BIOMECHANICAL REPORT

FOR THE

IAAF

WORLD INDOOR CHAMPIONSHIPS 2018

60 Metres Women

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INTRODUCTION

The women's 60 m sprint took place on the evening of Friday 2nd March. The final was to be a tight contest, as all eight finalists were coming into the competition with reasonably good form. Jamaica's Elaine Thompson was a potential favourite, having run a personal best of 6.98 s in Birmingham one year previous. Murielle Ahouré (Ivory Coast) would also be a favourite for the race as the current world leader in the 60 m sprint. Indeed, Ahouré took the gold medal in convincing fashion. With a new world leading time of 6.97 s (tied-sixth all-time), Ahouré saw off her opponents by at least 0.08 s. Ahouré's compatriot Marie-Josée Ta Lou took the silver medal, as she did in the World Outdoor Championships in London 2017. Mujinga Kambundji (Switzerland) took the bronze medal ahead of Elaine Thompson.

IAAF World Indoor Championships

Birmingham (GBR)
1-4 March 2018

RESULTS

60 Metres Women - Final

RECORDS	RESULT	NAME	COUNTRY	AGE	VENUE	DATE
World Indoor Record WIR	6.92	Irina PRIVALOVA	RUS	26	Madrid	11 Feb 1993
World Indoor Record WIR	6.92	Irina PRIVALOVA	RUS	27	Madrid	9 Feb 1995
Championship Record CR	6.95	Gail DEVERS	USA	27	Toronto (The Sky Dome)	12 Mar 1993
World Leading WL	6.97	Murielle AHOURÉ	CIV	31	Birmingham	2 Mar 2018

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

2 March 2018 21:42 START TIME

PLACE	NAME	COUNTRY	DATE of BIRTH	LANE	RESULT		REACTION	Fn
1	Murielle AHOURÉ	CIV	23 Aug 87	4	6.97	WL	0.162	
2	Marie-Josée TA LOU	CIV	18 Nov 88	6	7.05 (.043)	PB	0.170	
3	Mujinga KAMBUNDJI	SUI	17 Jun 92	5	7.05 (.048)		0.160	
4	Elaine THOMPSON	JAM	28 Jun 92	3	7.08		0.174	
5	Dafne SCHIPPERS	NED	15 Jun 92	2	7.10		0.170	
6	Michelle-Lee AHYE	TTO	10 Apr 92	7	7.13	SB	0.138	
7	Carolle ZAHI	FRA	12 Jun 94	1	7.19		0.157	
8	Remona BURCHELL	JAM	15 Sep 91	8	7.50		0.169	

Timing and Measurement by SEIKO AT-60-W-f--1--.RS1..v1 Issued at 21:46 on Friday, 02 March 2018

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asics SEIKO TDK

METHODS

Five vantage locations for camera placement were identified and secured. Each location had the capacity to accommodate multiple cameras placed on tripods. Two locations were situated on broadcasting platforms around the stadium, one was located close to the Seiko box, and 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).

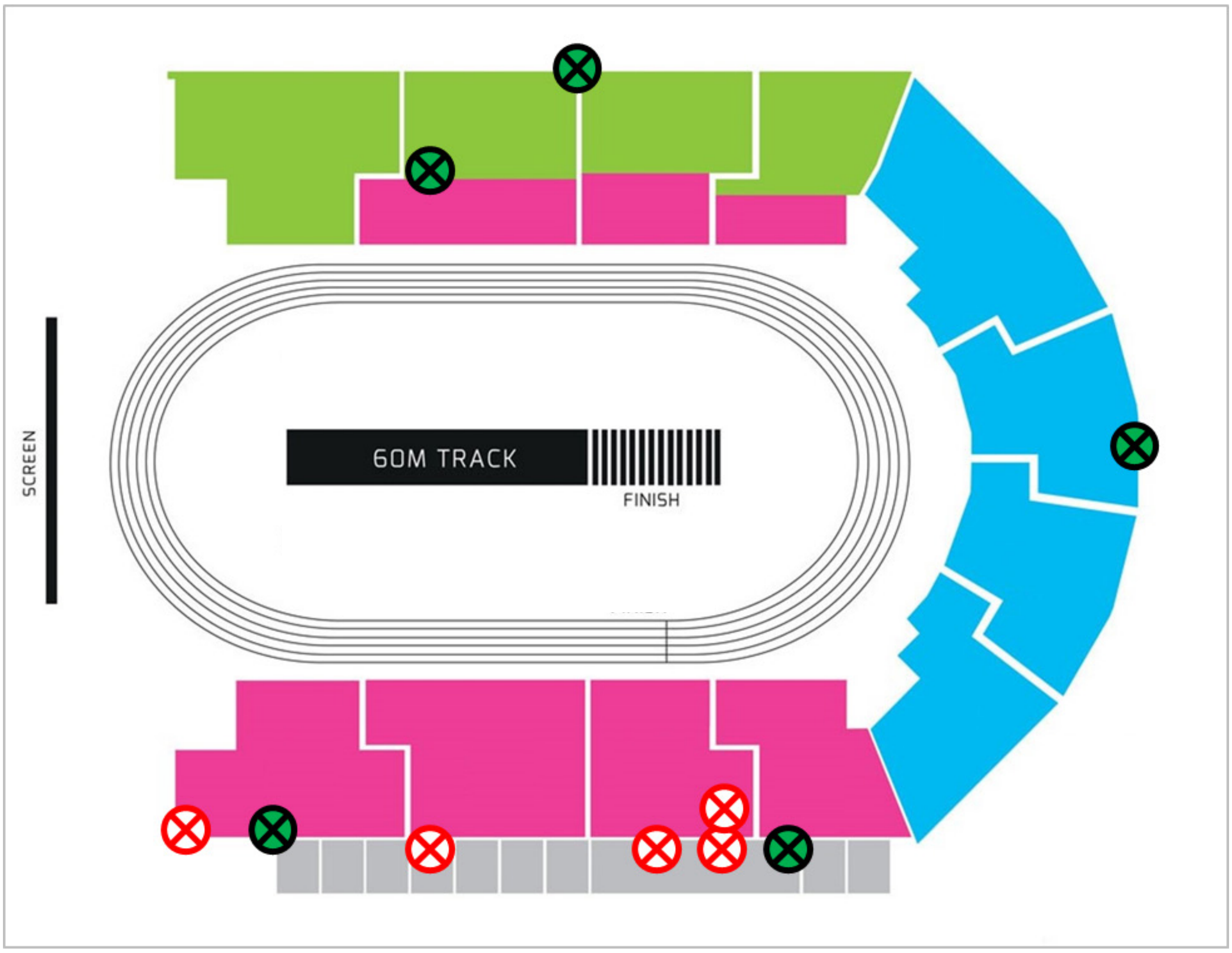

Figure 1. Camera layout for the women's 60 m indicated by green-filled circles.

Two separate calibration procedures were conducted before and after the event. First, a series of eight interlinked training hurdles were placed at the 10 m point on the track ensuring that the crossbar of each hurdle, covered with black and white tape, was aligned with the track's transverse line. Second, 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, eight high-speed cameras were employed to record the action during the 60 m 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 at the 10 m mark in order to capture motion in the sagittal plane and provide footage for the analysis of the 10 m split time. Two Sony RX10 M3 cameras operating at 100 Hz were used to provide extra angles for qualitative confirmation of the split time calculations. Five Sony RX10 M3 cameras operating in HFR (high frame rate) mode at 250 Hz (shutter speed: 1/1250; ISO: 2000-3600; FHD: 1920x1080 px) were used to capture motion of athletes within the calibrated volume around block exit and the sprint start.

Figure 3. The block start of the women's 60 m 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 were processed through SIMI Motion by using the 200 Hz and 250 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.
Time to 10 m	The time that each athlete took to reach the 10 m mark.
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 / 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.

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.

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 10 m (based on time to 10 m in 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 eight finalists.

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)
AHOURÉ	0.163	0.128	0.291	0.453
TA LOU	0.181	0.136	0.317	0.487
KAMBUNDJI	0.207	0.132	0.339	0.499
THOMPSON	0.204	0.160	0.364	0.538
SCHIPPERS	0.181	0.176	0.357	0.527
AHYE	0.167	0.168	0.335	0.473
ZAHI	0.208	0.164	0.372	0.529
BURCHELL	0.185	0.152	0.337	0.506

Table 2 (above) shows the time each athlete spent in the different phases that make up block exit. Total block time is the sum of push time, double-leg block time and single-leg block time. As can be seen from the results, Murielle Ahouré displayed the shortest total block time of all finalists. This allowed Ahouré to be the first athlete to exit the blocks, despite only having the fourth shortest reaction time (Table 3). Figure 4 (below) shows the different phases of block exit as a percentage of total block time, showing, for example, that Michelle-Lee Ahye (6th placed) showed the shortest relative reaction time but the longest relative single-leg push phase.

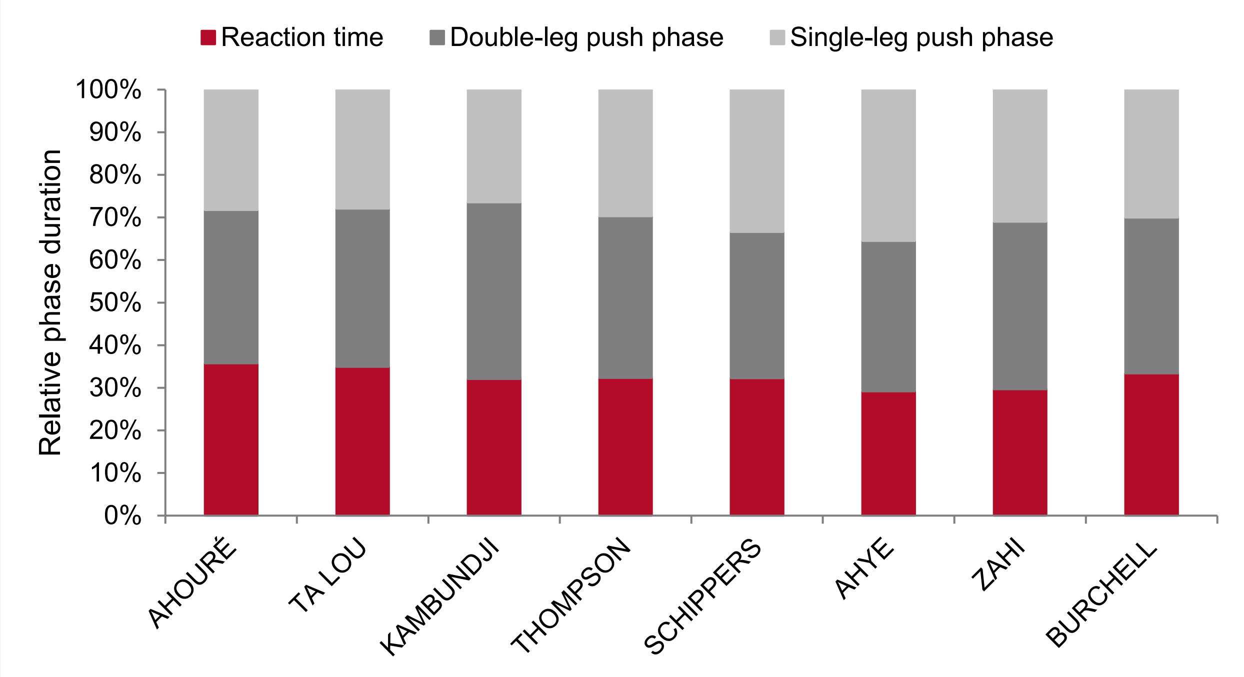

Figure 4. Relative duration of block exit phases, displayed relative to total block time for each finalist.

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
AHOURÉ	4	1	1
TA LOU	=6	3	2
KAMBUNDJI	3	4	5
THOMPSON	8	8	6
SCHIPPERS	=6	6	8
AHYE	1	2	3
ZAHI	2	7	7
BURCHELL	5	5	4

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. Figure 5 shows that Murielle Ahouré had the shortest block clearance distance, whilst Michelle-Lee Ahye touched down furthest from the start line. Figure 6 highlights the fact that Ahye also had the longest block flight time.

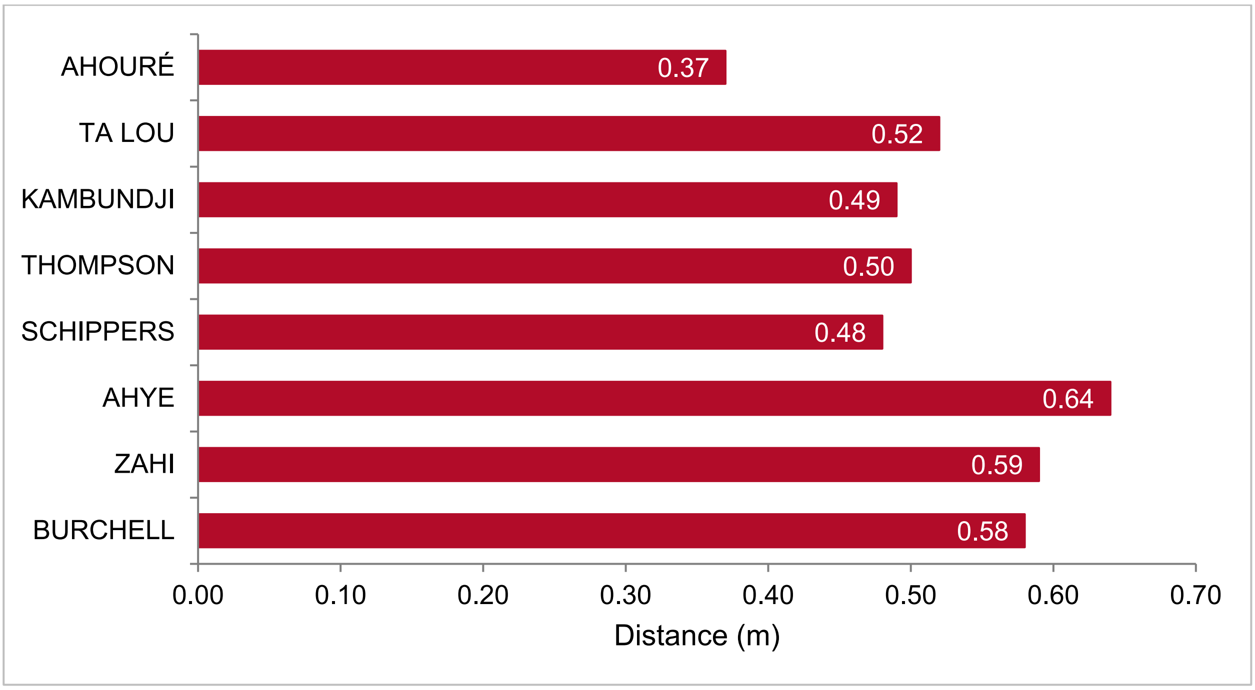

Figure 5. Block clearance distance (horizontal distance between start line and point of initial ground contact) for each of the finalists.

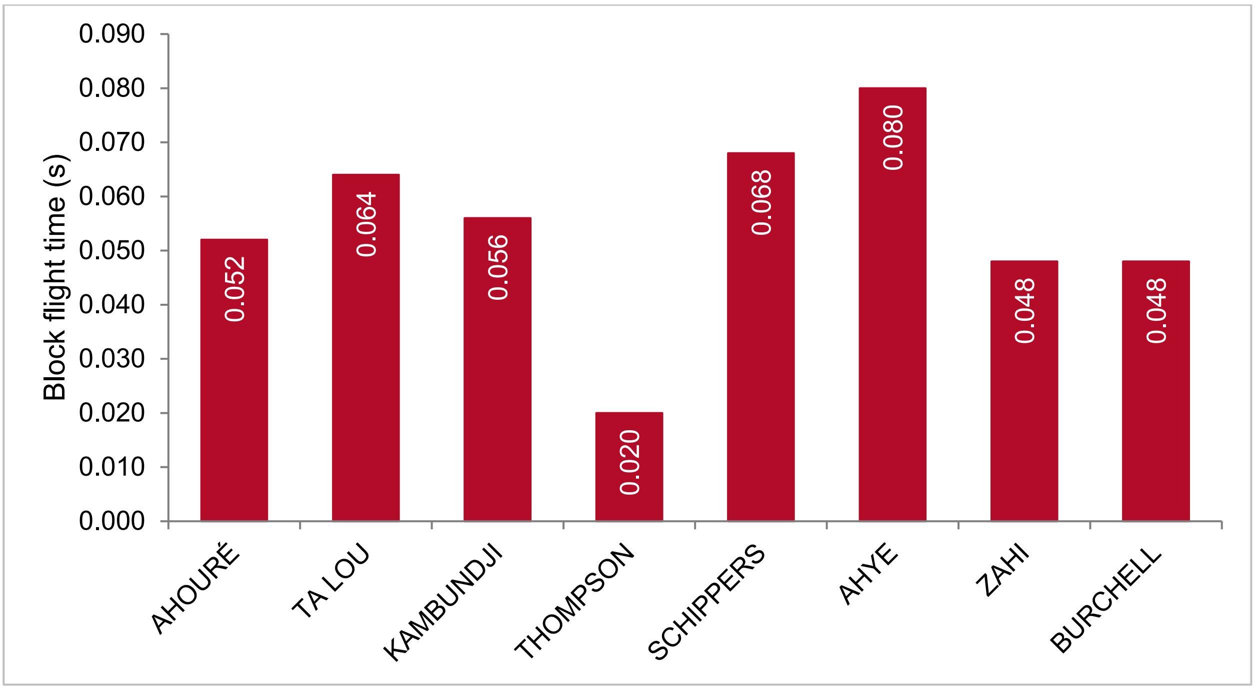

Figure 6. Block flight time (from block clearance to initial ground contact) for each of the finalists.

Figure 6 shows that Elaine Thompson clearly displayed the shortest block flight time, which may explain why she was the 6th athlete to reach initial touchdown, despite being last out of the blocks.

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

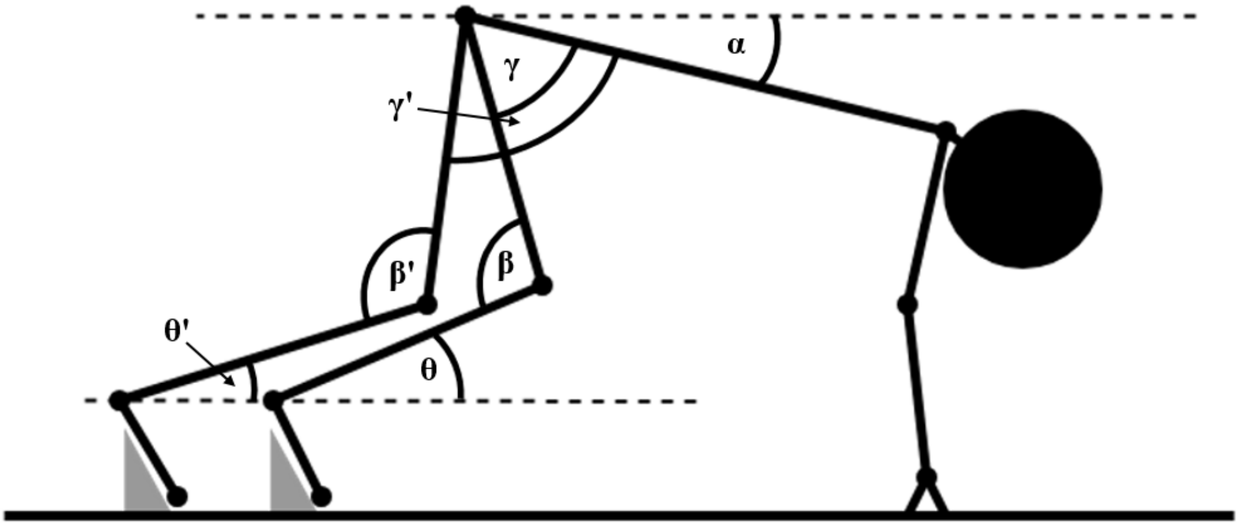

Figure 7. Body schematic denoting joint and segment angles measured in the set position.

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'
AHOURÉ	−23.7	49.5	79.0	110.4	130.1	36.5	28.1
TA LOU	−10.1	45.4	72.7	81.7	106.6	27.0	22.1
KAMBUNDJI	−19.8	37.9	75.3	94.8	120.1	34.4	27.2
THOMPSON	−27.2	40.3	71.7	115.9	138.1	48.9	38.6
SCHIPPERS	−16.7	48.8	90.4	92.7	133.9	28.5	24.9
AHYE	−19.0	38.4	87.0	89.6	134.2	32.6	27.5
ZAHI	−16.7	45.8	90.7	106.2	143.1	45.0	35.0
BURCHELL	−21.9	47.1	84.4	104.2	129.9	35.2	23.8

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

As can be seen from Table 4, the top four athletes tend to show a smaller rear-leg hip angle than the bottom four finishers. This may indicate that the hip extensors are at a longer muscle-tendon length, indicating a potential pre-stretch before contracting during block clearance. 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.

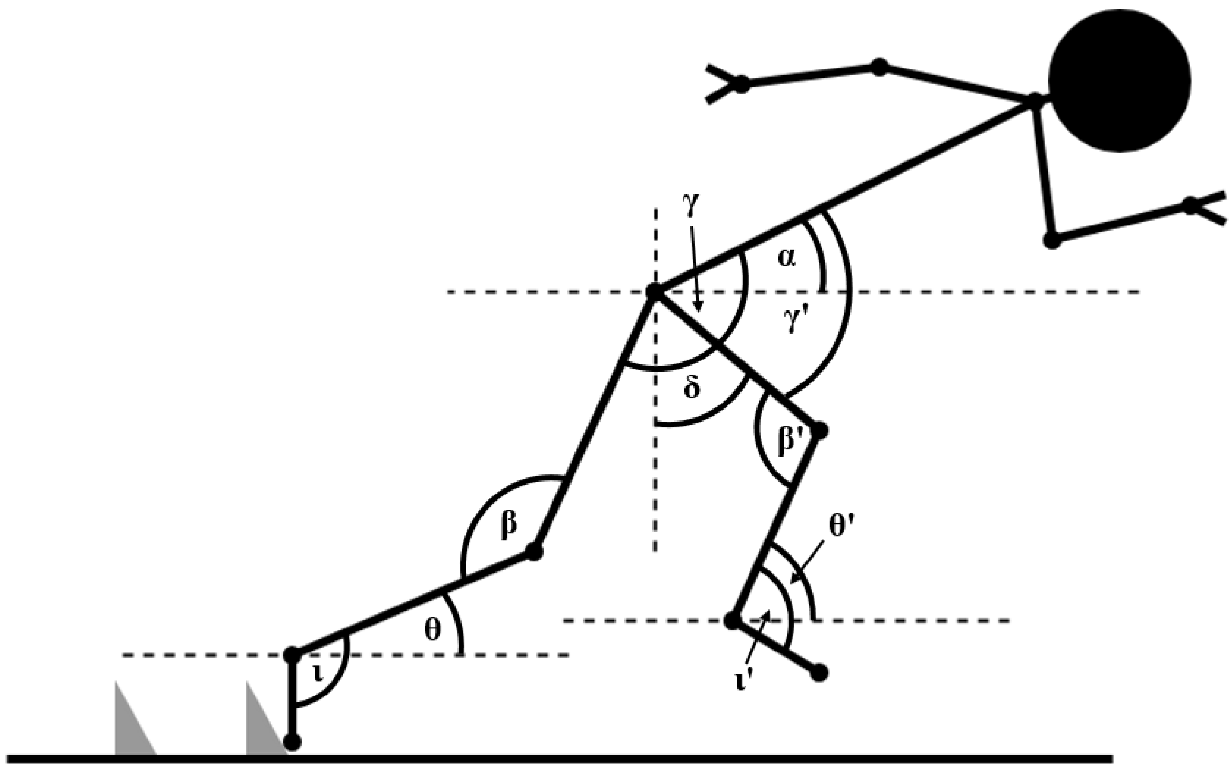

Figure 8. Body schematic denoting joint and segment angles measured at block exit.

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'	ι	ι'
AHOURÉ	24.2	160.6	79.7	34.8	169.6	73.9	32.4	18.1	137.5	90.1
TA LOU	22.5	153.4	66.2	48.7	170.0	81.5	35.5	40.1	130.9	93.0
KAMBUNDJI	30.9	167.8	69.4	52.5	168.3	77.7	31.1	40.8	136.3	96.9
THOMPSON	29.7	162.1	75.8	45.2	163.1	95.1	29.9	50.3	134.3	98.4
SCHIPPERS	26.9	171.4	66.2	48.7	176.3	84.7	38.2	43.4	147.7	84.2
AHYE	30.5	167.2	76.1	47.0	170.7	79.8	32.4	37.1	130.4	96.0
ZAHI	35.4	172.1	78.2	51.6	170.5	84.8	28.6	46.6	118.9	81.2
BURCHELL	28.6	167.7	66.7	58.2	173.3	78.1	31.5	46.7	121.4	93.1

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 athletes who finished 7th and 8th overall showed the lowest degree of ankle plantarflexion at the point of block exit (Zahi = 118.9°; Burchell = 121.4°). This may indicate that they may not be fully utilising the plantarflexor muscles during block clearance. It may also be noted that Ahouré showed the most acute shank angle in the lead leg (angle θ') compared to the other finalists. This has the capacity to reduce the moment of inertia around the hip joint during swing, thus potentially increasing angular velocity of hip flexion.

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.

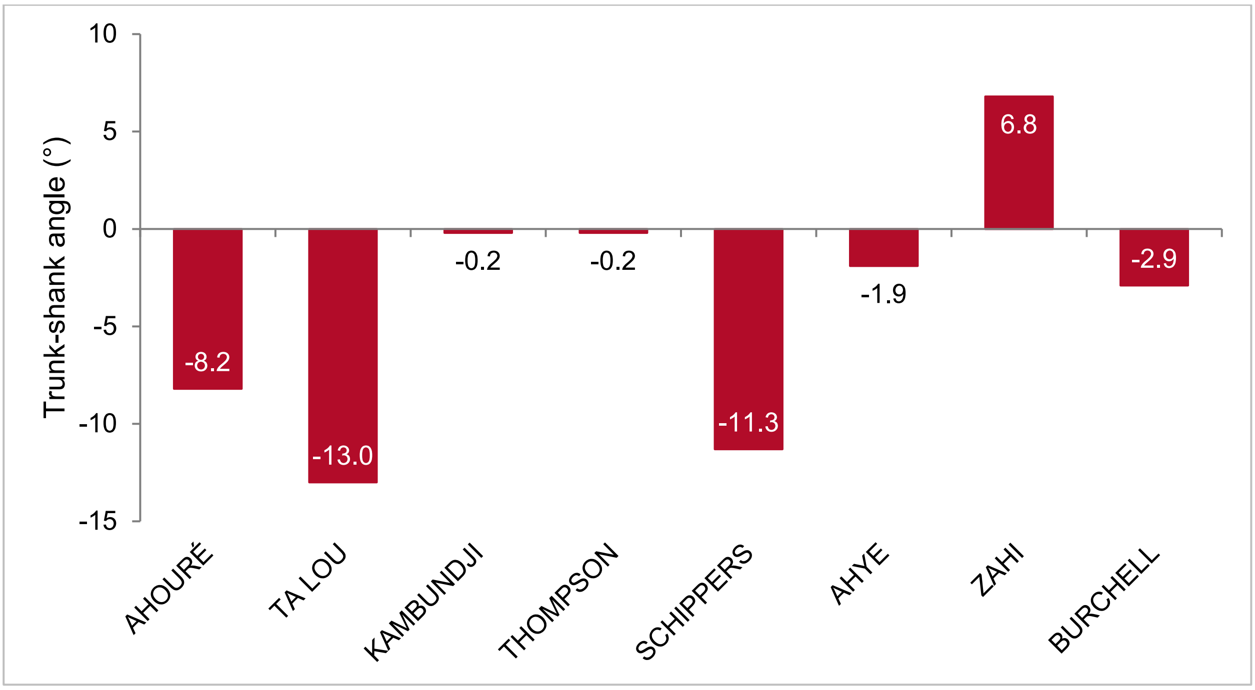

Figure 9. Trunk-trailing shank angle of incidence ($\alpha-\theta$) at block exit for each of the finalists.

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 0.10 to 0.25 m, whilst CM height ranged from 0.54 to 0.63 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)
AHOURÉ	0.58	0.16
TA LOU	0.54	0.10
KAMBUNDJI	0.56	0.25
THOMPSON	0.63	0.18
SCHIPPERS	0.57	0.24
AHYE	0.58	0.10
ZAHI	0.62	0.23
BURCHELL	0.57	0.14

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.

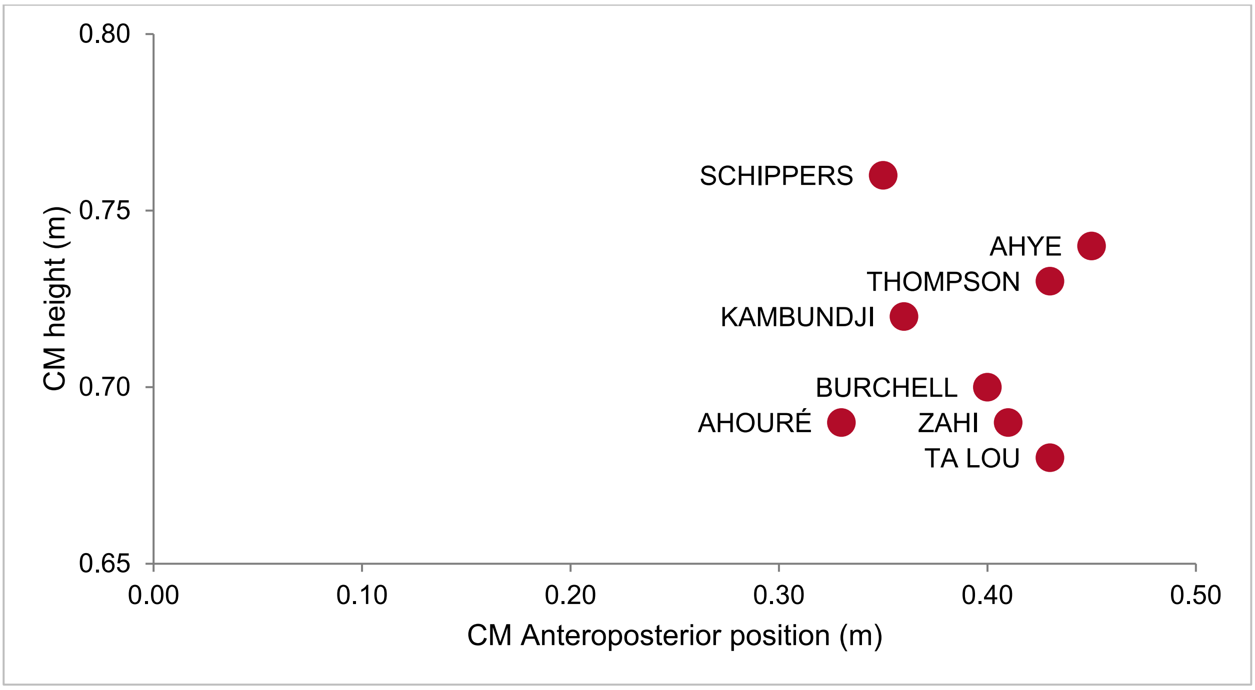

Figure 10. CM position (relative to the start line) for each finalist at the instant of block exit.

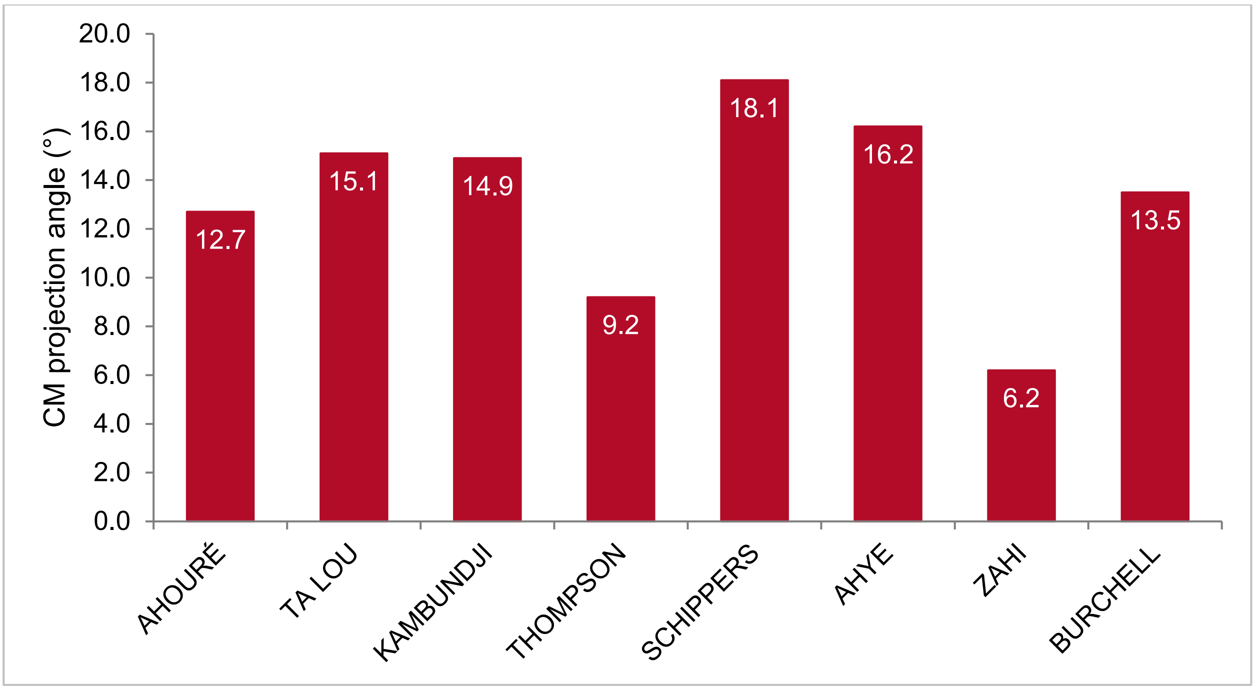

Figure 11. CM projection angle from set position to block exit for each finalist.

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)		
	1st step	2nd step	3rd step
AHOURÉ	0.180	0.140	0.156
TA LOU	0.180	0.124	0.144
KAMBUNDJI	0.168	0.140	0.144
THOMPSON	0.212	0.160	0.148
SCHIPPERS	0.176	0.152	0.140
AHYE	0.176	0.128	0.132
ZAHI	0.192	0.164	0.152
BURCHELL	0.208	0.136	0.152

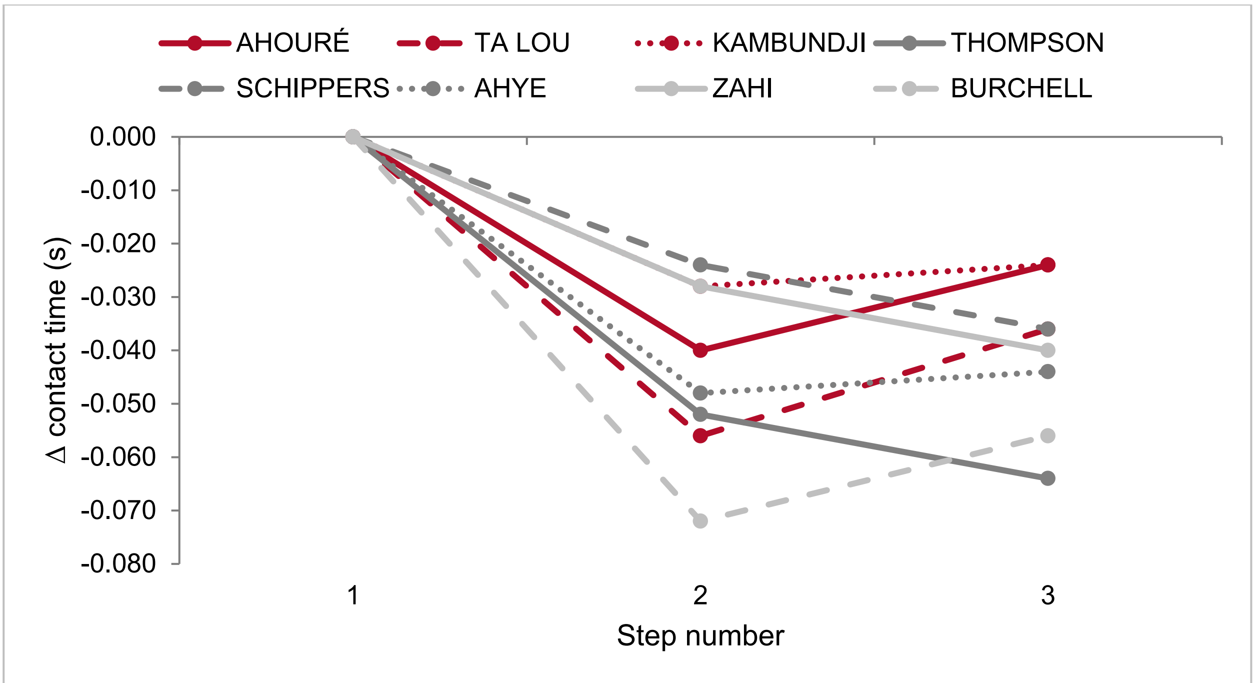

Figure 12. Change in ground contact time throughout the first three steps (1-2, 1-3) of the race for all finalists (first contact is used as zero reference point for the other two contacts).

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

Athlete	Flight time (s)		
	1st step	2nd step	3rd step
AHOURÉ	0.064	0.044	0.076
TA LOU	0.072	0.068	0.072
KAMBUNDJI	0.076	0.056	0.060
THOMPSON	0.044	0.048	0.060
SCHIPPERS	0.064	0.068	0.076
AHYE	0.088	0.080	0.088
ZAHI	0.064	0.060	0.084
BURCHELL	0.072	0.072	0.060

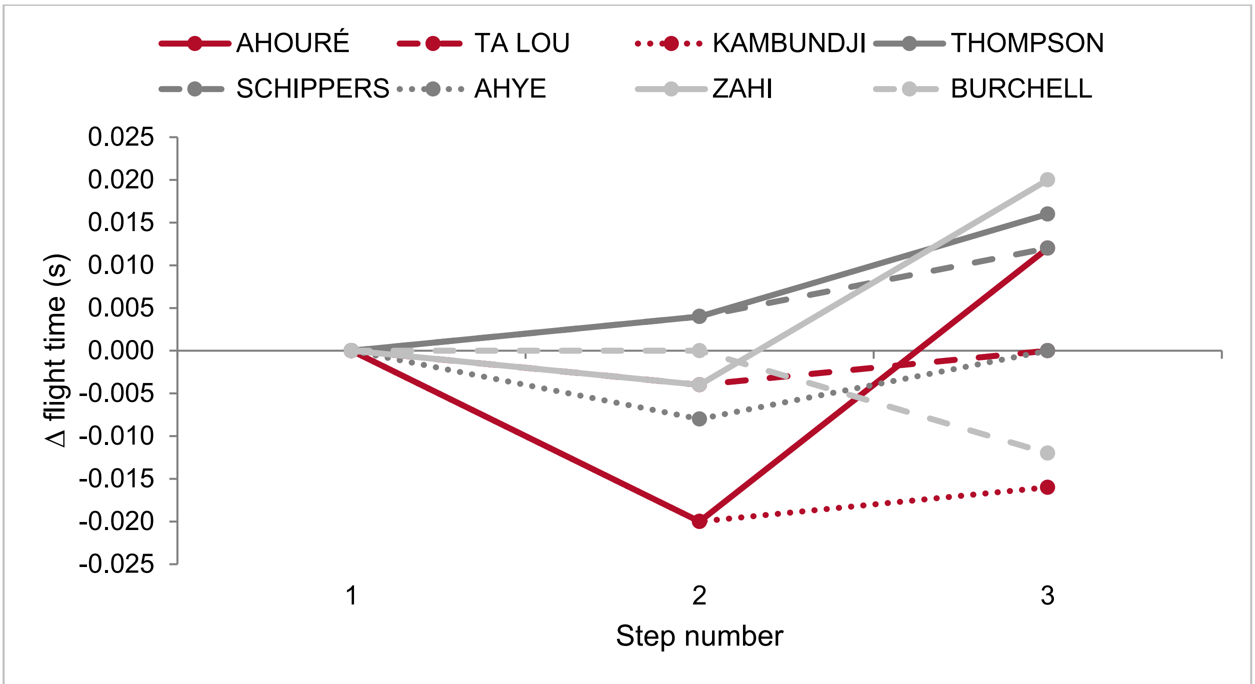

Figure 13. Change in flight time throughout the first three steps (1-2, 1-3) of the race for all finalists (first flight is used as zero reference point for the other two flights).

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

Athlete	Step time (s)		
	1st step	2nd step	3rd step
AHOURÉ	0.244	0.184	0.232
TA LOU	0.252	0.192	0.216
KAMBUNDJI	0.244	0.196	0.204
THOMPSON	0.256	0.208	0.208
SCHIPPERS	0.240	0.220	0.216
AHYE	0.264	0.208	0.220
ZAHI	0.256	0.224	0.236
BURCHELL	0.280	0.208	0.212

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

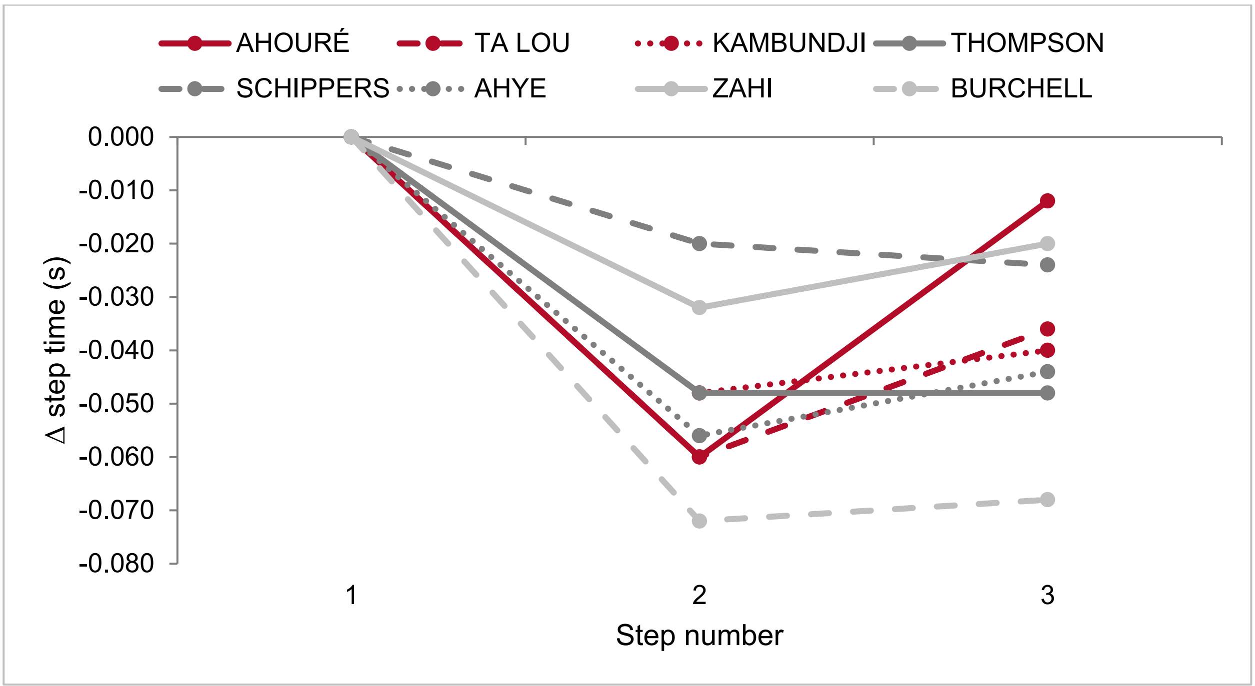

Figure 14. Change in step time throughout the first three steps (1-2, 1-3) of the race for all finalists (first step is used as zero reference point for the other two steps).

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 rankings for second, third and fourth touchdowns (TD).

Athlete	Ranking		
	2nd TD	3rd TD	4th TD
AHOURÉ	1	1	1
TA LOU	3	2	3
KAMBUNDJI	2	3	2
THOMPSON	4	4	4
SCHIPPERS	8	7	7
AHYE	5	5	5
ZAHI	6	8	8
BURCHELL	7	6	6

The following table shows each athlete's time to the 10 m mark. When time to 10 m includes reaction time, two out of the three eventual medallists (Ahouré and Kambundji) were already the three race leaders after 10 m. This indicates that athlete performance around block exit and the first few metres plays a decisive role in final race outcome. To highlight the importance of this stage of the race, athletes spend approximately 29% of their race time within the first 17% of the race distance (Table 11).

Table 11. 10 m split times (excluding and including reaction time) for each of the finalists. The race ranking at 10 m is also displayed as well as the time to 10 m (incl. RT) as a percentage of the official 60 m time.

Athlete	Time to 10 m (excl. RT) (s)	Time to 10 m (incl. RT) (s)	Ranking at 10 m	Time to 10 m (% 60 m time)
AHOURÉ	1.820	1.982	1	28.44
TA LOU	1.870	2.040	5	28.73
KAMBUNDJI	1.875	2.035	3	28.87
THOMPSON	1.880	2.054	6	28.81
SCHIPPERS	1.910	2.080	7	28.93
AHYE	1.880	2.018	2	28.62
ZAHI	1.880	2.037	4	28.77
BURCHELL	1.935	2.104	8	28.05

Note: *RT = reaction time.*

Kinematic characteristics of the sprint start

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

Table 12. Step lengths and step frequencies of the first three steps for each of the finalists.

Athlete	Variable	1st step	2nd step	3rd step
AHOURÉ	Step length (m)	1.03	1.01	1.30
	Step frequency (Hz)	4.10	5.43	4.31
TA LOU	Step length (m)	0.85	1.10	1.24
	Step frequency (Hz)	3.97	5.21	4.63
KAMBUNDJI	Step length (m)	0.93	1.14	1.21
	Step frequency (Hz)	4.10	5.10	4.90
THOMPSON	Step length (m)	0.96	1.07	1.22
	Step frequency (Hz)	3.91	4.81	4.81
SCHIPPERS	Step length (m)	0.97	1.11	1.16
	Step frequency (Hz)	4.17	4.55	4.63
AHYE	Step length (m)	1.04	1.14	1.25
	Step frequency (Hz)	3.79	4.81	4.55
ZAHI	Step length (m)	1.10	1.20	1.16
	Step frequency (Hz)	3.91	4.46	4.24
BURCHELL	Step length (m)	0.91	1.10	1.22
	Step frequency (Hz)	3.57	4.81	4.72

As can be seen from Table 12, athletes tended to increase their step length throughout the first three steps. This is typical for an acceleration phase of a sprint, as increasing this parameter will result in an increase in running speed. It may be worth noting that Murielle Ahouré (gold medallist) displayed the highest step frequency in the second step (5.43 Hz) as well as the longest absolute step length during the third step (1.30 m) of all finalists. 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.

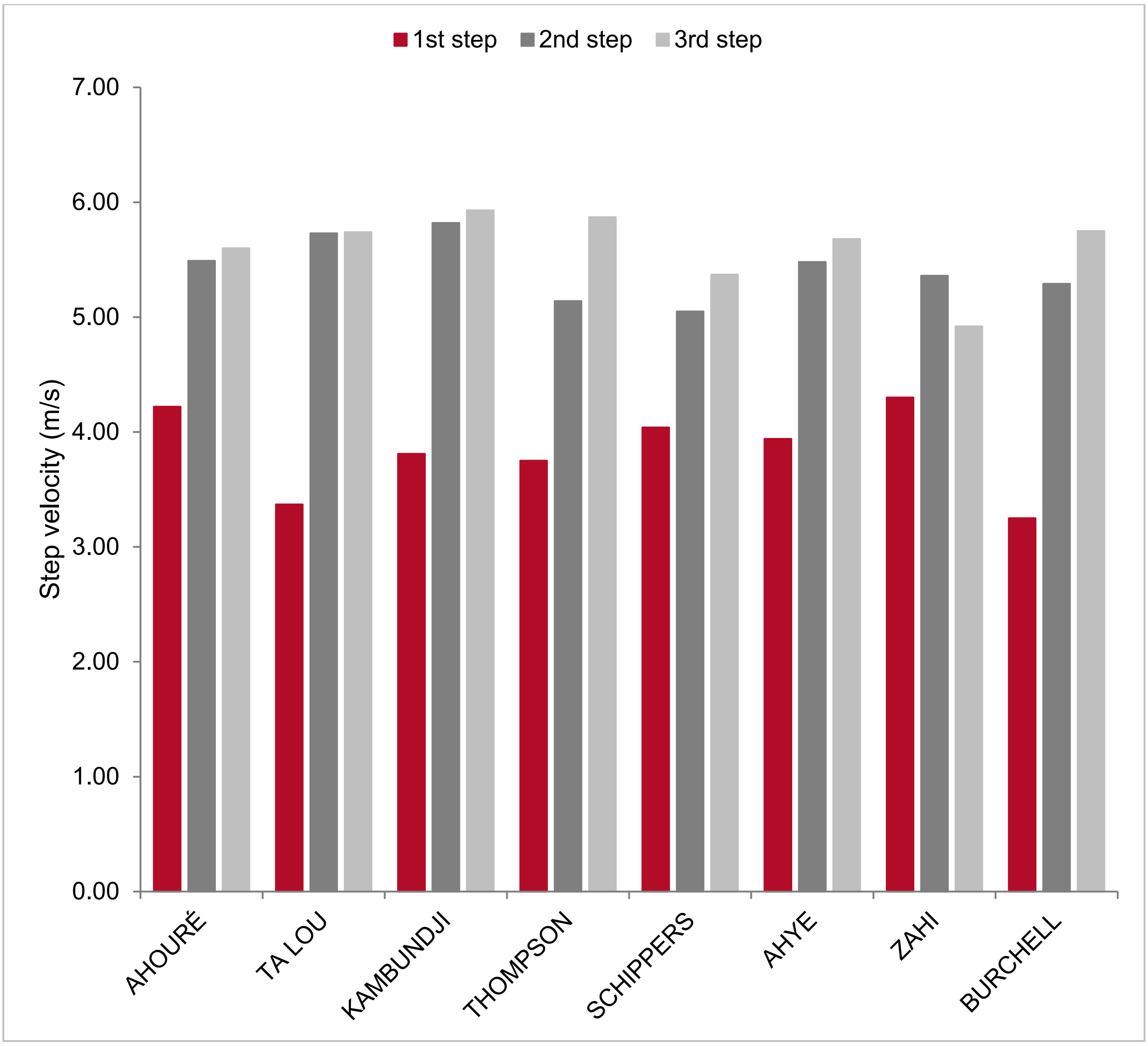

Figure 15. Step velocity for the first three steps of the race for each of the finalists.

The following two pages show the postural characteristics of each athletes' 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.

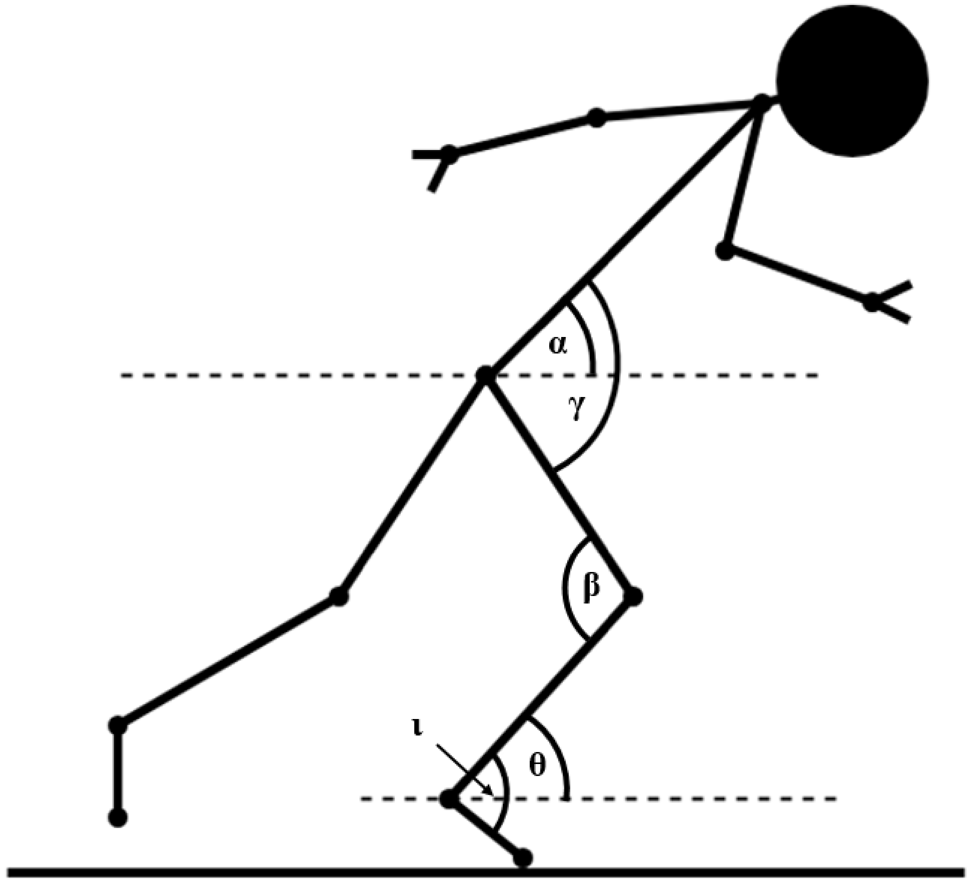

Figure 16. Body schematic denoting joint and segment angles measured at touchdown.

Table 13. Joint and segment angles at touchdown for the three medallists.

Athlete	Step number	Joint angle (°)				
		α	γ	β	θ	ι
AHOURÉ	1	30.7	81.1	88.8	38.3	92.7
	2	39.8	92.6	105.2	49.6	107.4
	3	43.4	93.5	110.8	62.0	94.4
TA LOU	1	30.9	101.5	114.2	48.8	97.8
	2	39.9	94.7	108.8	48.7	97.7
	3	42.3	98.4	115.4	61.8	94.5
KAMBUNDJI	1	34.6	84.7	92.3	42.8	93.5
	2	43.7	111.4	112.8	48.8	91.3
	3	49.8	109.2	120.3	60.9	98.5

Table 14. Joint and segment angles at touchdown for the remaining finalists.

Athlete	Step number	Joint angle (°)				
		α	γ	β	θ	ι
THOMPSON	1	31.2	82.8	99.4	49.8	98.9
	2	43.7	100.3	111.0	54.1	96.3
	3	40.0	89.5	113.4	64.4	98.7
SCHIPPERS	1	32.9	94.0	110.6	49.1	98.7
	2	39.6	107.2	122.5	57.4	103.7
	3	40.1	97.3	123.6	65.0	98.5
AHYE	1	35.3	91.2	103.9	49.1	101.3
	2	50.5	116.4	116.3	50.7	99.5
	3	46.1	114.6	134.1	66.0	107.6
ZAHI	1	36.1	91.4	102.8	51.2	86.4
	2	43.3	91.5	114.5	63.0	90.9
	3	43.8	97.3	120.5	69.4	96.7
BURCHELL	1	27.9	85.9	105.2	53.2	96.2
	2	51.5	123.8	121.5	51.8	103.6
	3	53.8	113.4	121.5	63.8	104.1

Athletes tend to increase trunk angle throughout the sequence of ground contacts, except for a few. This progression in trunk angle indicates a transition from the block start into high velocity sprinting, and it appears that different athletes tend to vary their approach to this. Tables 13 and 14 show that athletes also tend to touch down with a progressively more extended knee joint (angle β) during the first three steps. This may also be indicative of the transition from block clearance to high-velocity running. 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.

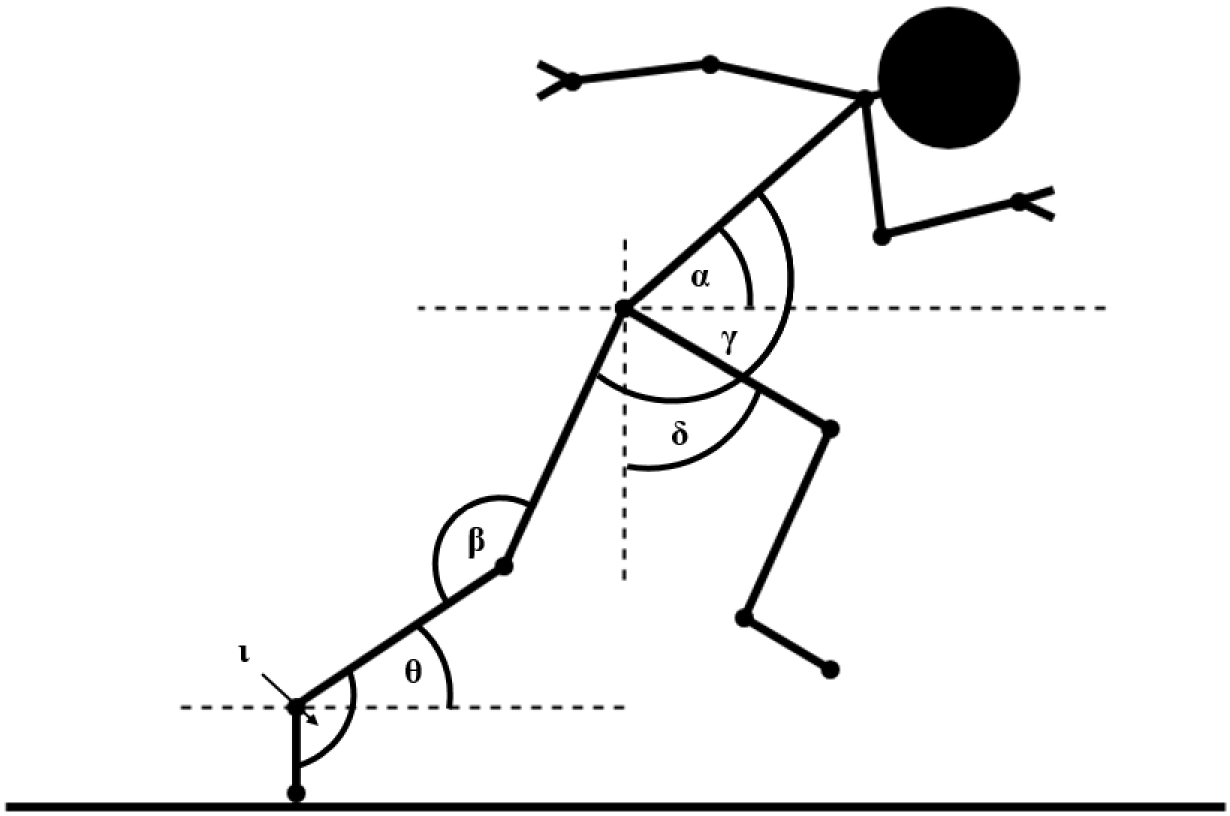

Figure 17. Body schematic denoting joint and segment angles measured at toe-off.

Table 15. Joint and segment angles at toe-off for the three medallists.

Athlete	Step number	Joint angle (°)					
		α	γ	δ	β	θ	ι
AHOURÉ	1	37.5	164.2	59.9	156.4	29.3	143.8
	2	41.6	167.0	59.4	159.5	33.1	130.9
	3	49.3	175.3	68.8	158.9	31.2	137.3
TA LOU	1	30.3	154.4	60.9	155.7	32.4	124.5
	2	40.0	159.0	63.2	158.0	35.1	141.1
	3	42.5	173.4	70.1	170.2	36.9	137.9
KAMBUNDJI	1	39.0	165.9	57.7	165.2	35.9	131.3
	2	43.4	162.9	62.6	153.3	32.4	143.8
	3	47.5	170.3	62.0	159.8	34.4	129.3

Table 16. Joint and segment angles at toe-off for the remaining finalists.

Athlete	Step number	Joint angle (°)					
		α	γ	δ	β	θ	ι
THOMPSON	1	39.8	160.9	53.2	150.1	28.1	132.8
	2	45.1	169.9	59.8	157.1	31.2	133.4
	3	43.9	168.9	59.3	163.4	36.5	131.0
SCHIPPERS	1	37.2	160.1	52.7	161.2	37.0	136.3
	2	40.3	165.5	61.9	164.1	40.3	138.1
	3	42.0	163.9	53.6	167.2	42.7	141.7
AHYE	1	45.4	174.4	57.4	161.0	31.5	141.0
	2	46.3	173.7	60.6	166.2	37.9	135.7
	3	48.7	173.3	59.8	168.4	41.2	134.2
ZAHI	1	38.3	161.9	59.0	157.4	31.4	123.4
	2	40.8	166.8	61.7	161.4	33.2	123.2
	3	43.4	169.5	62.2	164.4	36.7	122.6
BURCHELL	1	47.2	157.9	60.2	142.4	27.3	133.7
	2	51.3	172.0	57.9	160.4	36.3	137.5
	3	49.9	169.7	60.9	165.5	36.3	129.2

Figure 18 (below) shows the change in trunk angle throughout the first three steps at toe-off. As previously mentioned, athletes tend to show progressive increases in trunk angle at both touchdown and toe-off. It may be noted that the three medallists (shown in crimson in Figure 18) show a greater change in trunk angle by the third toe-off than the other five finalists, although all athletes do show a net increase in trunk angle from toe-off in step one to toe-off in step three.

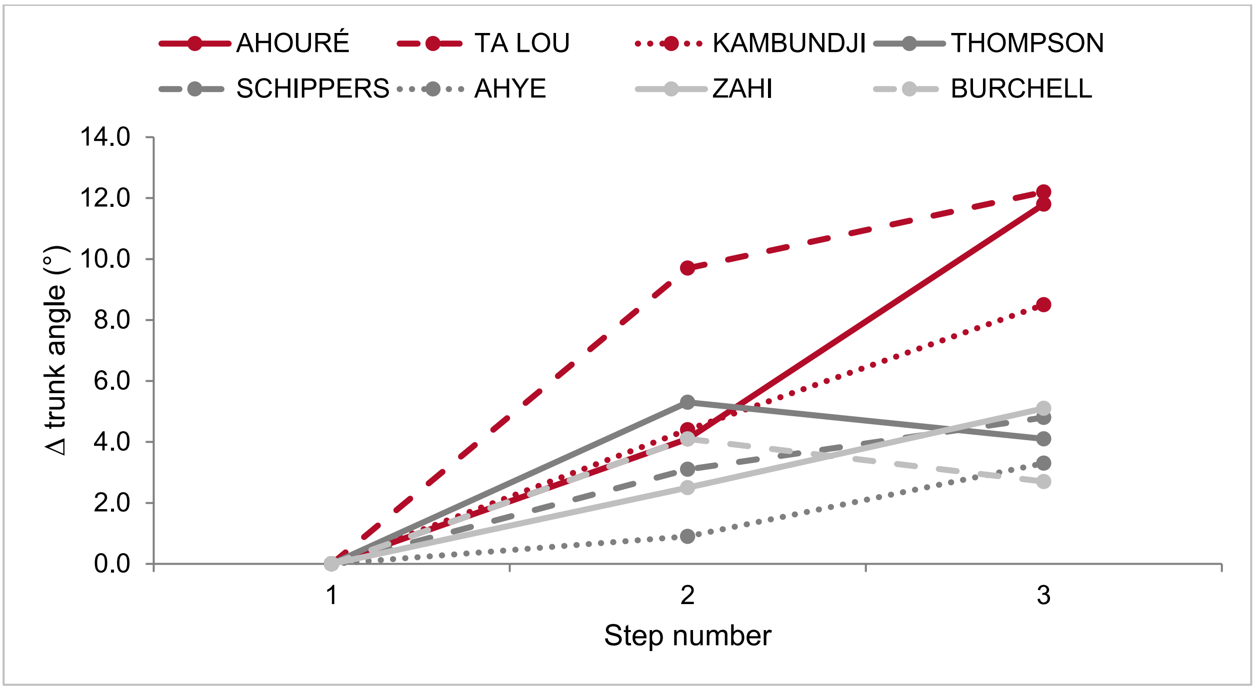

Figure 18. Change in trunk angle at toe-off throughout the first three steps (1-2, 1-3) of the race for all finalists (first toe-off is used as zero reference point for the other two toe-offs).

The following two pages contain four tables (Tables 17-20). Tables 17 and 18 show the trunk-shank angle of incidence at touchdown and toe-off, respectively, for the first three steps of the race. Tables 19 and 20 show the anteroposterior location of the CM relative to the point of ground contact, both at touchdown (Table 19) and toe-off (Table 20). Data are shown for the first three steps of the race. As can be seen from Table 19, all athletes touch down with their CM ahead of, or above, the point of ground contact. This may corroborate with some of postural characteristics shown previously.

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

Athlete	Trunk-shank angle (°)		
	1st step	2nd step	3rd step
AHOURÉ	−7.6	−9.8	−18.6
TA LOU	−17.9	−8.8	−19.5
KAMBUNDJI	−8.2	−5.1	−11.1
THOMPSON	−18.6	−10.4	−24.4
SCHIPPERS	−16.2	−17.8	−24.9
AHYE	−13.8	−0.2	−19.9
ZAHI	−15.1	−19.7	−25.6
BURCHELL	−25.3	−0.3	−10.0

Table 18. Trunk-shank angle of incidence at toe-off for the first three steps for each of the finalists.

Athlete	Trunk-shank angle (°)		
	1st step	2nd step	3rd step
AHOURÉ	8.2	8.5	18.1
TA LOU	−2.1	4.9	5.6
KAMBUNDJI	3.1	11	13.1
THOMPSON	11.7	13.9	7.4
SCHIPPERS	0.2	0.0	−0.7
AHYE	13.9	8.4	7.5
ZAHI	6.9	7.6	6.7
BURCHELL	19.9	15.0	13.6

Table 19. 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)		
	1st step	2nd step	3rd step
AHOURÉ	0.12	0.08	−0.11
TA LOU	0.11	0.11	−0.05
KAMBUNDJI	0.08	0.09	−0.02
THOMPSON	0.01	−0.03	−0.11
SCHIPPERS	0.11	0.03	−0.07
AHYE	0.07	0.10	−0.03
ZAHI	0.00	−0.07	−0.16
BURCHELL	0.01	0.13	−0.05

Note: *A negative value 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 20. 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)		
	1st step	2nd step	3rd step
AHOURÉ	0.80	0.69	0.75
TA LOU	0.68	0.68	0.70
KAMBUNDJI	0.73	0.76	0.69
THOMPSON	0.74	0.73	0.68
SCHIPPERS	0.74	0.72	0.71
AHYE	0.75	0.69	0.66
ZAHI	0.73	0.72	0.68
BURCHELL	0.67	0.67	0.67

Note: *A negative value 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 (bottom of 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.

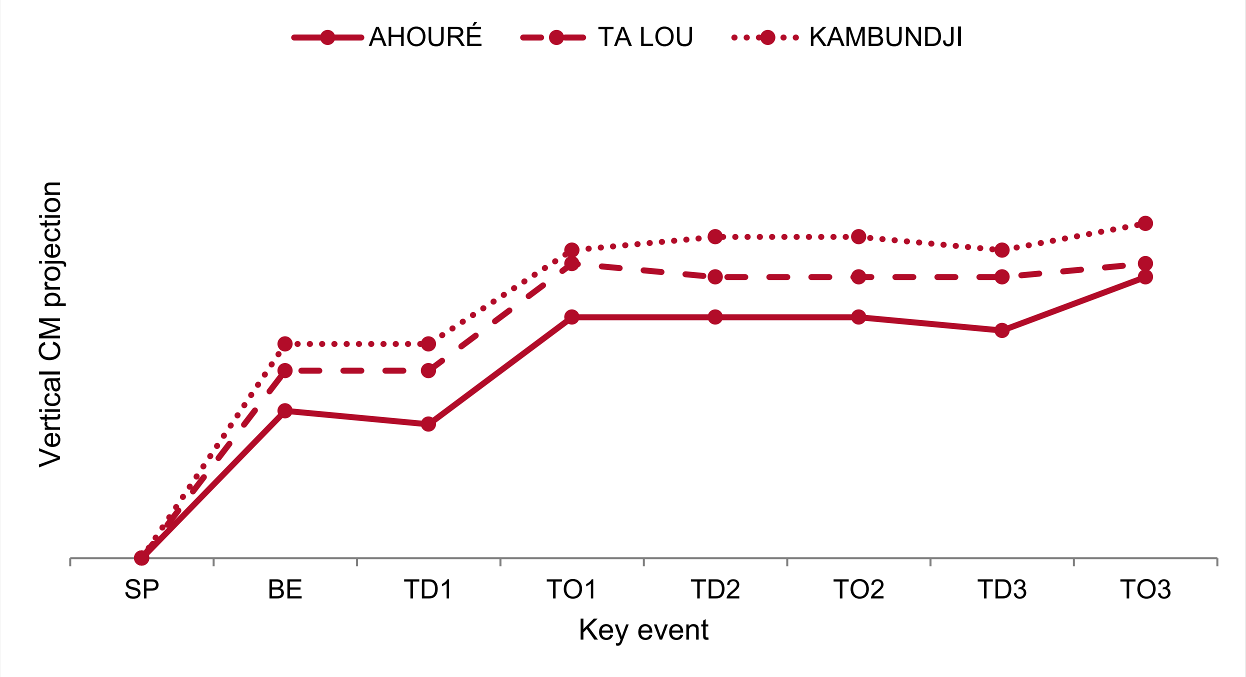

Figure 19. Vertical projection of the CM pathway throughout multiple key events during the sprint start for the medallists only.

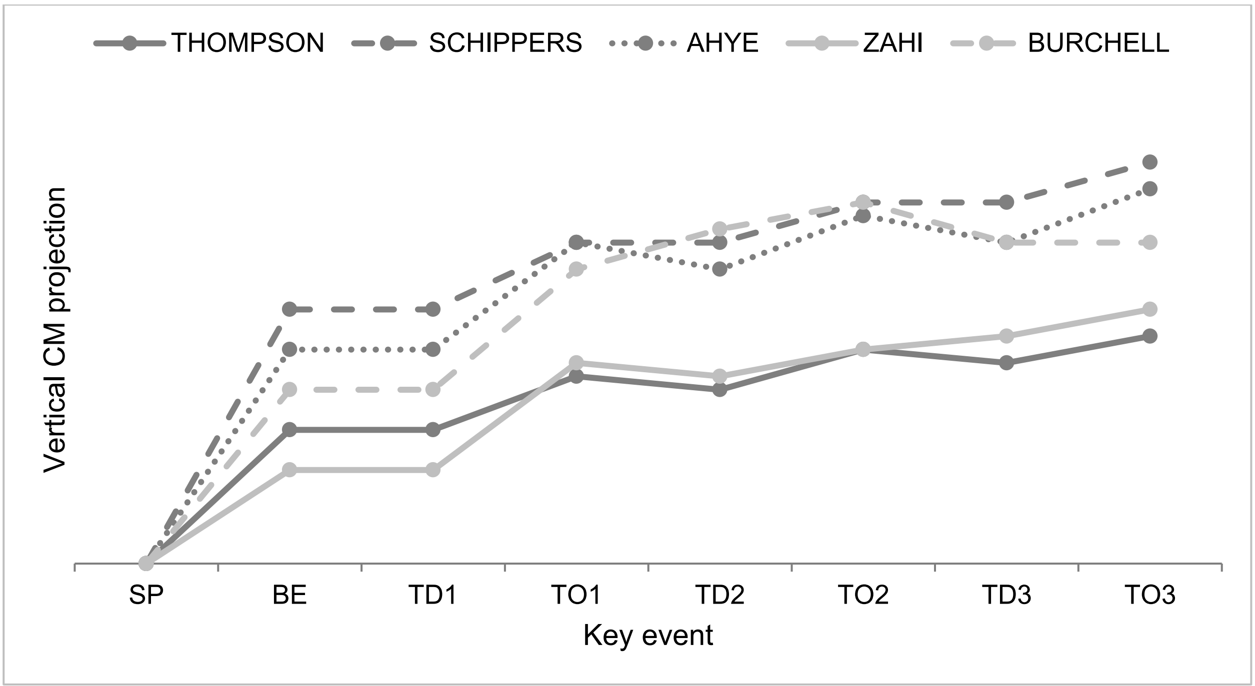

Figure 20. Vertical projection of the CM pathway throughout multiple key events during the sprint start for the remaining five finalists.

COACH'S COMMENTARY

Coaching commentary – Matthew Wood

With the gold medallist, Murielle Ahouré (6.97 s) declaring after the race that she was focused upon 'getting out of the blocks', coaches and athletes would be forgiven for thinking the skill required to be a world class starter was that simple. What Ahouré's comments do highlight is the importance placed upon the start by athletes, and subsequently coaches. The data presented here eloquently illustrates the key principles of a good sprint start characterised by the effective acceleration mechanics and timing of force application during the first 10 m that resulted in a performance worthy of a World Championship Gold.

Ahouré was in fact the first to exit the blocks and also displayed the shortest touchdown distance beyond the start line (0.37 m) in comparison to the other finalists, who displayed significantly longer clearance distances (0.48 – 0.64 m). Again, as with other data presented, this highlights the uniquely individual nature of events surrounding the block start. Coaches therefore should consider holistically what is happening before attempting to fit an athlete to a one size fits all model.

Another area of variation perhaps for coaches to consider is in the block set up. It would appear that the athletes in the women's final displayed a larger range of knee angles in comparison to their male counterparts. The typical rule of thumb used by coaches may be tested when working with female athletes. This perhaps goes some way to explaining the variation in step lengths presented. For example, Ahouré demonstrates a higher set position and is more extended at both knees. Whilst the second placed athlete, Ta Lou, shows a shallower set position and therefore more flexion at both knees. This contrast in knee angles is perhaps the result of variation in foot placement in the blocks (not shown in the data but observable in the race) and the athletes' own individual preferences for set up that enables them to achieve optimal hip extension from the blocks. A further consideration might be the relative contribution of upper body strength in the female athletes and their ability to hold themselves in a particular position in the blocks. These thoughts combined should highlight to coaches the relative value in exploring bandwidths of set up and execution of skills in this area when working with females.

As suggested, the top four athletes display noticeably smaller rear thigh to trunk angles regardless of their set position. Ta Lou for example settles relatively shallow in comparison but matches her top four counterparts for rear hip angle. This might indicate some considerations when setting up and conditioning female athletes for sprint starts, as the relative contribution of hamstring and glute strength in hip extension in the double and single leg proportion of the block clearance might suggest exercises that emphasise an ability to achieve powerful hip movements in contrast to knee dominated exercises.

An obvious difference between Ahouré and the other finalists is her ability to achieve a smaller angle in the shin of the recovering leg which may contribute to here achieving the joint highest step frequency in the first step. Perhaps more significantly, she then achieves the highest frequency in the second step which translates to her being significantly ahead at this point in the race. This ability to achieve high frequency coupled with a horizontal projection from the blocks is an optimal combination for acceleration. Ahouré's relatively short second step perhaps explains the higher frequency, but whatever she may give away in distance covered, she maximises in her next step. Again, this highlights the individual nature of an athlete's acceleration pattern. The principle of an acute shin angle being an advantage during initial acceleration, coupled to an ability to generate stride frequency is evident in Ahouré's superior starting performance.

It is useful for coaches to see that there is a much more pronounced shift between first and second step velocities across all eight female finalists, in contrast their male counterparts. This characteristic is perhaps not something coached in the athletes, but more a reflection of the differences in relative strength and force generating capacities of female athletes. It does also suggest some variation between female athletes' concept of the task of starting and their intentions when performing a competitive start. The intention to be first out or to react to the gun may be a higher priority, for example. Future research in this area would be enlightening for coaches. The dynamics of a female athlete from the blocks may therefore be considered more of a jump than a push seen in the men's event. This again possibly contributes to explaining the differences seen in set up of the women's set positions. The second and third step data corroborate the idea of pushing often encouraged by coaches and might indicate an area of future focus as the continuation of acceleration is characteristic of the aggressive angle of incidence achieved in subsequent steps following block clearance.

It would appear that female sprinters aim to achieve a combination of horizontal projection and step frequency from the starting blocks, however there appears to be a greater emphasis on the initial block clearance above the progressive pushing in steps two and three. This characteristic highlights the need for coaches to consider the differences between athletes' physical abilities and skills when setting up starting practice tasks. Coaches should consider that an athlete's performance from the blocks and 10 m acceleration is the whole skill required of the athletes in the competitive environment, and therefore the two elements should be combined in representative practice tasks. Thus, the value of decontextualized or part practices that focus one element, block clearance or progressive pushing (sled pulls or pushes) might be questioned or at least considered more purposefully.

The combination of a female athlete's physical ability and starting skills in combination with their individual intentions 'to get out first' interact to produce a sprint start performance. Athletes capable of producing optimal step length to project the centre of mass forward from the blocks whilst achieving high step frequency are those most proficient in the block start skill. Coaches of female athletes should therefore consider the conditioning and athleticism of athletes in combination with the practice design they employ in developing these skills.

Historical analysis and coaching commentary – Pierre-Jean Vazel

For the first time ever, a comprehensive biomechanical is published on women's 60m, with a special focus on the starting technique of the current best sprinters in the world.

The coaching commentary will cover the main technical features of the medallists going through the data of the report and the historical analysis will clarify the evolution of the false-start detection in sprints.

Technical features of the 2018 World medallists

The level of performance in Birmingham was particularly high: 7.10 s was not enough to go through the final, and nobody in the world ran faster than the winner's 6.97 s in the last 19 years.

Murielle Ahouré (CIV) 1st in 6.97 s

Her "set" position on the blocks is characterised by high hips and a pronounced forward lean.

Her exceptional power can be measured by the temporal characteristics of her block clearance. Out of all the finalists, she had the fastest actions on the blocks and the first to put the first foot down on the track, way behind her centre of mass. She can give the impression that she is falling while she is fully using the momentum created by her forward leaned position. Driving vigorously her action with the arms, her first three steps are achieved with a high frequency. Her first ground contact is the shortest of all the competitors but by the third contact, she is the longest on the ground. Indeed, at mid-way of the 100 m final at 2017 World Championships, her contact times were among the longest and it could be linked with the fact that while she finished fourth in the race, she had one of the slowest top velocities (IAAF WC 2017 Biomechanical Report). The aim to push horizontally seems to be always important during Ahouré's start practices and warm-ups, using a 3-stance start (one hand on the ground) and performing the first sprints slowly with limited flight times and increasing cadence start after start.

The start is therefore Ahouré's best part of the race. Out of all the kinematic parameters, her low knee angle at touch down is probably the best characteristic of her ability to apply high forces on the ground on a more horizontal direction (behind her). Higher knee angles would suggest that the push on the track is oriented more vertically, beneath the body. Empirical observations tend to show that the later is more useful at mid race where short ground contacts are related to higher top velocities. At the 10 m mark, Ahouré was timed in 1.982 s (including a poor reaction time of 0.162 s). Anything under 2.00 s is considered as outstanding, and the best time ever published for a female athlete is 1.91 s by Nelli Cooman (NED) at the 1988 European Indoor Championships, where she won in 7.01 s (reaction time 0.130 s), only 0.01 s off her at that time World Record (Moravec 1989).

Marie-Josée Ta Lou (CIV) 2nd in 7.05 s

In this personal-best performance, Ta Lou was fifth at the 10m mark (2.040 s) and eventually finished second. Thus, her start might not be her best feature. Conversely, she had the highest top speed at mid race during the world champs 100 m final in 2017. The slow-motion replay of the 60 m race in Birmingham showed that in the "set" position, she was not completely still, as the knee of her front leg was moving downwards. Fortunately, she wasn't applying any significant pressure on the blocks and it was not called a false start. Ta Lou uses a kind of group start position, where she has the lowest hips as measured by an almost horizontal trunk on set position and by the height of her CM at the block exit. However, her large trunk- shank angle of incidence indicates a sub-optimal force vector produced on the blocks. She also put her first foot contact down with the most opened knee angle of all competitors, showing that she was not pushing effectively in the horizontal direction. As a result of this, the velocity of her first step is the second lowest of all the finalists but by the second step, she is the second fastest. These data show that room for improvement lies in a better use of the starting blocks and that times under 7.00 s are within reach.

Mujinga Kambundji (SUI) 3rd in 7.05 s

Her 7.05 s was just 0.02 s shy of her personal best, so just like for Ahouré and Ta Lou, this performance is representative of her best abilities of the moment. For this commentary, Kambundji explained what a good start is for her and how she does it:

- Don't think, be in the present moment, be as instinctive as possible.

- Apply force actively on the ground.

- A good start is when there is no break, no stamping or drops.

- Visually, if she raises abruptly, that's a bad start, and vice-versa.

- She always keeping the same starting-blocks settings.

From the collection of data on this report and her own criteria, Kambundji had a fairly good start. She might not be happy to have the second largest trunk angle at block exit, but the rise of the centre of mass shows no break and a rather smooth action. Her knee angles at each touch down tend to be too high for an effective start, but this remark should be put in perspective with each athlete's gift to orientate force more horizontally or more vertically, as well as their power abilities.

Interestingly, the three medallists displayed the highest average frequency for the first three steps. It seems that this trait has not much incidence for the position at 10 m, since long steppers Ahye and Zahi were second and fourth at that point, while Kambundji and Ta Lou were third and fifth. It would be interesting to test the hypothesis that a higher frequency at the beginning of the 60 m race positively influences the outcome of the race.

History of the reaction time in sprint events

The reaction time is the only human sport performance that cannot be improved indefinitely. Indeed, a 0.100 s limit was adopted during the 1989 IAAF Congress in Barcelona (5-6 September), and included in the 1991 IAAF Rule book. In Birmingham's 60 m, the reaction times ranged between 0.138 s and 0.174 s for the finalists. A 0.099 s time or faster automatically induces an acoustic signal to recall the athletes. In sprint events, reaction time can be defined as the duration between the crack of the gun and the first pressure by the athlete's feet recorded automatically by a false start apparatus on the starting blocks. This time includes a) the travel of the sound, b) the neuromuscular process and c) the mechanical delay of the false-start detection device:

a) Since the velocity of the sound in the air is about 340 m/s, the sprinter will receive the signal 0.029 s after the firing of the gun if the starter is located 10m away; if the source of the sound is close to a sprinter on lane 1, the sprinter on lane 8 will hear the signal 0.025 later as each lane on the track is 1.22 m wide. Given that places on the finish line and records are often separated by a few thousandths of a second, sprinters must receive the signal simultaneously for a fair start. Efforts to reduce this delay were made using loudspeakers placed behind the blocks, for the first time in major competition in Mexico 1968 Olympics. However, sprinters not hearing the signal through the loudspeakers has been a factor in results in major championships such as Munich 1972 (Buthe-Pieper, 1973), Montreal 1976 (Young, 2001) Atlanta 1996 (Julin, 2003) or Athens 2004 Olympics Games (Brown, 2008), especially in the 200m and 400m races where outside lanes are the farthest from the gun.

b) The neuromuscular process leading to the first movement of the feet: Komi & al., 2006 divided the sequence through human body into several consecutive phases: Signal discharge, Ear, Brain stem, Auditory cortex, Cerebral cortex (Motor area), Spinal cord, Muscles, Force output.

c) The mechanical delay between the first movement of the foot and the automatic recording of the pressure on the blocks by the start control device: On the first types of detection apparatus, the pressure required to close the system was adjustable, and set at 30kg at the Munich 1972 Olympic Games. During Montreal 1976 Olympics, according to the Chief starter (Young, 2001) the system "was too sensitive early in the Games, indicating false starts on rear leg tremors. This was later corrected by increasing the pressure requirement". Due to those variations, the system was later set at 27kg in Los Angeles 1984 and Seoul 1988 Games by Omega (Bovay 1985, Omega 1988), but only at 24kg at Tokyo 1991 World Championships by Seiko (Nozaki & al., 1992) – making impossible the historical comparison of reaction times. Nowadays, an algorithm is used to detect the reaction time when the force-time curve (continuously recorded while the athlete's feet are in contact on the blocks) changes so much that it can only be caused by the athlete's starting motion.

The 0.100 s limit was adopted during the 1989 IAAF Congress in Barcelona (5-6 September) upon a proposition by French referees (Blanchet, 1989), and was included in the 1991 IAAF Rule book. Until then, the minimum reaction time allowed was left to the discretion of the Chief judge and manufacturer's choice: it varied between 0.120 (for example in 1987 World Championships in Rome or 1988 World Junior Championships) and 0.100 (e.g. Seoul Olympic Games). Munich 1972 Olympics were the first international competition using automatic false start detection system. Reaction times were record to the hundredth of a second, not yet recorded to the thousandth. The patent of the device, applied in 1966, was owned by Junghans whose scientists performed tests on sprinters to determine the minimum reaction time allowable. On the original patent document, it is mentioned that the reaction time is never shorter than 0.10 s, unless the runner anticipates the signal. Intensive tests in West German competitions in 1969 revealed that the fastest reaction for fair starts on the 809 measurements was 0.12 s (Bovay, 1992). Leading up to the Monaho Games, it was 0.11 s but the limit was set at 0.10 s, supposing that some extraordinary sprinter would show up. Indeed, some 0.10s were recorded in Munich. There, the swiftest of all athletes was arguably Martha Watson who reacted at 0.12 on lane 3 and 0.14 on lane 8 at the start of the USA's 4x100 m relay, which was exceptional given how far she was physically from the source of the sound. The most consistent sprinter has probably been the Soviet Valeriy Borzov, with times ranging from 0.10 to 0.125 in championships from 1972 to 1978. Hurdler Colin Jackson has shown a similar consistency as during 24 major competitions between 1988 and 2003, he was the fastest to reaction 14 times, with a best reaction of 0.102 s after having "committed" what was detected as a false start (2002 European Indoor Championships, 60m hurdles final).

Still, reaction times as recorded in competitions usually are slower for female sprinters, compared to their male counterparts. It was again the case in Birmingham 2018 and to date no scientific consensus has been found regarding any physiological explanations to this observation. However, it seems that the mechanical delay in recording the reaction time plays a role. Indeed, men are heavier and more powerful than women, hence, reach the threshold of the dynamometer earlier, even with the new and sophisticated machines that register the existing pressure on the pad and automatically detect significant change in the force-time curve. In an interesting study performed on 36 male and 36 female sprinters of the East German national squad, including World Record holders in both sexes (Dornhoff, 1977), reaction time was retrospectively measured at the inflexion of the force-time curve, and not automatically and depending on the sensitivity of the apparatus. This distinction is important, and women were found to have slightly faster - but not significantly - reaction times than men: 0.110 s (range 0.08 s - 0.13 s) compared to 0.118 s (range 0.09 s - 0.15 s).

It could be argued that some of the reaction times in this study are under the 'legal' limit of 0.100 s. This could be explained by the difference in measurement method as explained earlier, by the fact that these were time trials without the fear to be disqualified as in official competitions (however these were individual trials, without the temptation to beat rivals at the gun), and because these test races were performed over 30 m, and not 60 m or 100 m. Indeed, it is known since Oberste 1974 that the shorter the sprint race in competition, the shorter the reaction time. Since times as short as 0.10 - 0.12 s are often recorded in 100 m races , it would be logical that for very short sprint races, where all the focus and arousal are on the execution of the first steps, the reaction time could be found to be under the 0.100 s limit. These parameters are to be taken into account in the interpretation of the findings of scientific experimentations (Ionov, 1966, Pain

& Hibbs, 2007, Brown, 2008 and Komi, 2009) using very short sprints to test the validity of the current 0.100 s rule.

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