

Table 5. Joint and segment kinematics at the instant of block exit for all finalists.

Athlete	Joint angle (°)									
	α	γ	γ'	δ	β	β'	θ	θ'	τ	τ'
HARRISON	39.0	168.1	71.1	61.8	164.7	70.4	27.8	42.1	124.8	88.4
MANNING	39.0	165.6	69.6	62.2	158.3	74.2	23.9	45.7	136.9	91.3
VISSER	34.4	167.9	73.3	51.8	167.6	67.6	33.4	30.1	138.8	89.9
NELVIS	29.1	168.7	59.6	58.3	163.9	80.3	25.8	47.1	145.3	99.7
ROLEDER	25.7	156.1	62.6	53.7	167.9	89.3	35.7	53.3	149.8	99.7
PEDERSEN	33.0	172.3	70.7	54.1	174.9	70.2	35.3	16.8	147.9	91.7
AMUSAN	42.2	175.7	82.8	53.8	170.9	81.6	34.1	45.9	153.0	93.0
CHARLTON	38.9	174.5	70.4	63.3	172.4	63.4	31.0	36.8	131.3	76.2

Note: The 2-D schematic above should not be used as a model to combine angles as different landmarks have been used for defining certain joint angles.

As can be seen from Table 5, the bottom three finishers in the women's final showed the most extended knee angle in the push off leg (angle β). Conversely, Christina Manning, who was ranked first in reaction time and time to first touchdown (Table 3) showed the smallest push off knee extension angle (158.3°) compared to all other finalists ($163.9 - 174.9^\circ$).

The following figure shows the angle of incidence between the trunk (angle α) and the trailing shank (angle θ), thus an angle of zero would indicate the trunk and shank segments are in parallel alignment. An incidence angle close to zero has potential connections to the direction of the force vector being produced by the athlete to the start block.

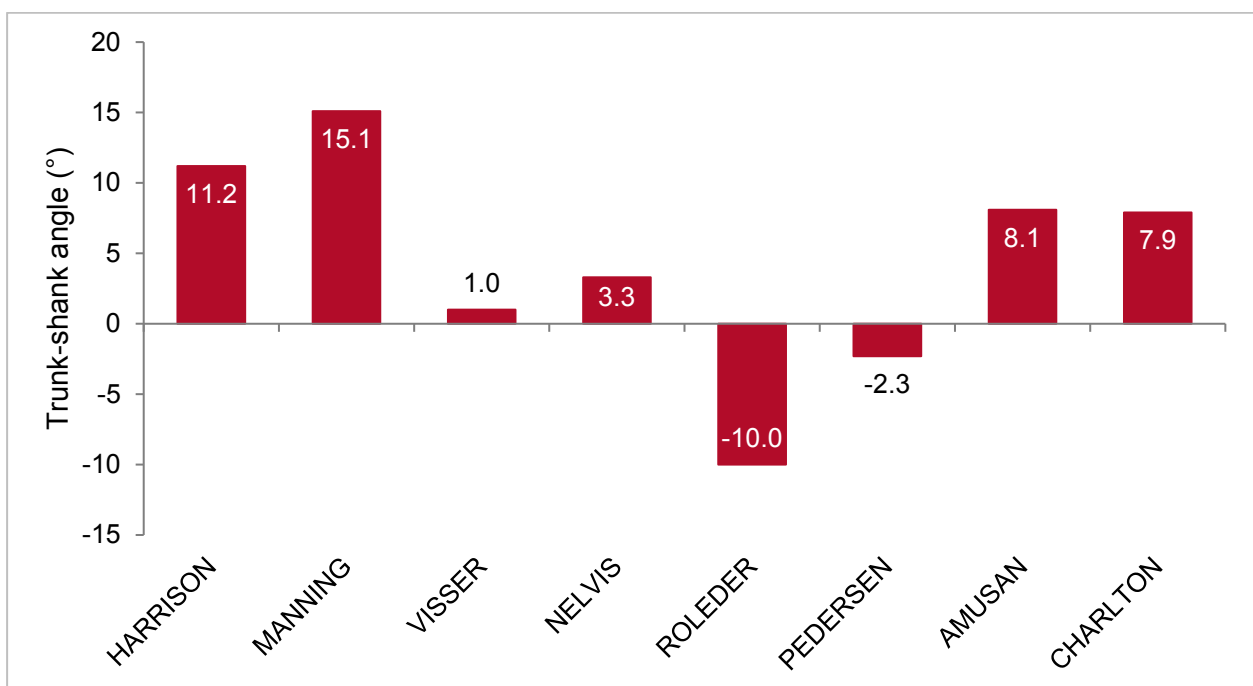


Figure 9. Trunk-trailing shank angle of incidence ($\alpha-\theta$) at block exit for each of the finalists.

The following series of tables and figures refers to body CM parameters around the set position and block exit. Table 6 shows the height of the CM whilst in the set position and the anteroposterior distance of the CM behind the start line. CM setback positions ranged from 0.18 to 0.28 m, whilst CM height ranged from 0.49 to 0.61 m.

Table 6. Height and setback position of the centre of mass whilst in the set position for each finalist.

Athlete	CM height in set position (m)	CM setback position (m)
HARRISON	0.49	0.20
MANNING	0.53	0.20
VISSER	0.52	0.23
NELVIS	0.52	0.31
ROLEDER	0.54	0.28
PEDERSEN	0.56	0.18
AMUSAN	0.61	0.21
CHARLTON	0.50	0.18

Note: CM = centre of mass. For the CM setback position, a positive value indicates the athlete's CM is behind the start line.

Figure 10 shows the CM position of each athlete at the point of block exit. Coordinates of the CM are displayed relative to the start line (the start line is the origin in the figure). Beneath Figure 10, Figure 11 shows the CM projection angle from the set position to block exit for each of the finalists. This projection angle indicates the direction the CM is travelling at the point of block exit; 0° would indicate a horizontal direction, where 90° would indicate a vertical direction of travel.

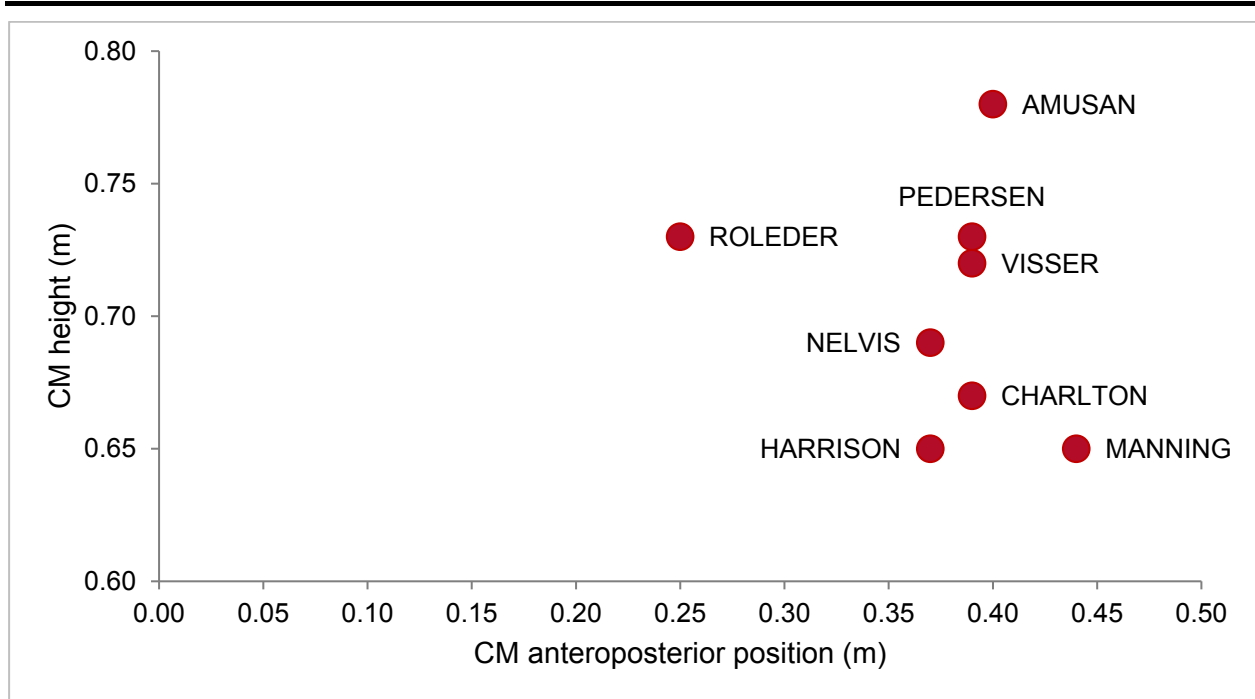


Figure 10. CM position (relative to the start line) for each finalist at the instant of block exit.

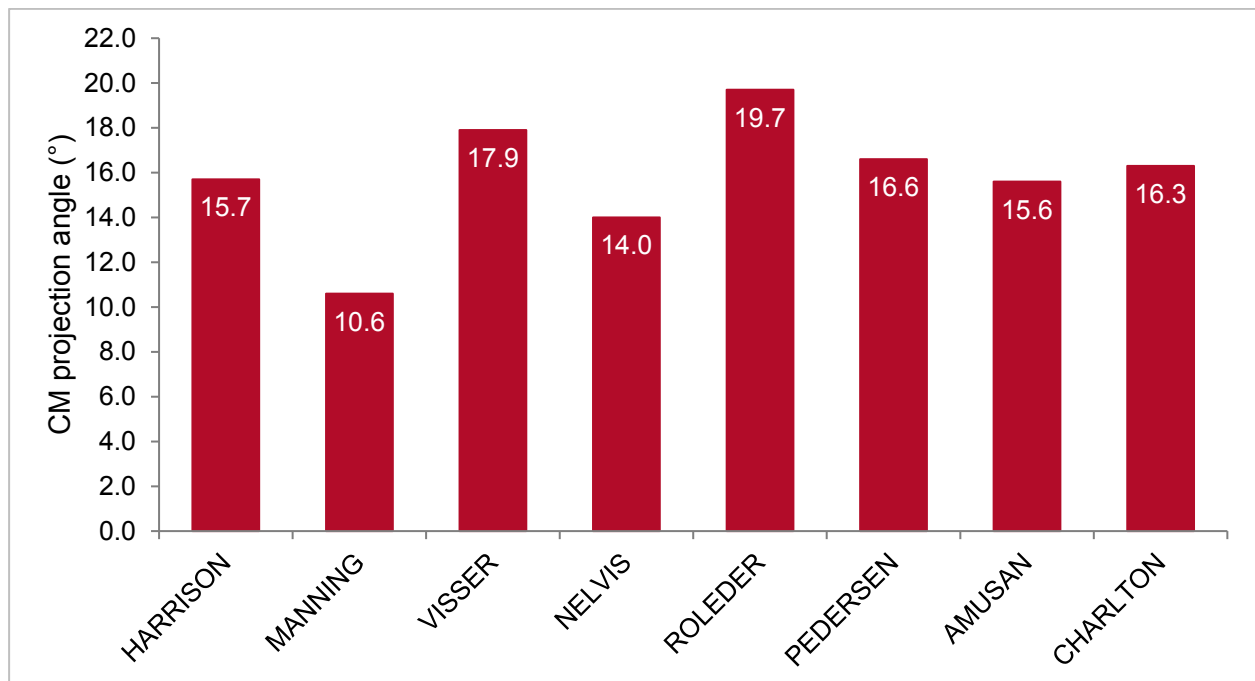


Figure 11. CM projection angle from set position to block exit for each finalist.

Temporal characteristics of the sprint start

The following section of results shows the temporal characteristics of the sprint start. Specifically, the first three steps of the race have been analysed for each athlete.

Table 7. Contact times of the first three steps of the race for each finalist.

Athlete	Contact time (s)		
	1 st step	2 nd step	3 rd step
HARRISON	0.193	0.167	0.160
MANNING	0.213	0.173	0.153
VISSER	0.173	0.180	0.147
NELVIS	0.233	0.193	0.147
ROLEDER	0.167	0.147	0.153
PEDERSEN	0.193	0.167	0.147
AMUSAN	0.160	0.193	0.153
CHARLTON	0.180	0.160	0.140

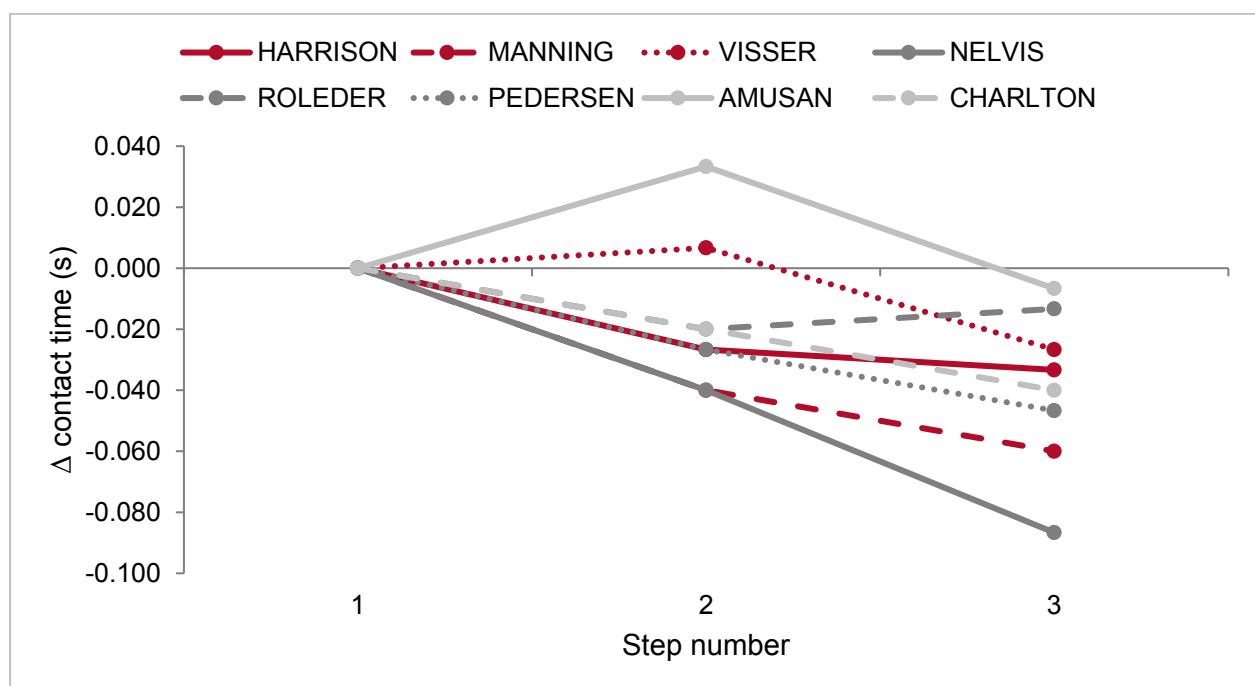


Figure 12. Change in ground contact time throughout the first three steps (1-2, 1-3) of the race for all (first contact is used as zero reference point for the other two contacts).

Table 8. Flight times of the first three steps of the race for each finalist.

Athlete	Flight time (s)		
	1 st step	2 nd step	3 rd step
HARRISON	0.053	0.053	0.080
MANNING	0.040	0.067	0.080
VISSER	0.053	0.080	0.060
NELVIS	0.047	0.060	0.080
ROLEDER	0.087	0.080	0.093
PEDERSEN	0.093	0.067	0.093
AMUSAN	0.060	0.067	0.073
CHARLTON	0.053	0.087	0.073

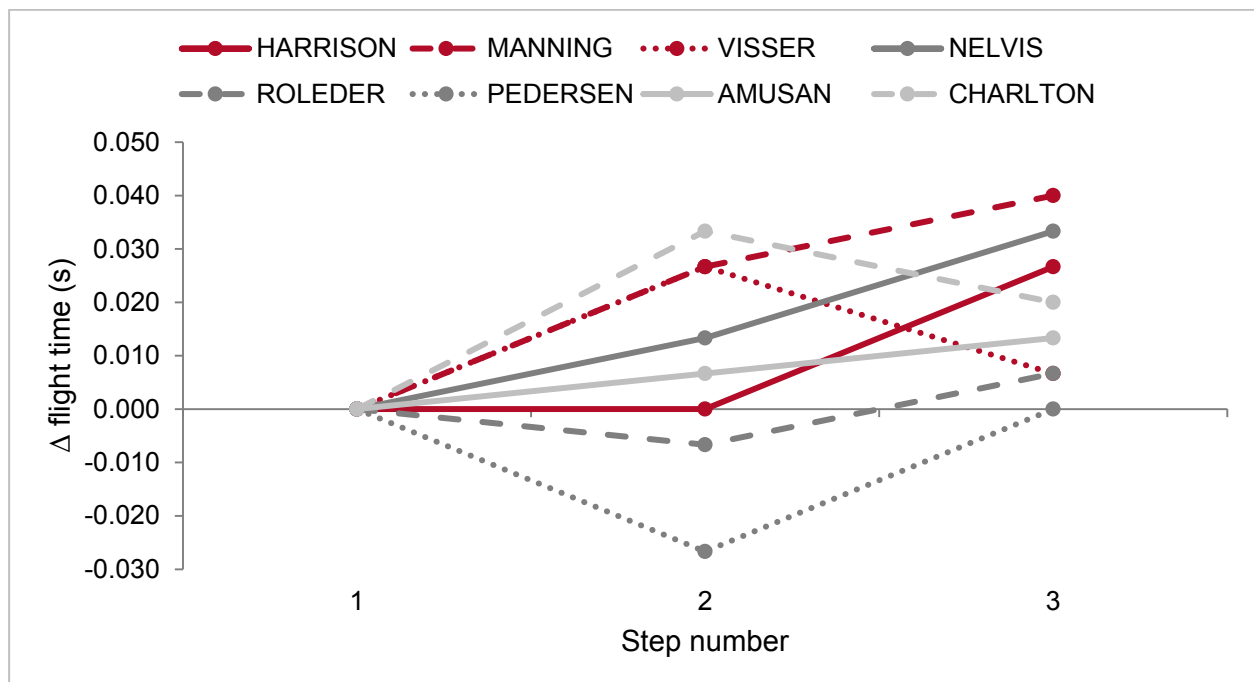


Figure 13. Change in flight time throughout the first three steps (1-2, 1-3) of the race for all finalists (first flight is used as zero reference point for the other two flights).

Table 9. Step times of the first three steps of the race for each finalist.

Athlete	Step time (s)		
	1 st step	2 nd step	3 rd step
HARRISON	0.246	0.220	0.240
MANNING	0.253	0.240	0.233
VISSER	0.226	0.260	0.207
NELVIS	0.280	0.253	0.227
ROLEDER	0.254	0.227	0.246
PEDERSEN	0.287	0.234	0.240
AMUSAN	0.220	0.260	0.226
CHARLTON	0.233	0.247	0.213

Note: Step times have been rounded to three decimal places.

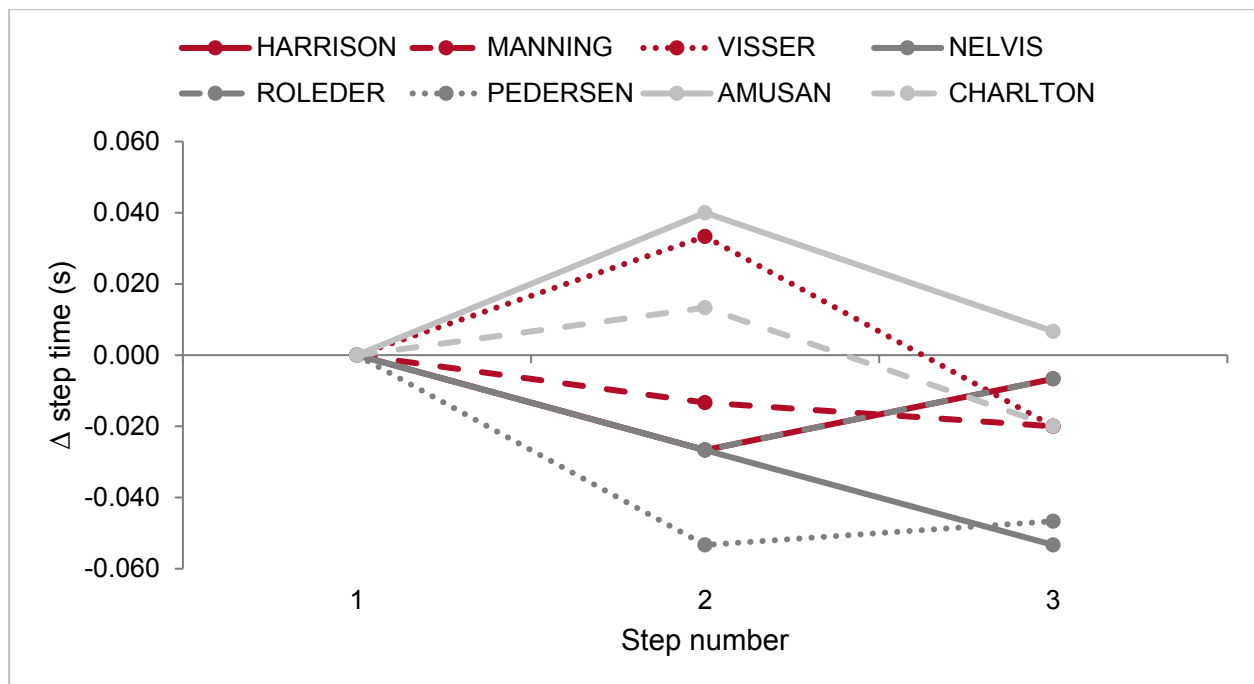


Figure 14. Change in step time throughout the first three steps (1-2, 1-3) of the race for all finalists (first step is used as zero reference point for the other two steps).

The following table shows the athletes' ranking to second, third and fourth ground contact. It should be noted here that this might not be indicative of the actual race rankings at these events, as touchdown time is individual to each athlete. Instead, these rankings provide an indication of which athletes reach their second, third and fourth steps earlier than other athletes do.

Table 10. Athlete ranking for second, third and fourth touchdowns (TD).

Athlete	Ranking		
	2 nd TD	3 rd TD	4 th TD
HARRISON	6	3	5
MANNING	1	1	1
VISSER	4	5	4
NELVIS	7	8	8
ROLEDER	2	2	3
PEDERSEN	8	7	7
AMUSAN	5	6	6
CHARLTON	3	4	2

Kinematic characteristics of the sprint start

The following section of this report shows the kinematic characteristics of the three steps of the race for each athlete.

Table 11. Step lengths and step frequencies of the first three steps for each of the finalists.

Athlete	Variable	1 st step	2 nd step	3 rd step
HARRISON	Step length (m)	1.06	1.26	1.39
	Step frequency (Hz)	4.05	4.55	4.17
MANNING	Step length (m)	1.16	1.23	1.46
	Step frequency (Hz)	3.95	4.17	4.29
VISSER	Step length (m)	1.10	1.29	1.33
	Step frequency (Hz)	4.41	3.85	4.84
NELVIS	Step length (m)	1.28	1.28	1.53
	Step frequency (Hz)	3.57	3.95	4.41
ROLEDER	Step length (m)	1.04	1.33	1.45
	Step frequency (Hz)	3.95	4.41	4.05
PEDERSEN	Step length (m)	1.20	1.29	1.50
	Step frequency (Hz)	3.49	4.29	4.17
AMUSAN	Step length (m)	1.18	1.30	1.41
	Step frequency (Hz)	4.55	3.85	4.41
CHARLTON	Step length (m)	1.10	1.31	1.44
	Step frequency (Hz)	4.29	4.05	4.69

As can be seen from Table 11, athletes tended to increase their step length throughout the first three steps. This is typical for an acceleration phase of a sprint, as increasing both parameters will result in an increase in running speed. Gold medallist Kendra Harrison showed the highest

step frequency in the second step (4.55 Hz), although her step length in this step (1.26 m) was one of the shortest in the field. Figure 15 (below) shows the step velocity for the first three steps of the race. Step velocity was calculated from step length and step time. Oluwatobiloba Amusan showed the highest step velocity in the first step, whereas in the third step, Sharika Nelvis and Devynne Charlton showed the highest.

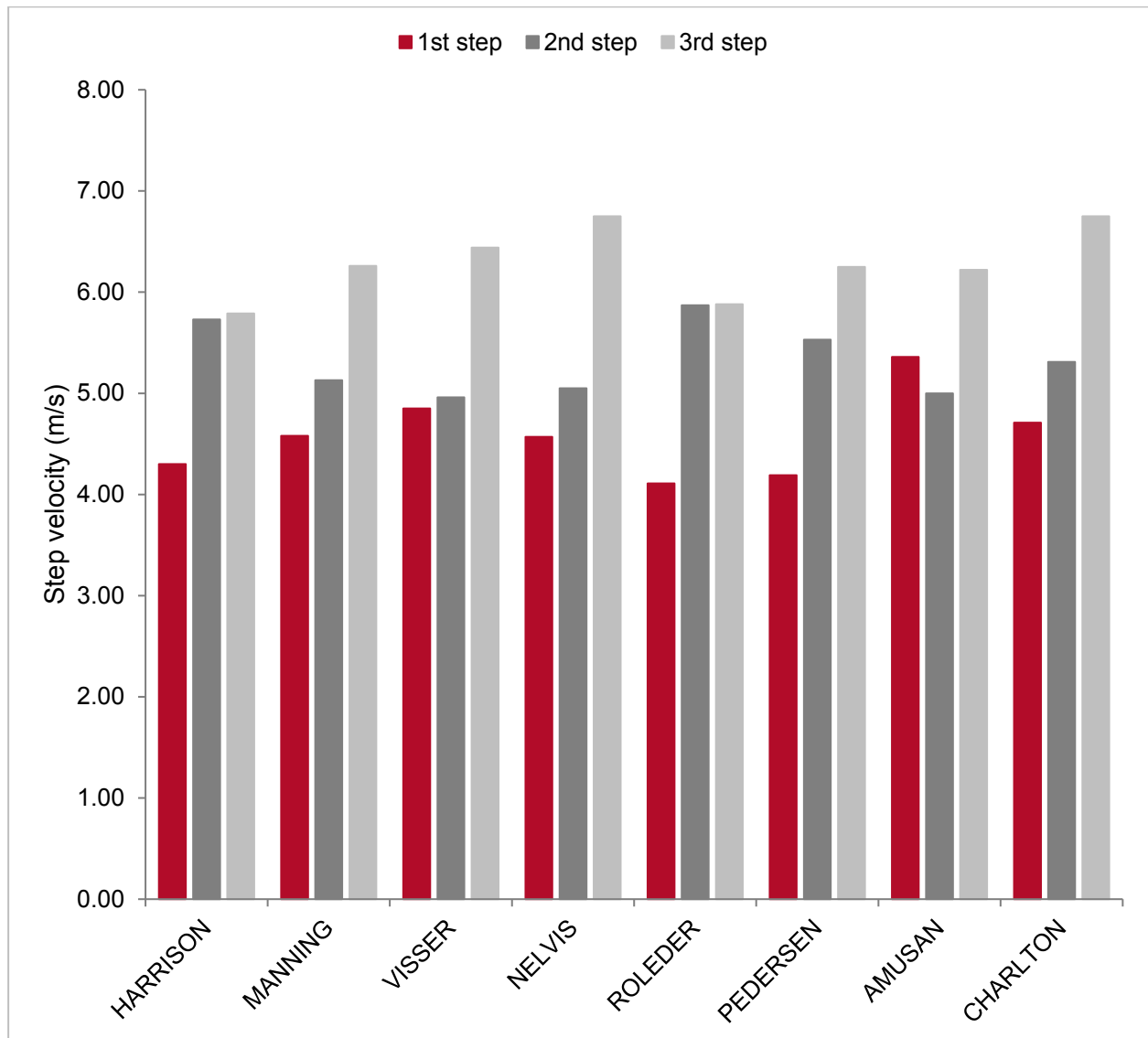


Figure 15. Step velocity for the first three steps of the race for each of the finalists.

The following two pages show the postural characteristics of each athlete's touchdown for the first three steps. Figure 16 is designed to display a typical touchdown posture and does not accurately represent any athlete in the field.

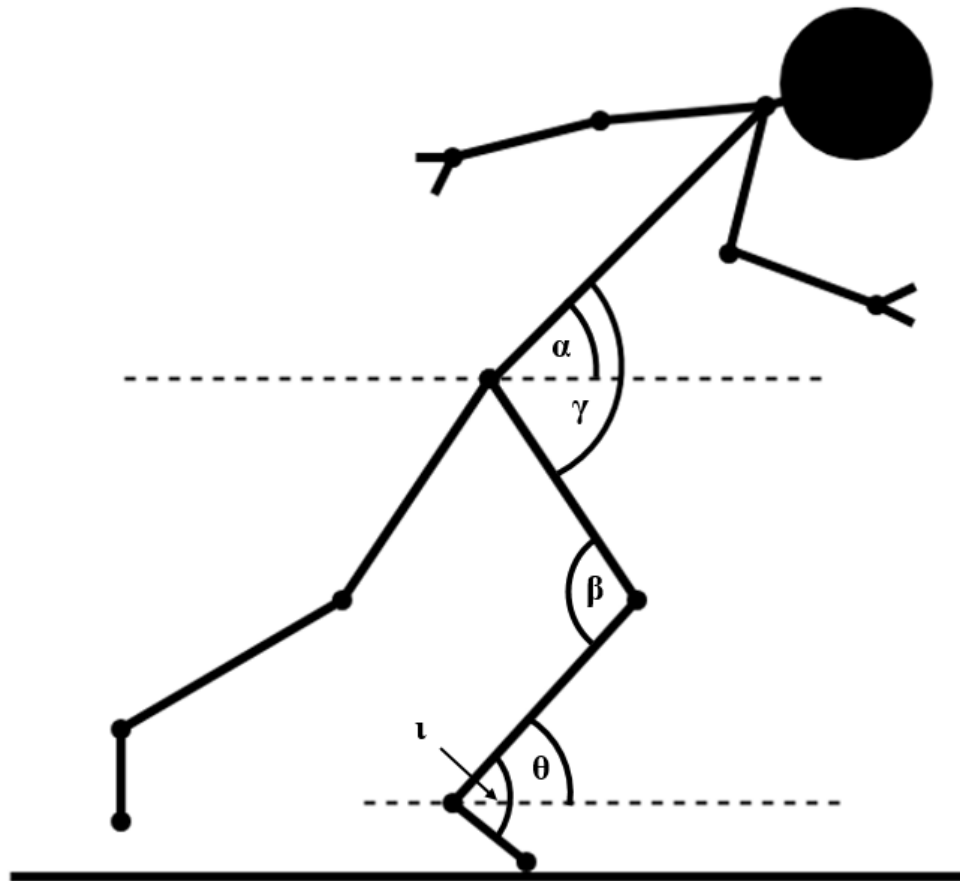


Figure 16. Body schematic denoting joint and segment angles measured at touchdown.

Table 12. Joint and segment angles at touchdown for the three medallists.

Athlete	Step number	Joint angle (°)				
		α	γ	β	θ	τ
HARRISON	1	43.2	91.2	88.1	43.0	91.9
	2	46.8	94.7	105.8	54.1	91.4
	3	48.1	93.0	103.3	62.5	97.1
MANNING	1	34.4	75.0	87.9	52.1	92.0
	2	47.6	90.1	100.6	57.4	93.9
	3	49.4	100.1	110.1	62.2	95.7
VISSER	1	44.6	102.0	101.4	43.6	93.3
	2	54.0	113.0	112.4	57.2	99.5
	3	57.6	124.9	120.7	57.3	94.4

Table 13. Joint and segment angles at touchdown for the remaining finalists.

Athlete	Step number	Joint angle (°)				
		α	γ	β	θ	ι
NELVIS	1	30.9	70.5	97.3	57.3	96.9
	2	37.3	77.9	101.8	63.0	98.3
	3	36.3	86.2	119.4	67.3	104.9
ROLEDER	1	38.2	103.0	110.5	42.3	92.5
	2	44.2	106.1	112.4	50.8	104.4
	3	50.7	108.6	121.4	61.7	95.0
PEDERSEN	1	36.3	93.1	100.9	46.9	88.5
	2	49.8	110.9	117.7	54.5	101.6
	3	56.7	114.1	116.8	56.1	91.8
AMUSAN	1	45.3	112.2	118.1	49.1	93.2
	2	50.4	98.9	106.4	59.3	107.7
	3	55.1	107.7	1116.5	64.1	101.8
CHARLTON	1	44.9	112.2	102.8	38.7	93.2
	2	53.2	103.4	96.9	50.5	96.5
	3	55.6	109.9	113.8	53.4	88.7

Athletes tend to increase trunk angle (angle α) throughout the sequence of ground contacts. The progression in trunk angle indicates a transition from the block start towards high velocity running. This is of particular importance in the hurdles, as the athletes have a limited number of steps (typically 7 or 8) to form a posture that will ensure a successful clearance of the first hurdle. All athletes generally showed a more acute shank angle (angle θ) at touchdown of the first step (average: 46.6°) when compared to the second and third ground contacts (averages: 55.9° and 60.6°, respectively). The following pages show the athletes' postural characteristics at toe-off for the first three steps. As with Figure 16, Figure 17 is designed to show a typical toe-off posture and does not accurately represent any athlete in the field.

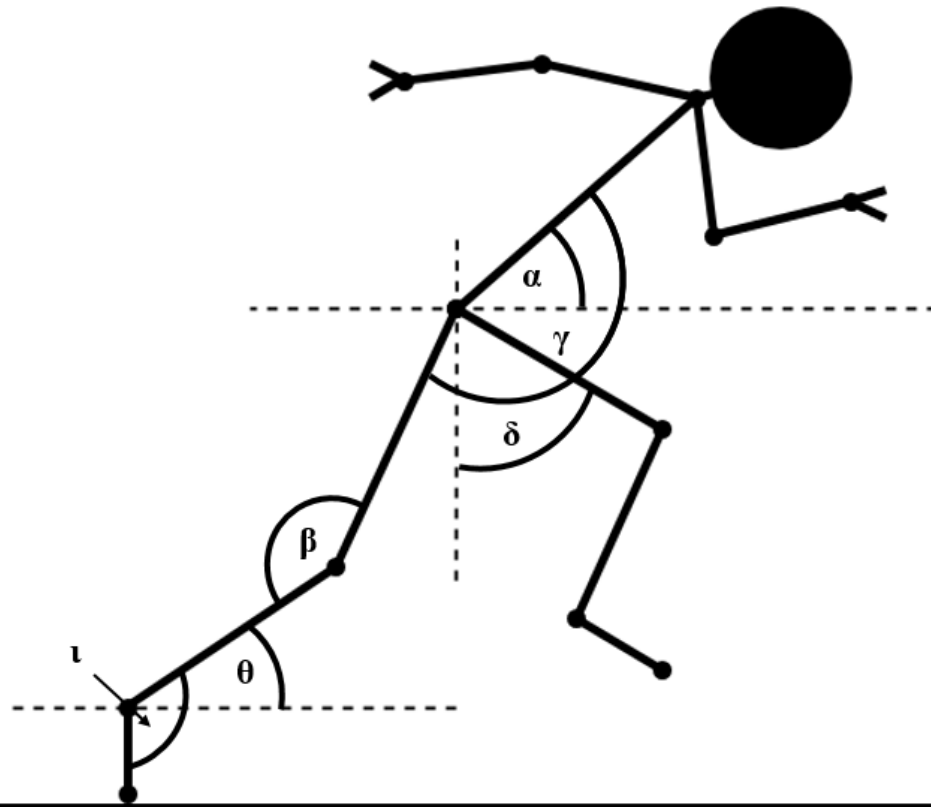


Figure 17. Body schematic denoting joint and segment angles measured at toe-off.

Table 14. Joint and segment angles at toe-off for the three medallists.

Athlete	Step number	Joint angle (°)					
		α	γ	δ	β	θ	τ
HARRISON	1	45.6	168.8	58.9	150.2	26.5	121.0
	2	50.3	175.6	68.8	161.0	31.7	144.0
	3	50.2	170.3	63.9	160.3	33.9	136.9
MANNING	1	40.0	158.5	68.0	144.4	25.1	136.4
	2	50.9	165.6	66.7	155.8	31.8	123.0
	3	48.2	166.8	70.2	155.1	34.0	133.6
VISSER	1	49.1	166.9	63.4	156.5	34.0	130.8
	2	53.2	178.8	65.0	163.2	34.9	146.4
	3	60.9	173.5	67.3	154.5	31.3	132.0

Table 15. Joint and segment angles at toe-off for the remaining finalists.

Athlete	Step number	Joint angle (°)					
		α	γ	δ	β	θ	ι
NELVIS	1	38.0	158.7	58.8	150.7	26.0	126.8
	2	34.3	161.5	63.1	161.4	35.2	137.2
	3	40.3	158.5	60.1	156.3	34.9	120.6
ROLEDER	1	40.4	160.2	62.0	164.1	38.4	133.3
	2	45.9	169.0	64.2	162.5	37.8	144.1
	3	53.4	171.5	69.5	163.6	38.5	138.1
PEDERSEN	1	52.3	177.2	65.7	173.2	23.1	141.2
	2	55.2	178.1	68.3	163.9	34.0	147.6
	3	63.2	163.8	71.5	178.9	24.7	135.8
AMUSAN	1	51.4	168.2	65.8	169.2	40.0	133.8
	2	54.5	177.0	70.7	168.0	37.1	149.5
	3	59.0	169.6	62.6	165.9	39.7	130.0
CHARLTON	1	54.2	177.0	68.8	153.5	27.1	136.6
	2	54.3	173.2	70.5	170.4	35.5	134.6
	3	55.8	172.7	73.4	160.9	32.7	128.9

Figure 18 (below) shows the change in trunk angle throughout the first three steps at toe-off. As previously mentioned, athletes tend to show a progressive increase in trunk angle at both touchdown and toe-off. According to these data, Sharika Nelvis was the only finalist to show a reduction in trunk angle from toe-off of the first step to toe-off of the second step. Most other finalists gradually increased throughout the three steps, apart from Harrison and Manning; they appeared to maintain or even slightly decrease their trunk angles at toe-off from step two to step three.

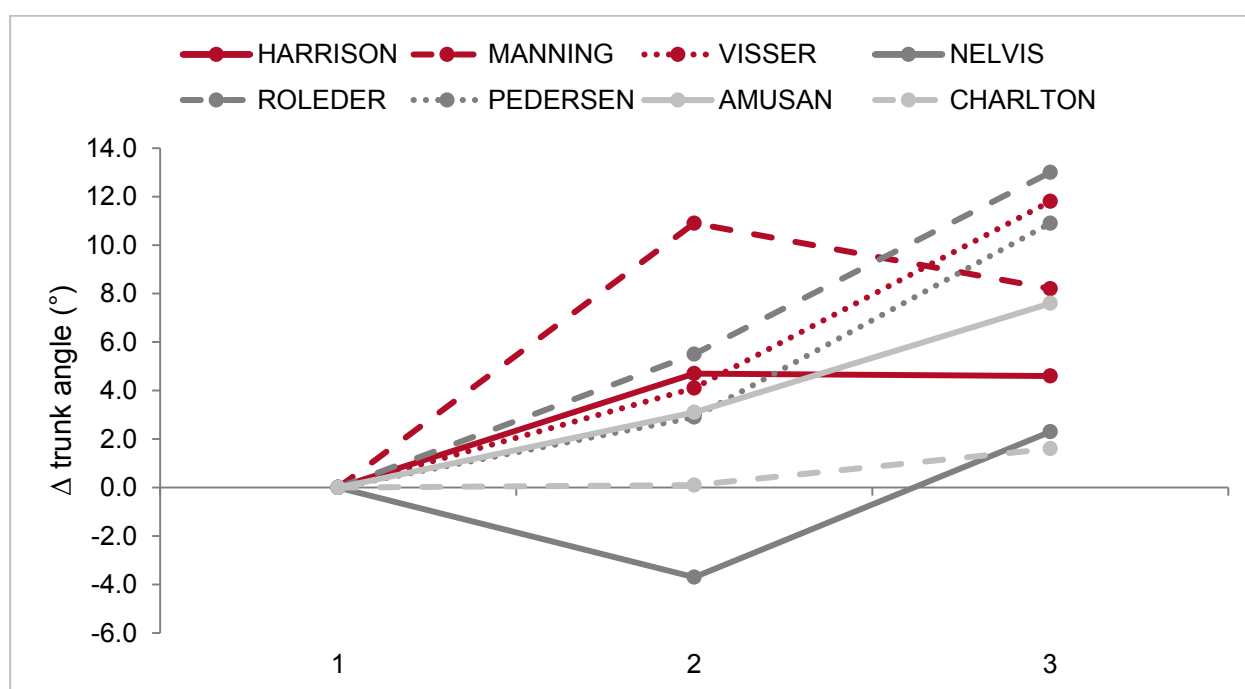


Figure 18. Change in trunk angle at toe-off throughout the first three steps (1-2, 1-3) of the race for all finalists (first toe-off is used as zero reference point for the other two toe-offs).

The following two pages contain four tables (Tables 16-19). Tables 16 and 17 show the trunk-shank angle of incidence at touchdown and toe-off, respectively, for the first three steps of the race. Tables 18 and 19 show the anteroposterior location of the CM relative to the point of ground contact, both at touchdown (Table 18) and toe-off (Table 19). Data are shown for the first three steps of the race. As can be seen from Table 18, some athletes touch down with their CM ahead of the point of ground contact. This may corroborate with some of postural characteristics shown previously.

Table 16. Trunk-shank angle of incidence at touchdown for the first three steps for each of the finalists.

Athlete	Trunk-shank angle (°)		
	1 st step	2 nd step	3 rd step
HARRISON	0.2	-7.3	-14.4
MANNING	-17.7	-9.8	-12.8
VISSER	1.0	-3.2	0.3
NELVIS	-26.4	-25.7	-31.0
ROLEDER	-4.1	-6.6	-11.0
PEDERSEN	-10.6	-4.7	0.6
AMUSAN	-3.8	-8.9	-9.0
CHARLTON	6.2	2.7	2.2

Table 17. Trunk-shank angle of incidence at toe-off for the first three steps for each of the finalists.

Athlete	Trunk-shank angle (°)		
	1 st step	2 nd step	3 rd step
HARRISON	19.1	18.6	16.3
MANNING	14.9	19.1	14.2
VISSER	15.1	18.3	29.6
NELVIS	12.0	-0.9	5.4
ROLEDER	2.0	8.1	14.9
PEDERSEN	29.2	21.2	38.5
AMUSAN	11.4	17.4	19.3
CHARLTON	27.1	18.8	23.1

Table 18. Anteroposterior distance to the centre of mass (DCM) at touchdown (TD) for the first three steps for each of the finalists.

Athlete	DCM TD (m)		
	1 st step	2 nd step	3 rd step
HARRISON	0.02	-0.31	-0.17
MANNING	-0.05	-0.09	-0.13
VISSER	0.11	-0.06	-0.01
NELVIS	-0.05	-0.16	-0.08
ROLEDER	0.17	0.13	-0.06
PEDERSEN	0.06	0.04	-0.09
AMUSAN	0.10	-0.10	-0.11
CHARLTON	0.10	-0.06	-0.07

Note: A negative values shows that the body's CM is behind the point of ground contact, whereas a positive value means that CM is ahead of the ground contact point.

Table 19. Anteroposterior distance to the centre of mass (DCM) at toe-off (TO) for the first three steps for each of the finalists.

Athlete	DCM TO (m)		
	1 st step	2 nd step	3 rd step
HARRISON	0.78	0.79	0.75
MANNING	0.79	0.72	0.74
VISSER	0.77	0.79	0.75
NELVIS	0.86	0.82	0.75
ROLEDER	0.79	0.81	0.76
PEDERSEN	0.77	0.82	0.71
AMUSAN	0.73	0.78	0.70
CHARLTON	0.78	0.73	0.72

Note: A negative values shows that the body's CM is behind the point of ground contact, whereas a positive value means that CM is ahead of the ground contact point.

Figures 19 and 20 show the progression of the CM vertical projection at key events around the sprint start. Figure 19 (below) contains the three medallists, whereas Figure 20 (next page) contains the remaining finalists. The key events are made up of the set position (SP), block exit (BE), and each subsequent touchdown (TD1-3) and toe-off (TO1-3) for the first three steps. All values are represented relative to the values of SP.

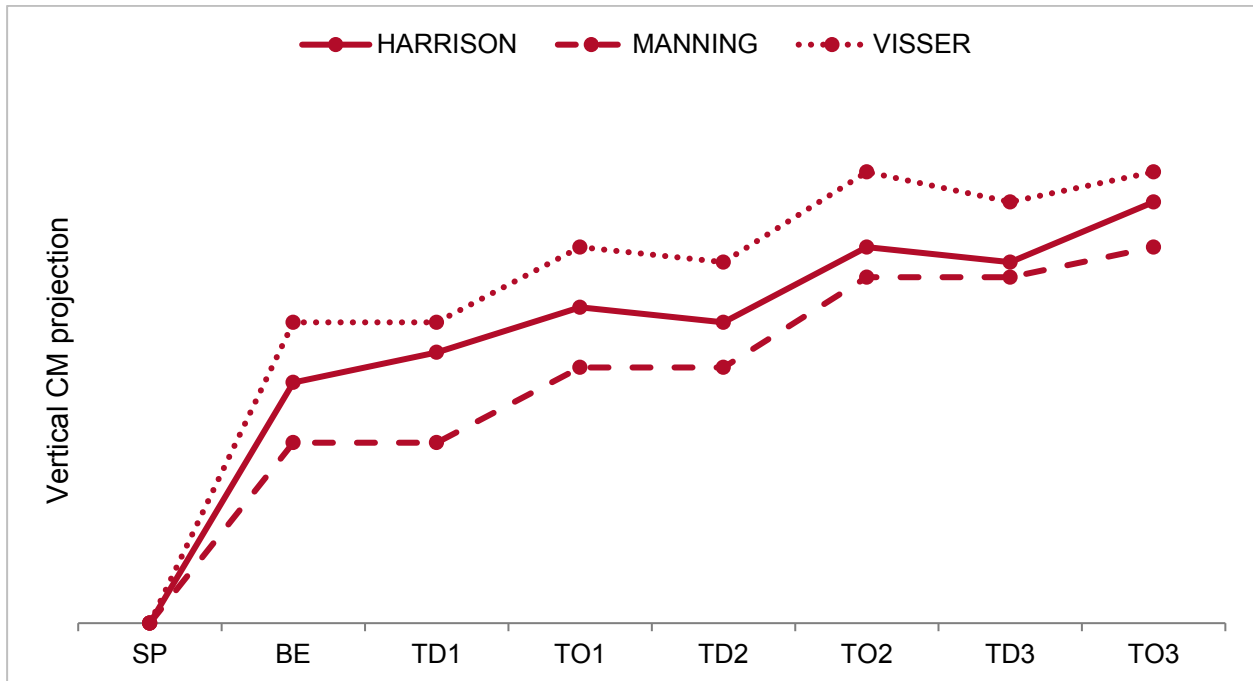


Figure 19. Vertical projection of the CM pathway throughout multiple key events during the sprint start for the medallists only.

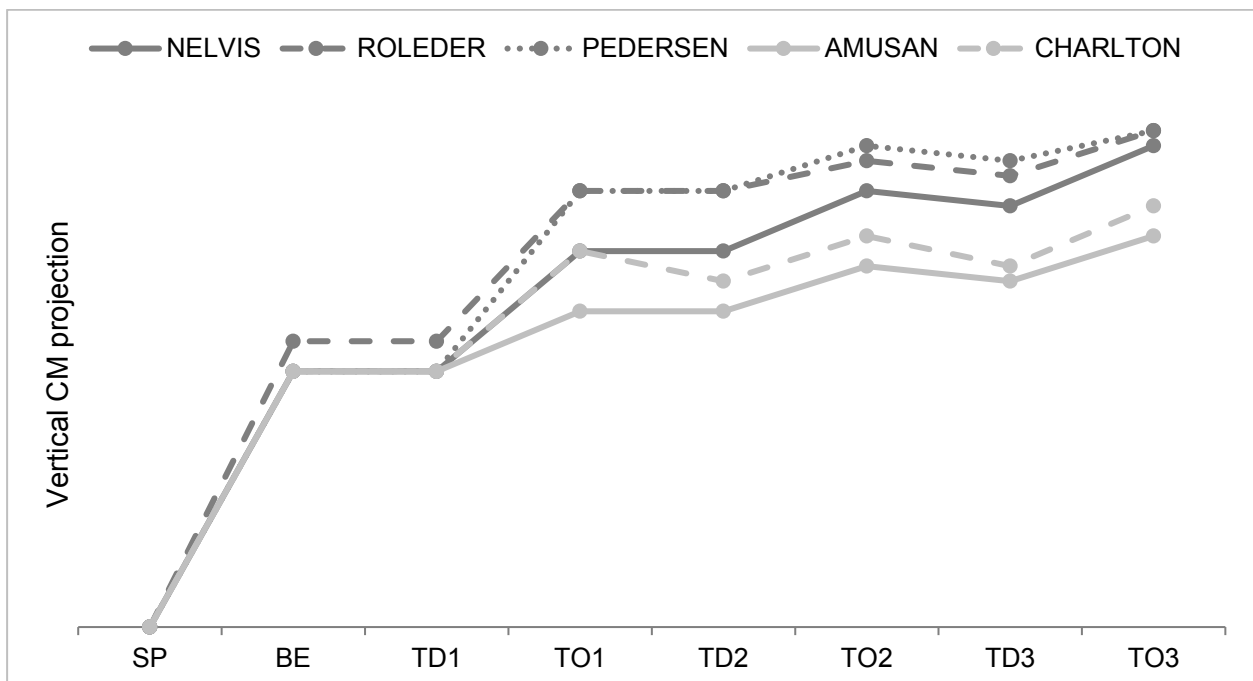


Figure 20. Vertical projection of the CM pathway throughout multiple key events during the sprint start for the remaining four finalists.

Hurdle split time analysis

The following section of results concerns each athlete's split time between each hurdle, as well as the cumulative split times and athlete rankings throughout the race. Table 20 (below) shows the individual split times for each athlete, between the start line and the first hurdle, between hurdles, and from the final hurdle to the finish line. As can be seen from Table 20, Kendra Harrison had the quickest (or joint quickest) between-hurdle split time on three occasions (H2 – H3, H3 – H4, H4 – H5). Further to this, Harrison was also the quickest athlete in the final split (H5 – FINISH), with a very quick 1.21 s; this was 0.05 s shorter than the next shortest split in this section (Visser and Roleder: 1.26 s). Harrison was also the only athlete to clock more than one 0.95 s between-hurdle split. These factors offer key explanations as to why Harrison was the strongest athlete and subsequently broke the Championship Record.

Table 20. Athlete split times between the start line and hurdle 1 (H1), between each hurdle (H1 – H5) and between H5 and the finish line.

Athlete	Hurdle split times (s)					
	START – H1	H1 – H2	H2 – H3	H3 – H4	H4 – H5	H5 – FINISH
HARRISON	2.61	1.02	0.95	0.96	0.95	1.21
MANNING	2.57	1.04	0.96	0.98	0.96	1.28
VISSER	2.65	1.01	1.01	0.96	0.95	1.26
NELVIS	2.62	1.03	1.00	0.97	0.96	1.28
ROLEDER	2.65	1.03	1.00	0.97	0.96	1.26
PEDERSEN	2.66	1.05	0.99	0.97	0.99	1.28
AMUSAN	2.67	1.02	1.05	0.98	0.97	1.36
CHARLTON	2.59	1.04	1.06	1.02	1.04	1.43

Note: 'Start – H1' includes reaction time. Data have been rounded to two decimal places.

On the next page, Table 21 shows the cumulative race time for each athlete and Figure 21 shows the athlete ranking at each hurdle, based on cumulative split times. As can be seen from Figure 21, Manning's impressive block start meant she was able to hold the lead until the fourth hurdle, where eventual winner Harrison took over after coming from third place at H1. A relatively poor

start meant that Nadine Visser was only able to claim third place at the final hurdle, strengthening the argument that a poor start will definitively limit your chances of a gold medal.

Table 21. Time to each hurdle and the finishing time for each of the finalists.

Athlete	Time to each hurdle (s)					
	H1	H2	H3	H4	H5	FINISH
HARRISON	2.61	3.63	4.58	5.54	6.49	7.70
MANNING	2.57	3.61	4.57	5.55	6.51	7.79
VISSER	2.65	3.66	4.67	5.63	6.58	7.84
NELVIS	2.62	3.65	4.65	5.62	6.58	7.86
ROLEDER	2.65	3.68	4.68	5.65	6.61	7.87
PEDERSEN	2.66	3.71	4.70	5.67	6.66	7.94
AMUSAN	2.67	3.69	4.74	5.72	6.69	8.05
CHARLTON	2.59	3.63	4.69	5.71	6.75	8.18

Note: 'H1' includes athlete reaction times. Data have been rounded to two decimal places.

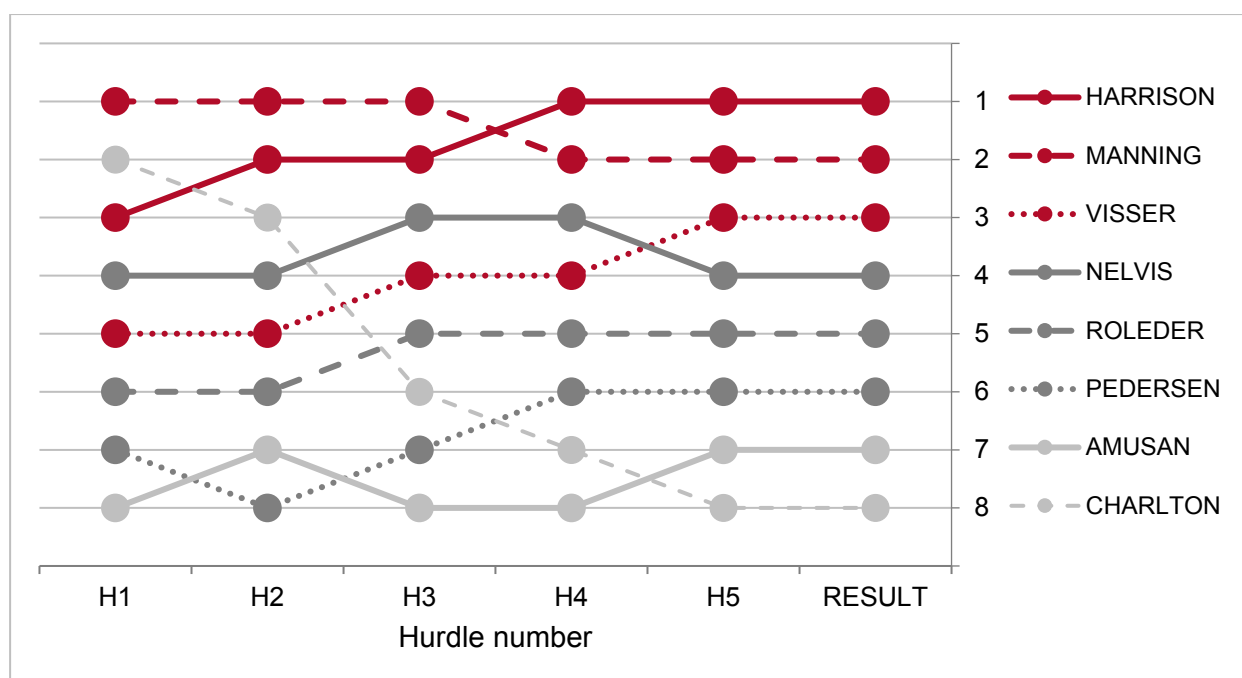


Figure 21. Athlete ranking at each hurdle throughout the final.

COACH'S COMMENTARY

Coaching commentary – Matthew Wood

The women's 60 m Hurdles was perhaps the most eagerly anticipated event at these World Championships because of the presence of such a high calibre field, including the current outdoor world record holder, Kendra Harrison, and in-form Sharika Nelvis, who at the time had run the world leading indoor time. The potential for a world record run therefore created a palpable excitement. By throwing into the mix several up and coming athletes, this was a highlight of the championships.

The initial analysis identifies the insignificance of the reaction time component to the outcome of the race. However, it does highlight a potential area that can be exploited to get closer to the WR. On this occasion, Harrison finished 0.02 s outside of the record, had she recorded the shortest reaction time (Manning: 0.137 s) the record would have been achieved. Manning's exceptional reaction coupled with her ability to project horizontally from the blocks sets her up to achieve an optimal acceleration in to the first hurdle. Overall, the athletes in the final demonstrated a relatively consistent execution of the skill of block starts. The balance between pushing through double and single leg support is perhaps individual to the athlete's personal physical capabilities.

Perhaps of interest are the relative rankings of Harrison during the initial phases of the race. Her reaction time of equal seventh perhaps reflects the pressure upon her to win the race and therefore she managed a controlled start. Manning, on the other hand potentially knew that her opportunity to win gold was to put pressure on the field from the start. Whilst Manning arrives at hurdle one ahead, Harrison's superior inter-hurdle speed sees her pulling ahead after hurdle two. Whilst the start is clearly an important focus for a coach's and athlete's attention, the need to set up an optimal hurdle clearance and therefore inter-hurdle running mechanics is perhaps more influential on the outcome of the overall performance of the women's hurdles event.

The detail presented around block exit characteristics is of interest to coaches as again it highlights the individual nature of each athlete's solution. For example, Cindy Roleder as the tallest athlete in the field demonstrates the shortest horizontal direction of travel but interestingly, not the greatest vertical displacement. This belies her skills as an effective starter despite being compromised for the event due to her stature. The shorter athletes in the field display an excellent athletic ability to project both horizontally and vertically. An optimal balance appears to be achievable whereby the female hurdles athletes reflect a more sprint like start model compared to their male counterparts. Whilst individual solutions are evident the need to achieve optimal lower joint angles in the first three steps are in line with those of a sprinter. Coaches should

therefore potentially set female hurdlers up in the blocks to execute horizontal forces similar to sprinters but maintain a focus on their ability to achieve an optimal take-off to hurdle one.

Data around the timing of each step is of interest to coaches; however, the more practical information of step length and subsequent joint angles achieved is of more use to practitioners. The varied anthropometry of athletes within this final demonstrates a need for coaches to have the ability to interpret individual performances within their understanding of the event. The quantitative data presented here has the potential to contribute to such coaching developments by facilitating coaches in the creation of individual models that make sense of the performance within the scale of each athlete.

It is common for coaches to express the speed of an athlete in terms of the relationship between stride length and frequency. Achieving a balance between these two components for a hurdle is critical to performance. This is perhaps most relevant in the inter-hurdle running segments, or rhythm units, of the race. The data confirms that stride length is not maximised in hurdles events and therefore frequency becomes more relevant. Coaches therefore should prioritise activities and practice design that reflects a demand on athletes to achieve high stride frequency whilst also performing the skill of hurdling. A simple example of this could be to reduce hurdle height and spacing to afford the opportunity of coupling frequency with the skill of hurdling.

Stand out data from the study are the individual hurdle segment times achieved by Harrison and Manning that are perhaps the key variable in explaining why they finished with gold and silver. Harrison achieved the fastest hurdle split time of 0.95 s, notably she achieved this for two segments, with her next lowest split time of 0.96 s contributing significantly to her overall time. Also of note are the split times for the final flat segment of the race. Harrison again was fastest with a 1.21 s split against Visser and Roleder as next fastest with 1.26 s. This information highlights the potential performance advantage female hurdlers can have with respect of exceptional flat speed. Further reflecting on this, it was the switching of places between Nelvis and Visser, caused by Nelvis hitting hurdle five, which compromised her final race segment.

Alongside the quantitative data presented here, it is also worth noting the need for a qualitative information to help explain the performances of individual athletes. Whilst the hurdles are lower in the women's event the element of jeopardy is no less a factor in comparison to the men's high hurdles. The outcome of a female athlete hitting a hurdle arguably has a greater influence on sprint velocity in women's hurdles, therefore more significantly influencing the outcome of the race than male athletes who in some cases can seemingly get away with it. Recent suggestions that the women's hurdle height should be increased ought to be muted with an understanding that such a change in competition specification would have the potential to change the nature of the event completely. The ensuing co-adaptation between performer and the new competition

environment has the potential to favour the capabilities of taller athletes and therefore change the event entirely.

An athlete's ability to distribute and maintain their effort across the various segments of the sprint hurdles race is potentially a key outcome for coaches to consider from this final. As is the overwhelming evidence that flat speed is a key differentiating factor in the women's hurdles event. An athlete's ability to express their sprinting ability whilst interacting with the skill of hurdling has been expertly demonstrated by the eight finalists in this report. The medallists have demonstrated on one level a near flawless performance for gold and an alternative perspective that medals were won and lost by athletes' who either regressed or progressed respectively of individual performances or the mistakes of others.

Historical analysis and coaching commentary – Pierre-Jean Vazel

The first ever comprehensive biomechanical report on women's hurdles gives insights on the technique of the world's best athletes, with special considerations on the start. This commentary will cover the question of the 7 or 8 steps approach, and will go through the main features of the three medallists.

The 7 or 8 step start?

Unlike men's 60 m hurdles, women's event has not seen a recent switch from 8 to 7 steps to the first hurdles. All the finalists in Birmingham took 8 steps. In the past some athletes with exceptional physical qualities adopted 7 steps, such as multi-eventer Chi Cheng (TPE, first woman under 13 s at 100 m hurdles in 1970), sprinter Irina Privalova (Russia, indoors in 2000 in preparation of her 400m hurdles Olympic title) and some tall heptathletes in the nineties. In recent years, former 60 m hurdles world champion Lolo Jones tried it and long jumper Janay DeLoach placed 5th at 2014 World Indoors by taking the same approach. While 8 steps is still the rule, some women seems to come too close to the hurdle, and the trick some find is to start farther from the starting line, like the 2014 World Indoor champion Nia Ali, with her hands placed some 30cm away from the line. However, defending successfully her title in 2016, she used a normal position from the line but she did not switch to 7 steps, rather she focused on higher step frequency in her approach.

In Birmingham, the distance covered for the first three steps by the female hurdlers was 3.86 m (range 4.09 - 3.71). That's more than what the female sprinters did, 3.30m (range 3.46 – 3.19), but the difference is much less than what was found in men: 4.69 m for hurdlers (all using 7 steps

approach) and 3.85 m for sprinters. In women's events, the rhythm being closer between hurdling and dash sprinting starts explains why the 7 step approach has not been employed yet. However, it is interesting to note that the former 100m hurdles world record holder Yordanka Donkova (Bulgaria, 12.21 s at 100 m hurdles and 7.74 s at 60m hurdles) tried successfully 7 steps at training, helped by her height (1.79 m) and her incredible power, but she did not make the change in competition although the times at the first hurdle were better. Indeed, 7 steps approach led to a focus on amplitude which was affecting negatively her ability to cover the first intervals between hurdles with a high frequency.

Technical features of the 2018 World Indoor medallists

Kendra Harrison (USA), 1st in 7.70 s: This performance made her the third best hurdler ever, only 0.02 s off the world record set by Suzanna Kallur (SWE) in 2008. However, during her own world record in 100 m hurdles (12.20 s in London 2016), Harrison was timed at 60 m in 7.65 s (with 6 hurdles instead of 5 hurdles in the 60 m hurdle race). At the fifth hurdle, her split was 6.33 s, compared to 6.49 s in Birmingham. This means that Harrison has the potential to run under 7.60 s for a 60 m hurdles indoors based on her best performance outdoors.

In Birmingham, Harrison had the slowest reaction time of the final, 0.168 s, while it was 0.149 s for her outdoor world record. Her early acceleration pattern was not optimal since she did not gained a lot of velocity from the second to third step, while it is desirable to keep increasing step rate at each of the 8 steps to the first hurdle. Former world champion outdoors and indoors Sally Pearson (AUS) was a model in that aspect.

Christina Manning (USA), 2nd in 7.79 s: Christina Manning was in the leading position after the first hurdles (2.57 s), mostly because she was the finalist who produced the most progressive increment in step length and frequency and consequently velocity in the first three steps. In doing so, Manning had the lowest, albeit progressive, relative CM height. Harrison's touchdown after the first hurdle happened in 2.61 s, much slower than the 2.49 s she did in London 2016. The fastest time ever published is 2.48 s by Cornelia Oschkenat (GDR) for her European indoor title in 7.77 s in 1988 (outdoors, she did 2.47 s during her 100 m hurdles semi-final at 1987 World Championships, data from by Dr Miskos, Athletics Laboratory UV CSTV, Prague). Harrison was able to win the race thanks to the fastest (or joint fastest) intervals after the second hurdle.

Nadine Visser (NED), 3rd in 7.84 s: Nadine Visser was only fifth after the first hurdle but she was as fast as Harrison in the last two intervals (0.96 s and 0.95 s). She was even the fastest in the first one, but she could not accelerate further during the second interval (1.01 s for both). This

erratic running scheme indicates large room of improvement for Visser, who set her PB in the semi-final with 7.83 s. A time close to 7.70 s shouldn't be out of reach provided that she can keep her centre of mass lower in the first three steps out of the blocks: the data showed she had the highest relative height of all the medallists, as opposed to efficient starter Manning. Video replays show that Visser had to break and lean her trunk slightly backwards before taking off for the first hurdle, as she seems to come too close. This observation is supported by the fact that she must clear the hurdle with an external rotation of her lead leg, in order to avoid hitting the hurdle. Being 1.75 m tall, this talented heptathlete might consider to switch to a 7 steps approach to the first hurdle.

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