IAAF World Indoor Championships
BIRMINGHAM 2018
1–4 MARCH

BIOMECHANICAL REPORT

FOR THE

IAAF

WORLD INDOOR CHAMPIONSHIPS 2018

60 Metres Men

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Table of Contents

Figures

Tables

INTRODUCTION

The men's 60 m sprint took place on the evening of Saturday 3rd March. The overwhelming favourite going into the event was Christian Coleman of the United States, having broken the World Indoor Record by 0.05 s only two weeks prior to the championships. Coleman had also been consistently performing extremely well throughout the indoor season. Other finalists such as Ronnie Baker (United States) and Su Bingtian (China) had also been performing well so were in contention for a medal but would have been hoping to cause an upset. In the end, Coleman dominated the race. His time of 6.37 s resulted in a new Championship record being set, which had previously stood for almost 20 years. Su Bingtian claimed the silver medal with a time of 6.42 s, which was a new Area Indoor Record. Ronnie Baker took the bronze medal in 6.44 s.

IAAF World Indoor Championships — Birmingham (GBR) 1-4 March 2018

RESULTS

60 Metres Men - Final

RECORDS		RESULT	NAME	COUNTRY	AGE	VENUE	DATE
World Indoor Record	WIR	6.34	Christian COLEMAN	USA	22	Albuquerque (USA)	18 Feb 2018
Championship Record	CR	6.37	Christian COLEMAN	USA	22	Birmingham	3 Mar 2018
World Leading	WL	6.34	Christian COLEMAN	USA	22	Albuquerque (USA)	18 Feb 2018

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

3 March 2018 21:12 START TIME

PLACE	NAME	COUNTRY	DATE of BIRTH	LANE	RESULT		REACTION	Fn
1	Christian COLEMAN	USA	6 Mar 96	4	6.37	CR	0.151	
2	Bingtian SU	CHN	29 Aug 89	3	6.42	AIR	0.162	
3	Ronnie BAKER	USA	15 Oct 93	6	6.44		0.151	
4	Zhenye XIE	CHN	17 Aug 93	5	6.52	PB	0.150	
5	Hassan TAFTIAN	IRI	4 May 93	7	6.53		0.160	
6	Ján VOLKO	SVK	2 Nov 96	1	6.59		0.165	
7	Sean SAFO-ANTWI	GHA	31 Oct 90	8	6.60		0.137	
8	Emre Zafer BARNES	TUR	7 Nov 88	2	6.64		0.164	

Timing and Measurement by SEIKO   AT-60-M-f--1--.RS1..v1   Issued at 21:15 on Saturday, 03 March 2018

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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).

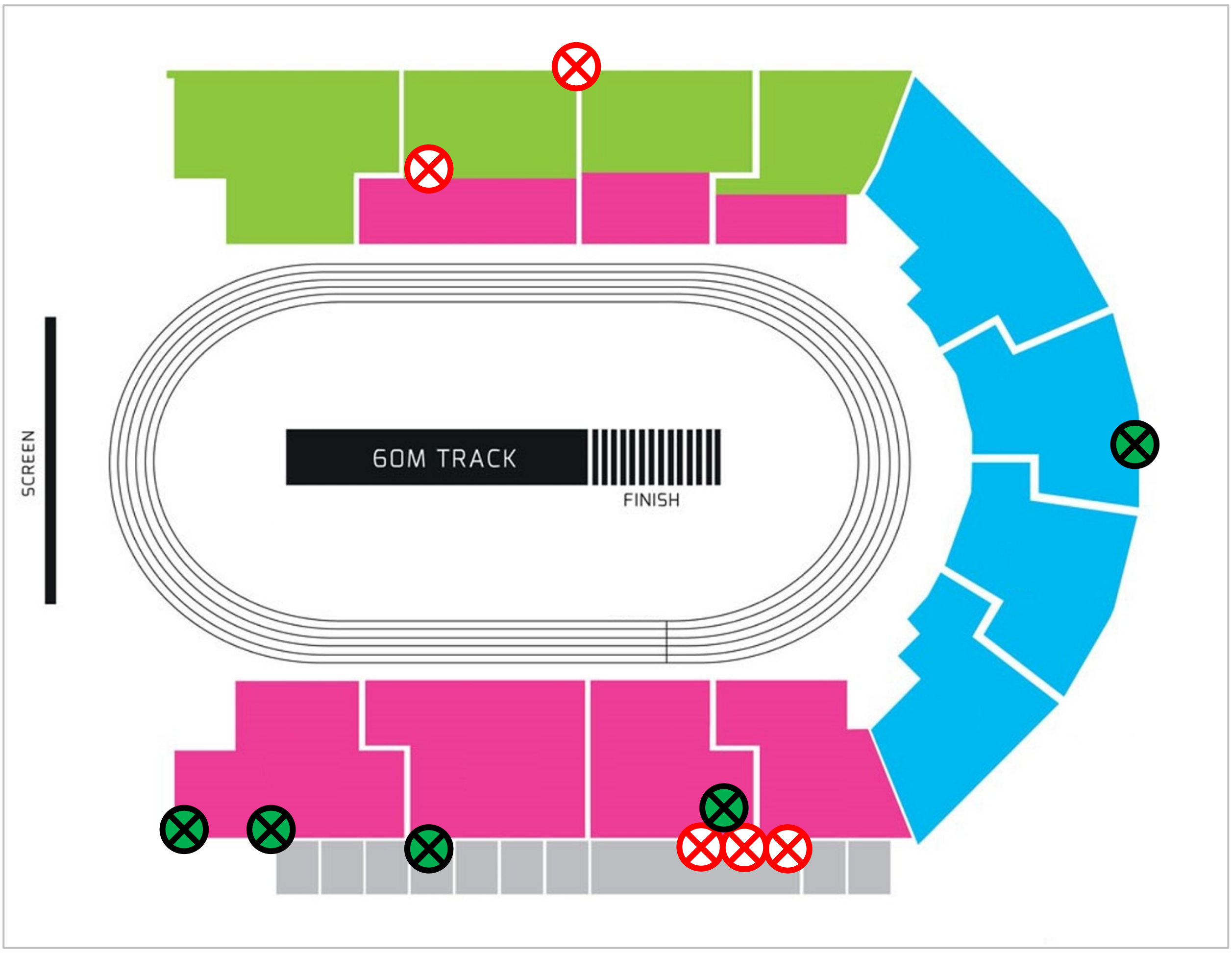

Figure 1. Camera layout for the men's 60 m indicated by green-filled circles.

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, 11 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. 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 men'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 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.
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 kinematics 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)
COLEMAN	0.163	0.127	0.290	0.441
SU	0.193	0.160	0.353	0.515
BAKER	0.210	0.140	0.350	0.501
XIE	0.177	0.160	0.337	0.487
TAFTIAN	0.207	0.153	0.360	0.520
VOLKO	0.215	0.120	0.335	0.500
SAFO-ANTWI	0.198	0.153	0.351	0.488
BARNES	0.187	0.173	0.360	0.524

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. As can be seen from the results, Christian Coleman displayed the shortest total push time and thus shortest total block time of all finalists. This allowed Coleman to be the first athlete to exit the blocks, despite only having the joint third shortest reaction time (Table 3). Figure 4 (below) shows the different phases of block exit as a percentage of total block time.

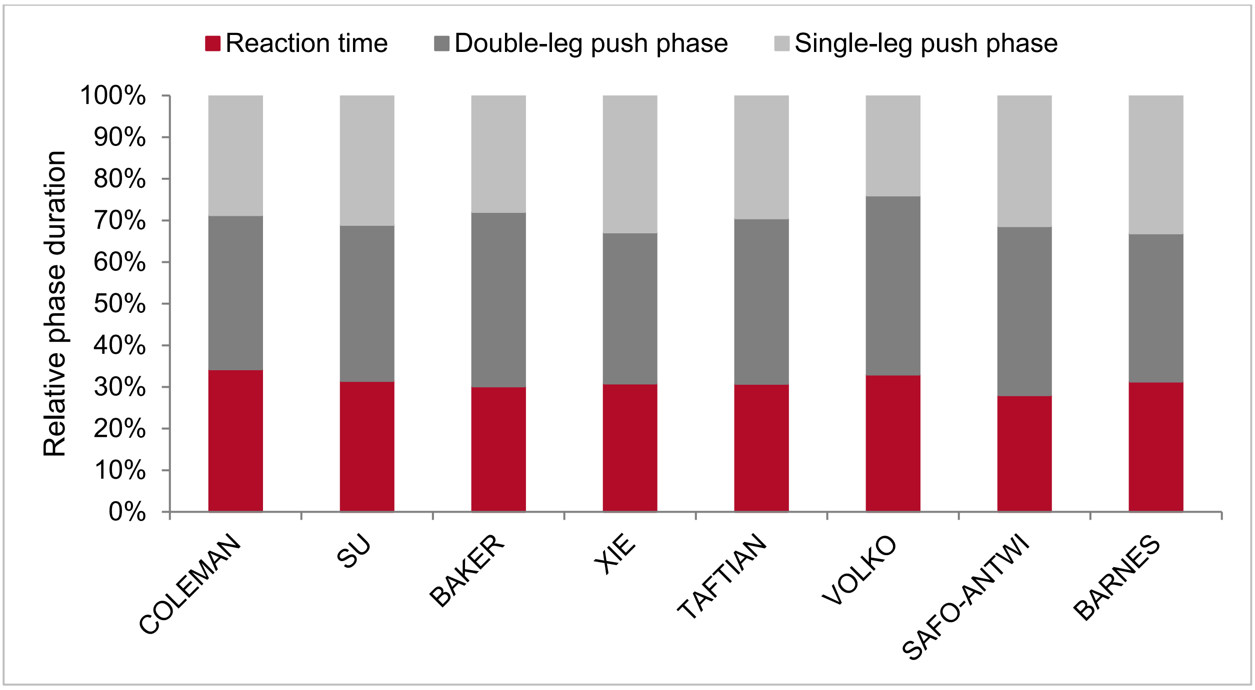

Figure 4. Relative duration of block exit phases, displayed relative to total block time for each finalist.

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
COLEMAN	=3	1	3
SU	6	6	5
BAKER	=3	5	=1
XIE	2	2	4
TAFTIAN	5	7	6
VOLKO	8	4	7
SAFO-ANTWI	1	3	=1
BARNES	7	8	8

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 Ronnie Baker and Emre Zafer Barnes touched down the furthest from the start line.

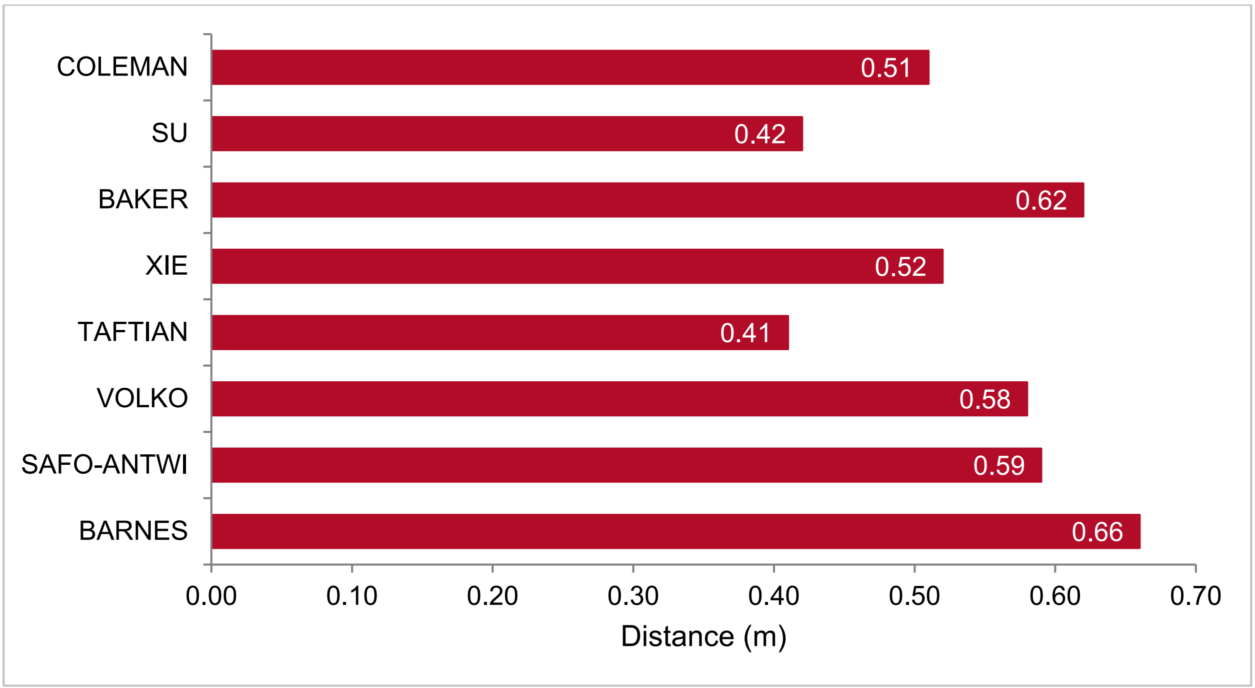

Figure 5. Block clearance distance (horizontal distance between start line and point of initial ground contact) for each of the finalists.

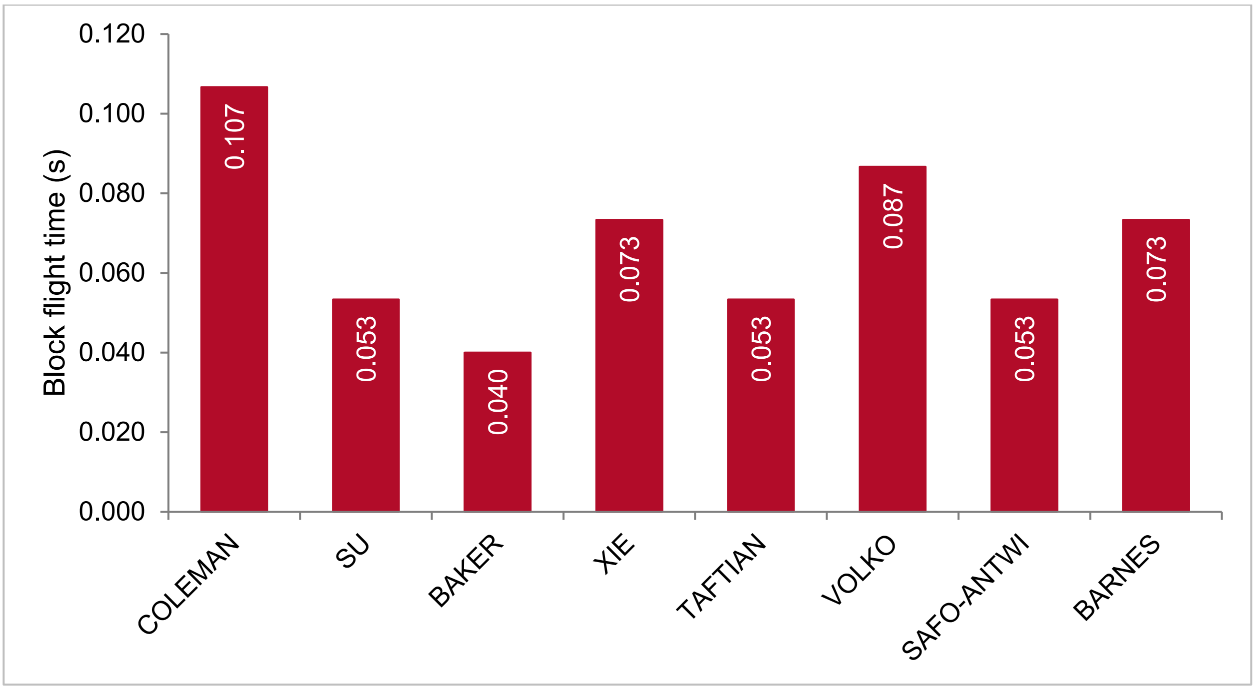

Figure 6. Block flight time (from block clearance to initial ground contact) for each of the finalists.

Christian Coleman showed clearly the highest block flight time (Figure 6), which could explain why he was ranked 3rd in time to first touchdown despite exiting the blocks first (Table 3).

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.

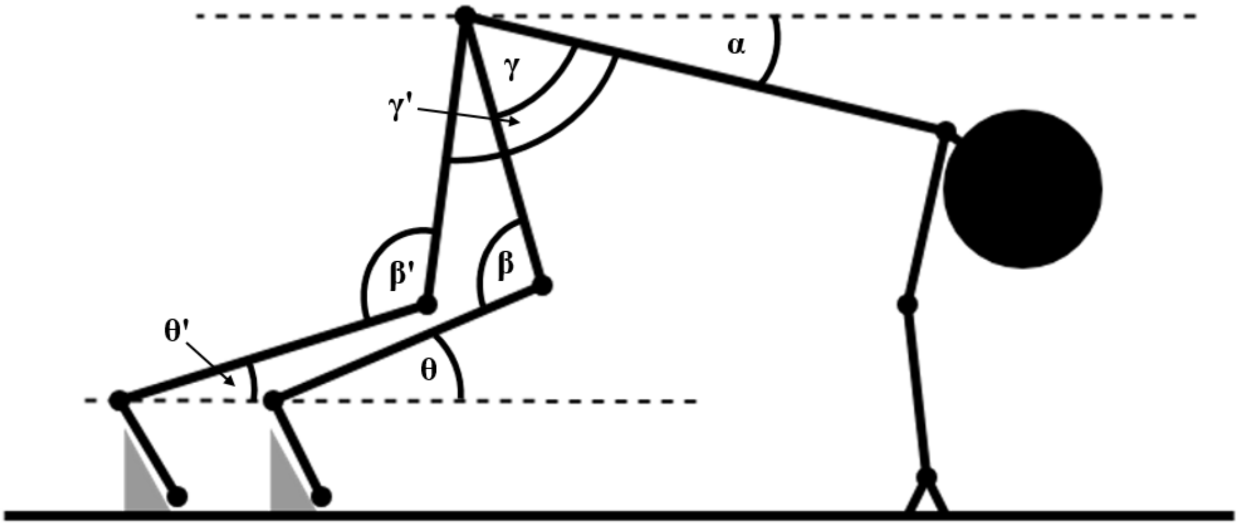

Figure 7. Body schematic denoting joint and segment angles measured in the set position.

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'
COLEMAN	−18.3	57.3	86.3	99.9	129.7	25.2	23.7
SU	−13.4	41.3	83.1	84.1	118.5	30.7	21.0
BAKER	−13.4	46.2	73.5	92.4	108.1	32.2	21.2
XIE	−12.6	53.4	94.8	89.6	126.7	25.1	18.3
TAFTIAN	−17.4	42.4	71.4	91.0	113.6	32.6	22.8
VOLKO	−20.2	37.7	68.1	99.0	111.3	40.9	22.6
SAFO-ANTWI	−22.0	41.5	78.2	94.8	127.8	33.3	25.3
BARNES	−22.8	43.0	85.1	92.0	131.5	26.9	23.0

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 the bottom three finishes (6th to 8th) appeared to show more extreme trunk angles than the other finalists. 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.

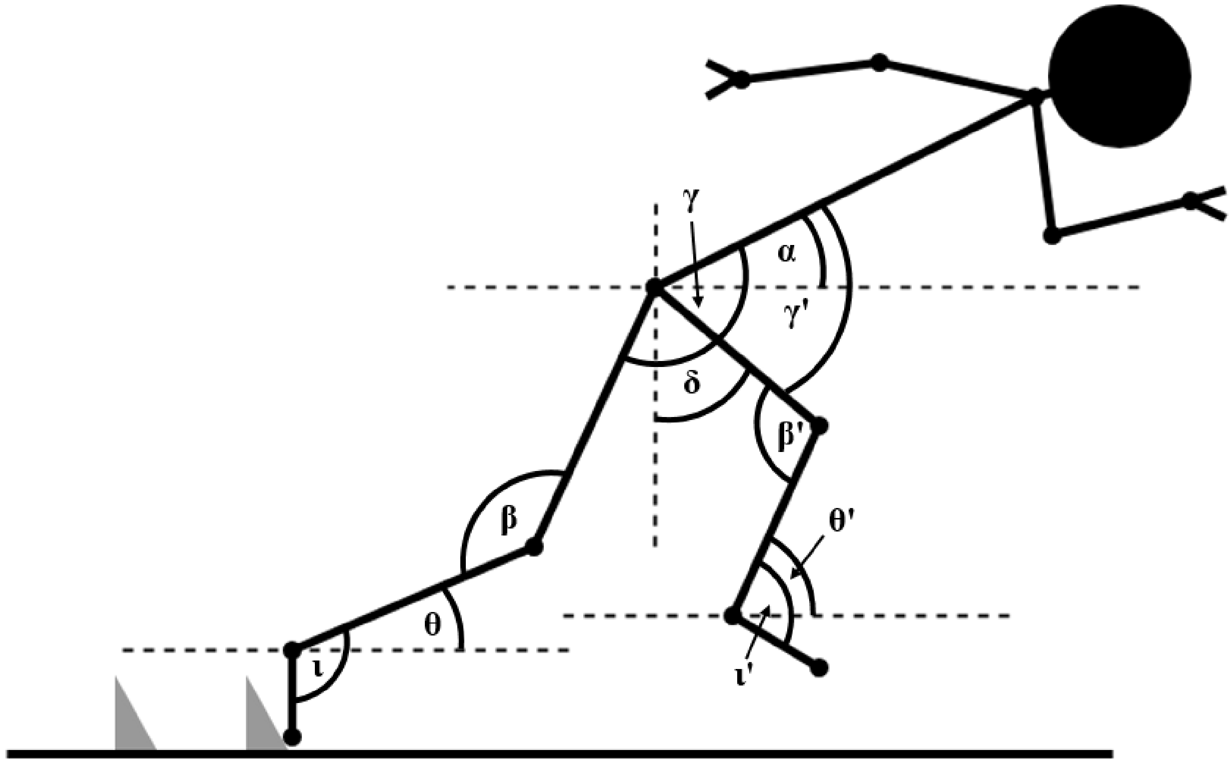

Figure 8. Body schematic denoting joint and segment angles measured at block exit.

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'
COLEMAN	40.2	172.7	92.1	39.1	164.0	51.7	24.3	0.6	137.3	104.4
SU	32.6	168.5	57.2	65.8	157.7	59.4	21.2	34.7	133.3	91.1
BAKER	41.5	174.5	73.8	57.4	157.9	49.5	19.1	16.5	129.4	70.9
XIE	29.3	168.0	62.6	57.1	166.3	73.1	28.5	40.1	143.8	90.0
TAFTIAN	40.1	168.9	74.2	57.8	162.4	57.4	26.8	26.3	135.1	84.9
VOLKO	36.3	168.2	85.6	42.0	163.0	59.9	27.4	11.9	129.4	91.8
SAFO-ANTWI	38.0	176.5	66.1	63.7	161.8	57.3	22.1	30.7	143.8	83.8
BARNES	31.8	168.9	60.4	63.0	163.0	74.7	23.6	48.0	139.8	97.9

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 greatest degree of hip extension in the push-off leg (angle γ) were shown by Christian Coleman (172.7°), Ronnie Baker (174.5°) and Sean Safo-Antwi (176.5°). Although a direct cause-and-effect inference cannot be made, these three athletes were the first three to reach first touchdown (Table 3). It may also be noted that Coleman's lead shank angle (angle θ') was very close to zero (0.6°), meaning the shank was almost parallel with the running surface. 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.

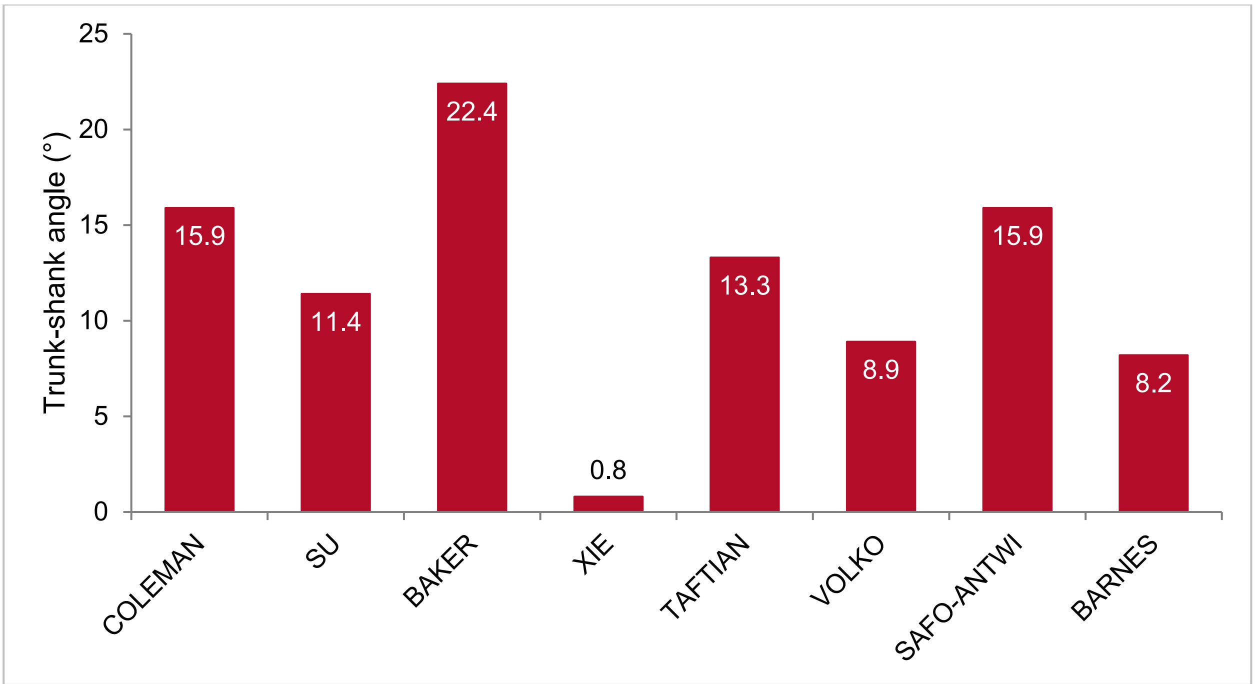

Figure 9. Trunk-trailing shank angle of incidence (α–θ) at block exit for each of the finalists.

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 0.21 to 0.31 m, whilst CM height ranged from 0.50 to 0.59 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)
COLEMAN	0.50	0.22
SU	0.52	0.31
BAKER	0.50	0.21
XIE	0.50	0.21
TAFTIAN	0.56	0.31
VOLKO	0.59	0.24
SAFO-ANTWI	0.53	0.31
BARNES	0.58	0.21

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.

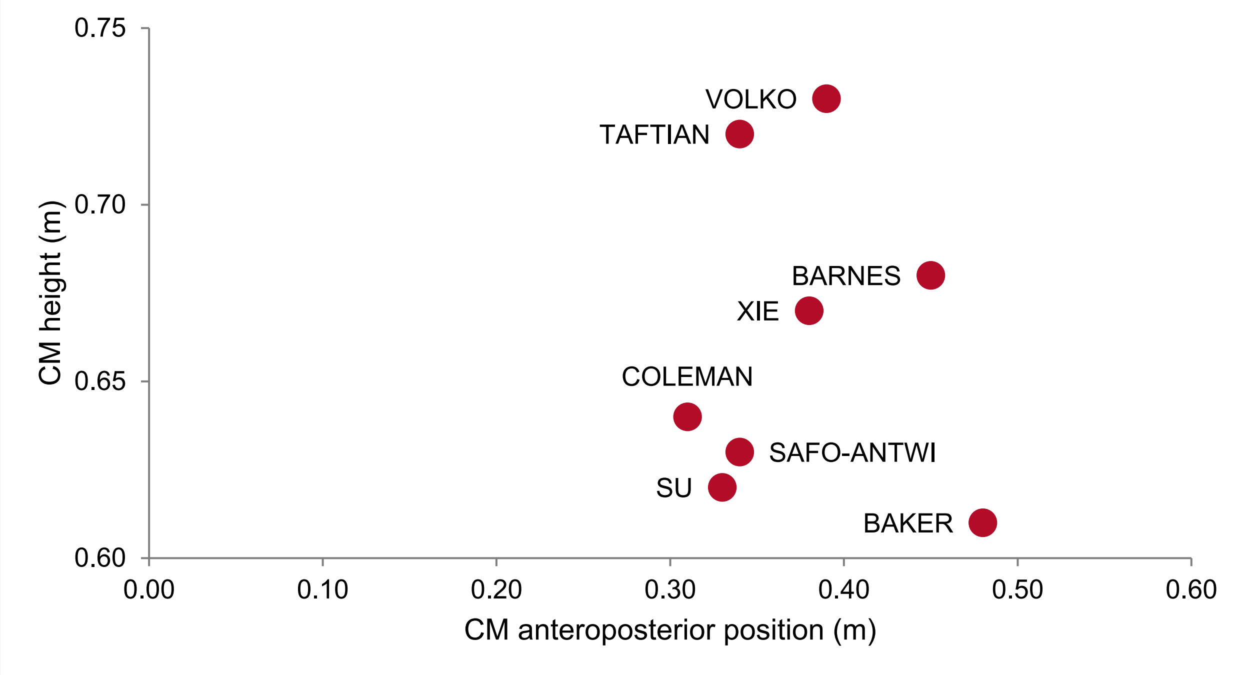

Figure 10. CM position (relative to the start line) for each finalist at the instant of block exit.

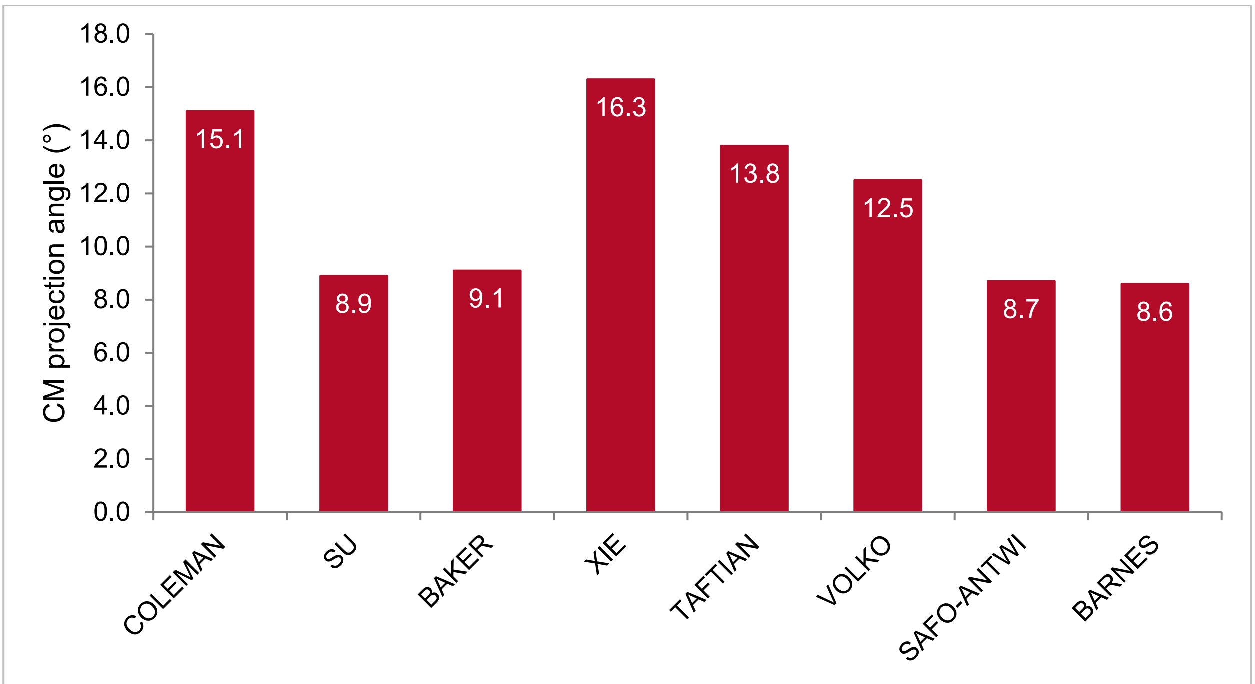

Figure 11. CM projection angle from set position to block exit for each finalist.

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
COLEMAN	0.160	0.167	0.140
SU	0.167	0.160	0.133
BAKER	0.187	0.193	0.153
XIE	0.167	0.160	0.120
TAFTIAN	0.193	0.187	0.147
VOLKO	0.160	0.153	0.127
SAFO-ANTWI	0.193	0.167	0.140
BARNES	0.173	0.180	0.140

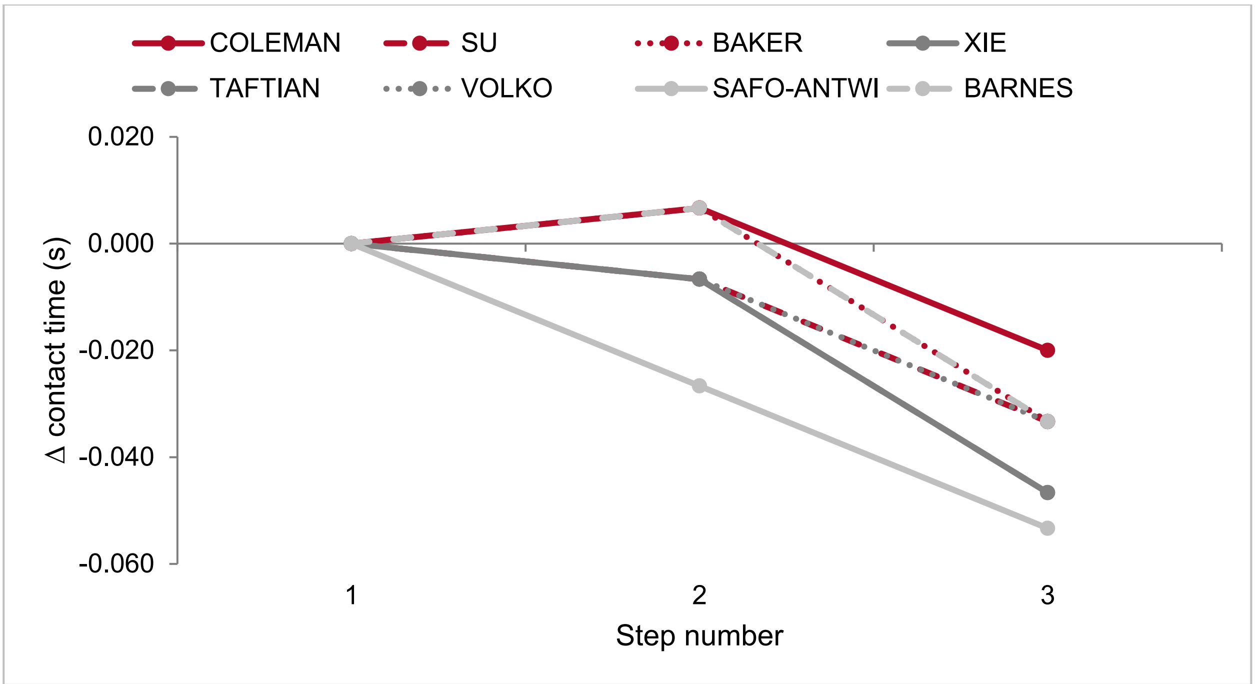

Figure 12. Change in ground contact time throughout the first three steps (1-2, 1-3) of the race for all finalists (first contact is used as zero reference point for the other two contacts).

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
COLEMAN	0.047	0.060	0.073
SU	0.047	0.047	0.053
BAKER	0.033	0.040	0.047
XIE	0.060	0.080	0.073
TAFTIAN	0.027	0.053	0.060
VOLKO	0.053	0.067	0.073
SAFO-ANTWI	0.033	0.060	0.047
BARNES	0.053	0.053	0.073

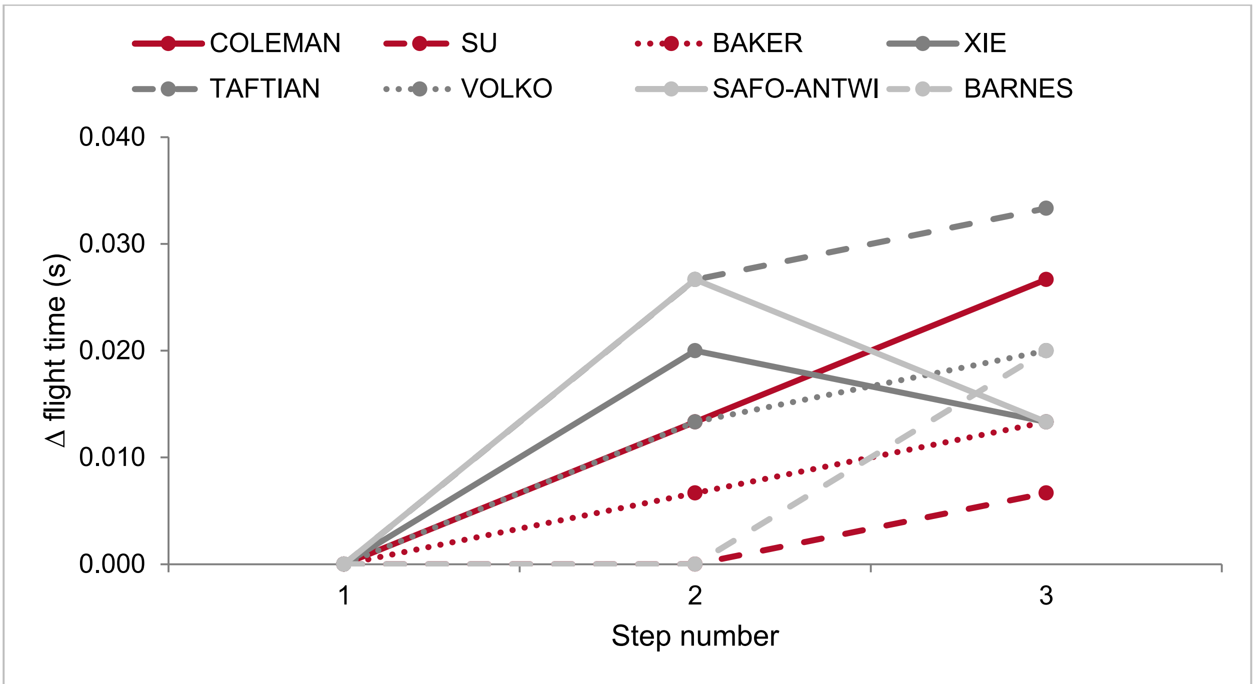

Figure 13. Change in flight time throughout the first three steps (1-2, 1-3) of the race for all finalists (first flight is used as zero reference point for the other two flights).

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

Athlete	Step time (s)		
	1st step	2nd step	3rd step
COLEMAN	0.207	0.227	0.213
SU	0.214	0.207	0.186
BAKER	0.220	0.233	0.200
XIE	0.227	0.240	0.193
TAFTIAN	0.220	0.240	0.207
VOLKO	0.213	0.220	0.200
SAFO-ANTWI	0.226	0.227	0.187
BARNES	0.226	0.233	0.213

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

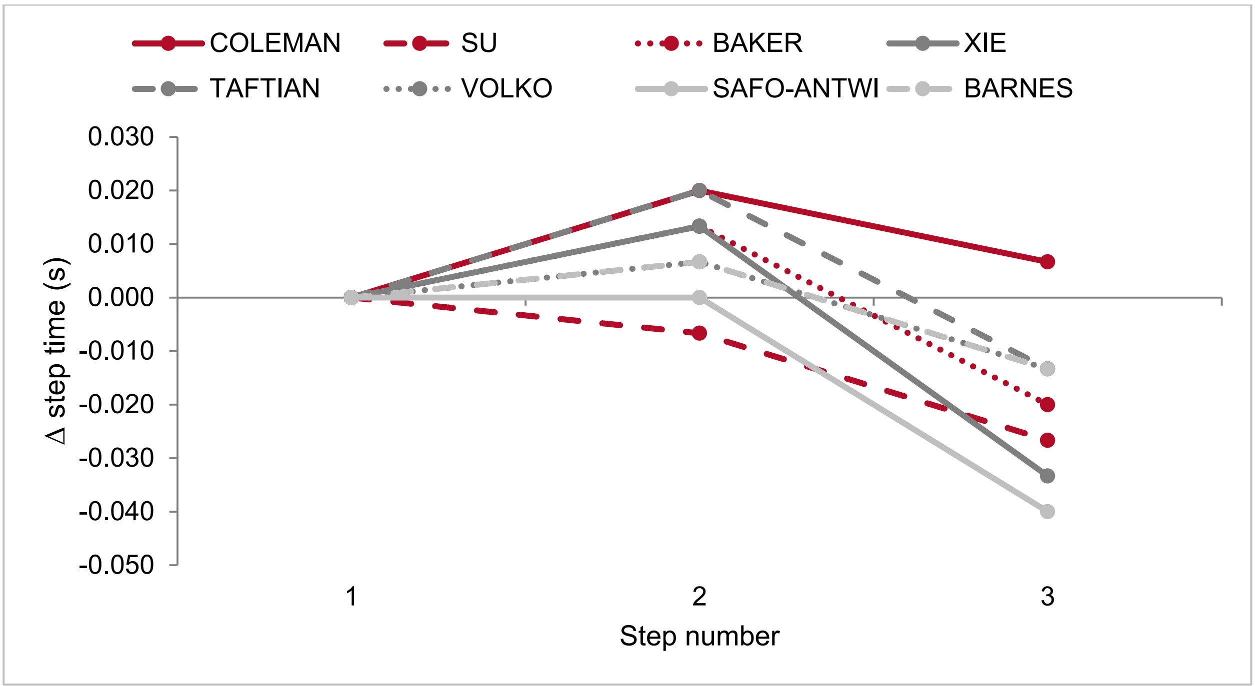

Figure 14. Change in step time throughout the first three steps (1-2, 1-3) of the race for all finalists (first step is used as zero reference point for the other two steps).

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

Athlete	Ranking		
	2nd TD	3rd TD	4th TD
COLEMAN	1	1	4
SU	4	2	1
BAKER	2	3	3
XIE	5	6	=5
TAFTIAN	6	7	7
VOLKO	7	5	=5
SAFO-ANTWI	3	4	2
BARNES	8	8	8

The following table shows each athlete's time to the 10 m mark. When time to 10 m includes reaction time, the three eventual medallists (Coleman, Su and Baker) 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)
COLEMAN	1.705	1.856	1	29.14
SU	1.725	1.887	3	29.30
BAKER	1.715	1.866	2	29.07
XIE	1.770	1.920	5	29.40
TAFTIAN	1.785	1.945	8	29.29
VOLKO	1.775	1.940	7	29.39
SAFO-ANTWI	1.760	1.897	4	29.10
BARNES	1.765	1.929	6	29.27

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
COLEMAN	Step length (m)	1.19	1.35	1.44
	Step frequency (Hz)	4.84	4.41	4.69
SU	Step length (m)	1.18	1.18	1.42
	Step frequency (Hz)	4.69	4.84	5.36
BAKER	Step length (m)	1.29	1.24	1.46
	Step frequency (Hz)	4.55	4.29	5.00
XIE	Step length (m)	1.18	1.24	1.36
	Step frequency (Hz)	4.41	4.17	5.17
TAFTIAN	Step length (m)	1.15	1.26	1.41
	Step frequency (Hz)	4.55	4.17	4.84
VOLKO	Step length (m)	1.08	1.22	1.23
	Step frequency (Hz)	4.69	4.55	5.00
SAFO-ANTWI	Step length (m)	1.12	1.24	1.37
	Step frequency (Hz)	4.41	4.41	5.36
BARNES	Step length (m)	1.28	1.32	1.57
	Step frequency (Hz)	4.41	4.29	4.69

As can be seen from Table 12, athletes tended to increase both their step length and their step frequency 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. It may be worth noting that

Christian Coleman (gold medallist) displayed the highest step frequency in the first step (4.84 Hz) as well as the longest absolute step length during the second step (1.35 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.

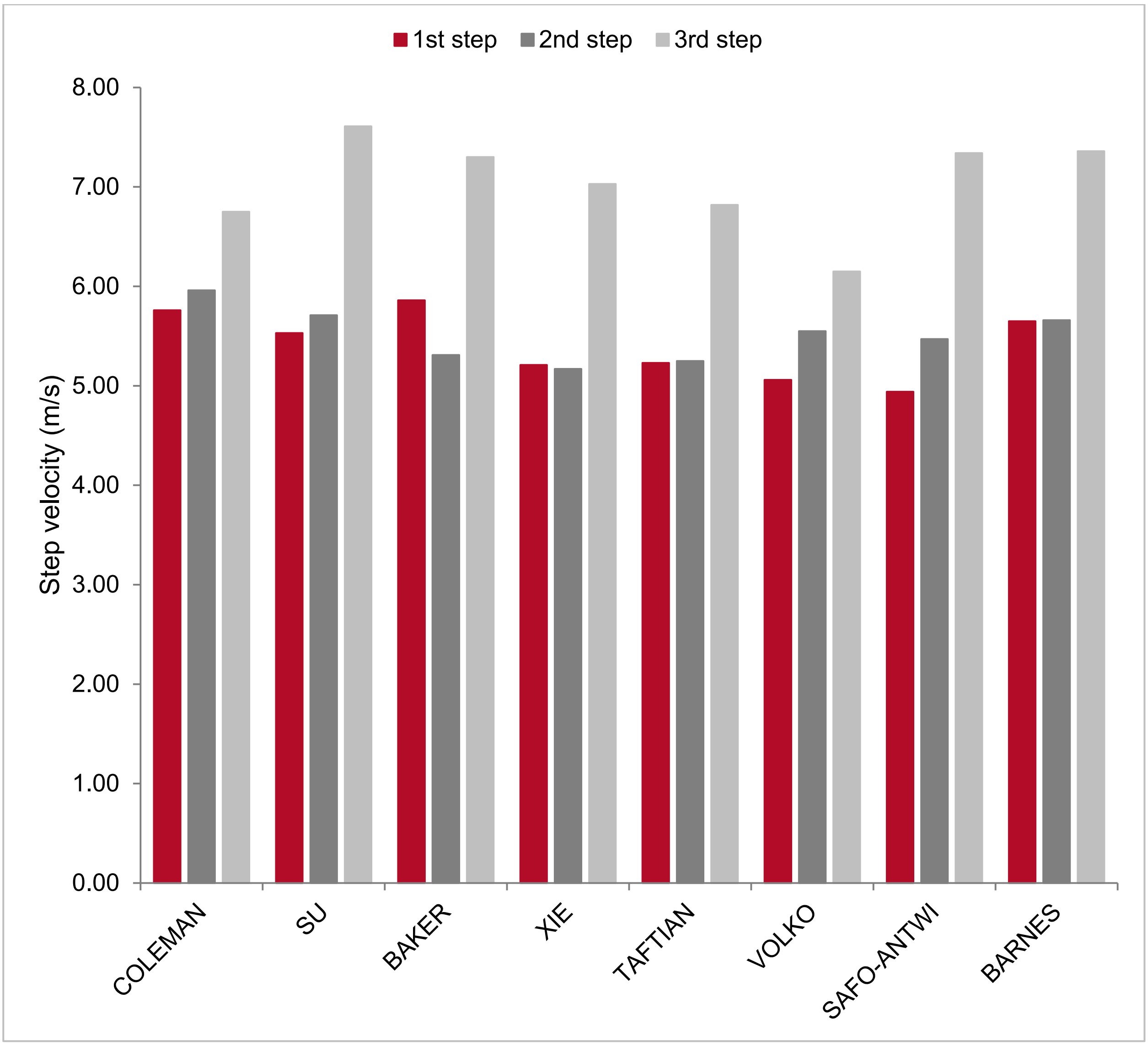

Figure 15. Step velocity for the first three steps of the race for each of the finalists.

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.

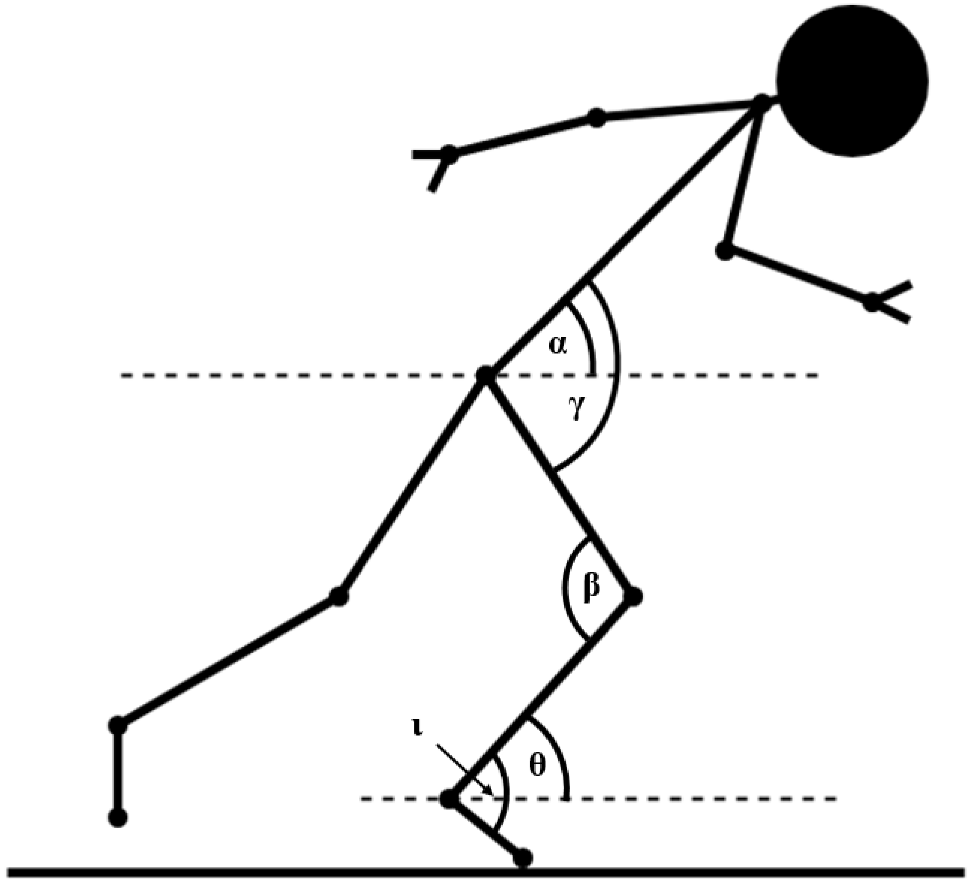

Figure 16. Body schematic denoting joint and segment angles measured at touchdown.

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

Athlete	Step number	Joint angle (°)				
		α	γ	β	θ	ι
COLEMAN	1	38.0	91.2	91.0	33.9	97.2
	2	41.4	85.2	90.0	47.7	98.5
	3	41.6	81.6	99.4	56.1	97.3
SU	1	36.6	81.1	78.8	32.0	80.0
	2	38.3	87.7	100.6	53.7	97.5
	3	43.7	91.6	105.6	55.7	95.0
BAKER	1	43.8	78.1	66.5	29.7	80.8
	2	48.3	87.3	93.3	57.8	91.6
	3	56.3	94.6	92.5	50.4	91.6

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

Athlete	Step number	Joint angle (°)				
		α	γ	β	θ	ι
XIE	1	33.9	88.6	91.6	36.3	85.8
	2	39.8	96.2	104.4	52.0	94.1
	3	44.3	104.7	116.7	53.7	91.6
TAFTIAN	1	42.4	87.9	80.3	33.1	96.9
	2	46.7	88.1	92.5	55.7	93.2
	3	46.1	88.4	100.1	54.3	93.8
VOLKO	1	37.9	96.6	94.2	37.4	92.6
	2	44.7	105.0	109.1	51.7	97.0
	3	41.9	103.0	116.8	56.0	91.0
SAFO-ANTWI	1	40.0	85.1	82.5	37.5	81.9
	2	40.3	90.6	103.8	51.5	97.0
	3	43.2	91.9	106.6	54.5	97.6
BARNES	1	37.5	84.1	85.9	39.6	86.1
	2	42.3	83.3	101.7	62.1	103.1
	3	48.5	96.9	106.5	56.7	89.0

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. All athletes show a notably more acute shank angle (angle θ) during the first ground contact (average: 34.9°) than in the second and third ground contacts (averages: 54.0° and 54.7°, 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.

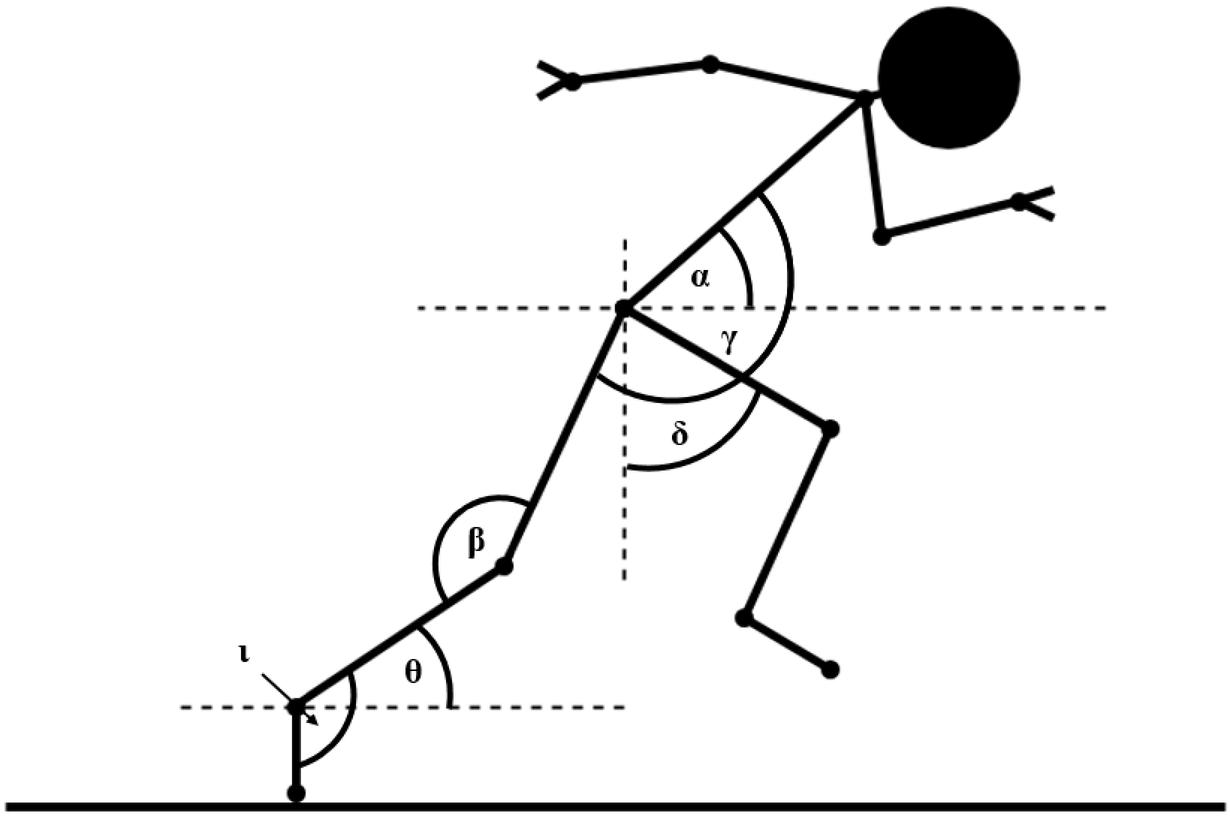

Figure 17. Body schematic denoting joint and segment angles measured at toe-off.

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

Athlete	Step number	Joint angle (°)					
		α	γ	δ	β	θ	ι
COLEMAN	1	41.5	166.6	65.6	156.0	26.2	137.4
	2	45.8	172.6	64.4	163.5	28.7	144.8
	3	46.8	166.8	66.1	158.8	32.2	130.8
SU	1	39.1	165.3	65.9	161.8	29.5	139.4
	2	40.4	167.3	68.0	157.4	29.2	140.7
	3	45.9	166.2	64.0	159.2	33.4	129.7
BAKER	1	45.1	170.3	66.3	150.8	23.3	119.8
	2	55.0	174.9	61.3	146.6	23.1	139.5
	3	58.4	173.5	70.9	143.8	24.0	142.3

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

Athlete	Step number	Joint angle (°)					
		α	γ	δ	β	θ	ι
XIE	1	38.9	155.5	51.9	149.0	26.5	115.0
	2	42.2	162.6	68.5	151.8	30.7	137.0
	3	47.3	158.4	61.1	153.3	33.9	129.1
TAFTIAN	1	47.8	168.1	64.1	149.0	23.1	126.1
	2	44.6	167.9	69.3	149.2	24.6	133.9
	3	44.8	164.3	67.0	160.2	33.9	135.6
VOLKO	1	44.6	162.2	66.7	156.0	30.5	125.9
	2	42.6	165.6	64.6	160.5	35.9	142.0
	3	46.1	161.4	65.2	159.4	37.9	120.1
SAFO-ANTWI	1	41.5	163.7	63.8	150.7	22.4	133.1
	2	41.5	167.5	65.5	156.2	28.3	136.2
	3	43.1	165.6	68.3	159.3	32.5	140.3
BARNES	1	43.0	173.0	56.5	161.8	27.4	123.9
	2	44.6	173.0	63.1	153.5	22.1	126.2
	3	52.4	175.9	73.5	162.2	29.9	113.2

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. According to Figure 18, Hassan Taftian (5th place) is the exception to this.

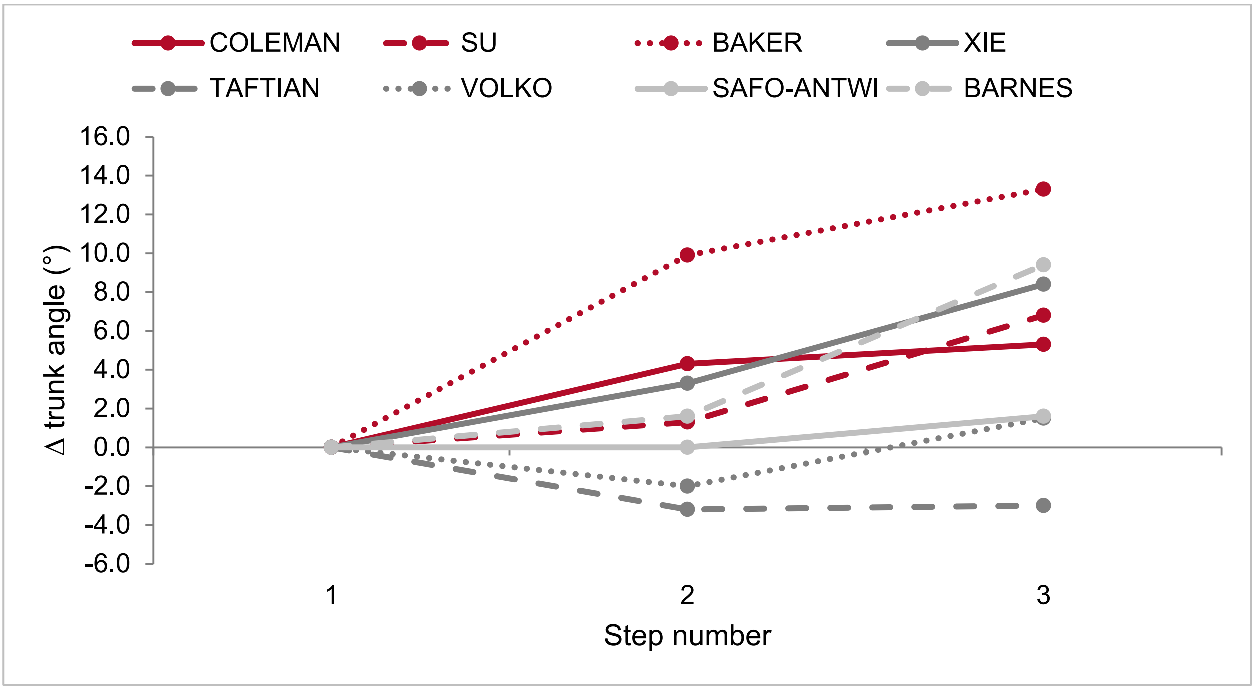

Figure 18. Change in trunk angle at toe-off throughout the first three steps (1-2, 1-3) of the race for all finalists (first toe-off is used as zero reference point for the other two toe-offs).

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
COLEMAN	4.1	−6.3	−14.5
SU	4.6	−15.4	−12.0
BAKER	14.1	−9.5	5.9
XIE	−2.4	−12.2	−9.4
TAFTIAN	9.3	−9.0	−8.2
VOLKO	0.5	−7.0	−14.1
SAFO-ANTWI	2.5	−11.2	−11.3
BARNES	−2.1	−19.8	−8.2

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
COLEMAN	15.3	17.1	14.6
SU	9.6	11.2	12.5
BAKER	21.8	31.9	34.4
XIE	12.4	11.5	13.4
TAFTIAN	24.7	20.0	10.9
VOLKO	14.1	6.7	8.2
SAFO-ANTWI	19.1	13.2	10.6
BARNES	15.6	22.5	22.5

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
COLEMAN	0.21	−0.01	−0.04
SU	0.13	−0.01	−0.04
BAKER	0.05	−0.17	−0.07
XIE	0.14	−0.01	0.07
TAFTIAN	0.15	−0.12	−0.05
VOLKO	0.17	0.02	0.00
SAFO-ANTWI	0.00	−0.04	−0.01
BARNES	0.10	−0.09	−0.07

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
COLEMAN	0.90	0.88	0.82
SU	0.87	0.83	0.80
BAKER	0.89	0.87	0.89
XIE	0.84	0.81	0.78
TAFTIAN	0.90	0.86	0.83
VOLKO	0.81	0.81	0.74
SAFO-ANTWI	0.87	0.81	0.81
BARNES	0.87	0.87	0.80

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.

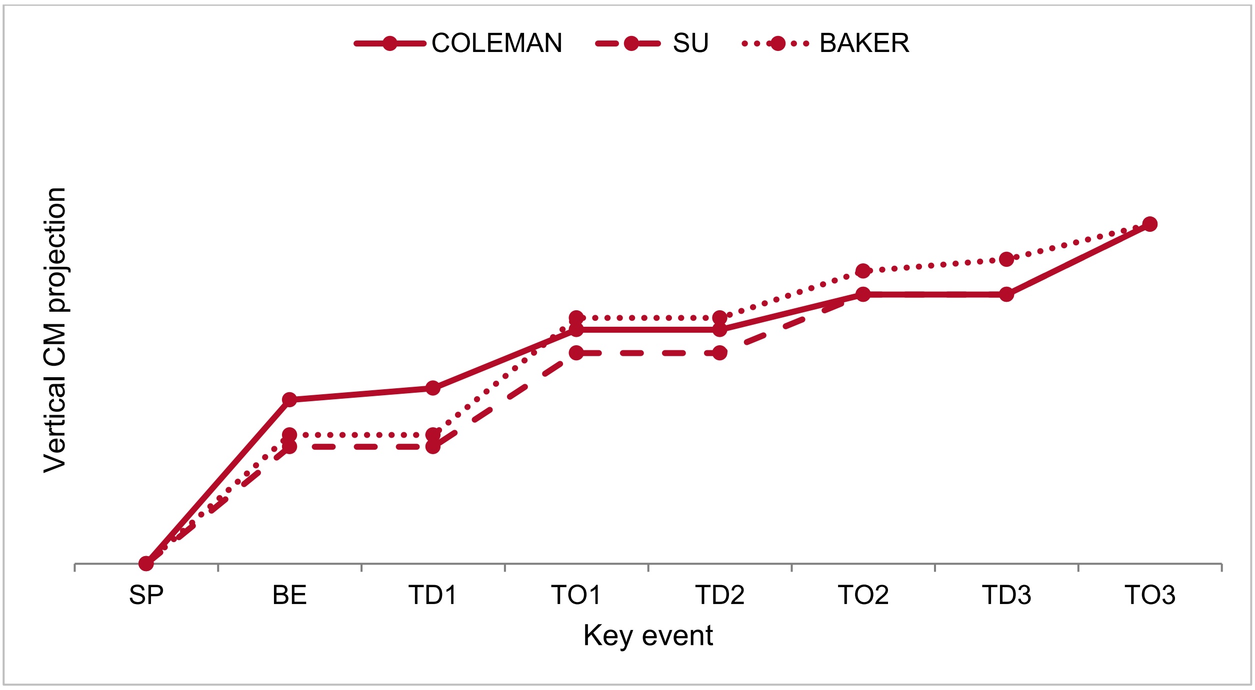

Figure 19. Vertical projection of the CM pathway throughout multiple key events during the sprint start for the medallists only.

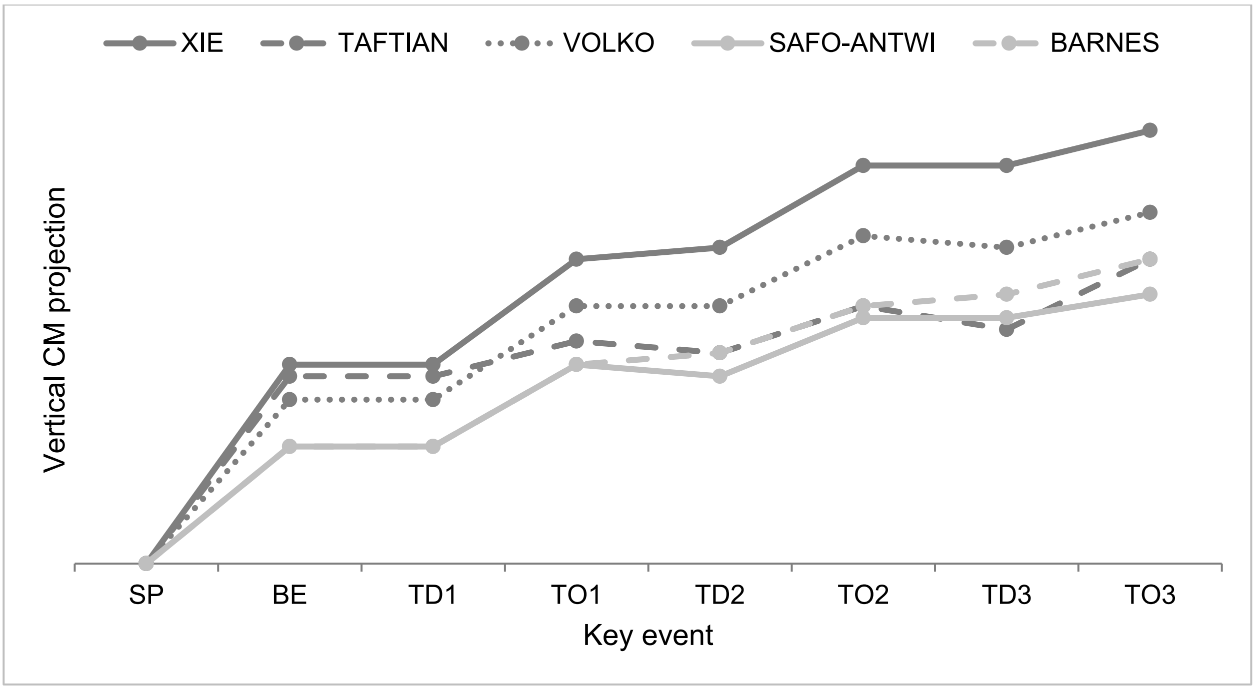

Figure 20. Vertical projection of the CM pathway throughout multiple key events during the sprint start for the remaining five finalists.

COACH'S COMMENTARY

Coaching commentary – Matthew Wood

All eyes were on the start for the final of the men's 60 m. Having recently broken the world record, Coleman's passage to the final set up a mouth-watering head to head with China's Su Bingtian in the men's 60 m final. The full line-up underlined the global reach of sprinting excellence with finalists from: USA, China, Iran, Slovak Republic, Ghana, and Turkey. To win Gold sprinters must be adept at adapting to the competitive environment, coping with unique differences between the different contexts of heats, semis and ultimately a highly competitive and pressurised final. How athletes and coaches prepare for such a performance requires a principled understanding of the complexity of the starting skills required to affect optimal acceleration to achieve a sprinters top speed.

Underlining his quality is the evidence that Christian Coleman displayed the shortest total block time in the final. This is perhaps surprising as previous research and coaching literature has differentiated between being quick from the blocks and being powerful. The exceptional starting skills of Coleman certainly afford him an advantage in the 60 m. As has been seen with other world indoor champions, this athlete characteristic does not always transfer to the outdoor distance of 100 m. Where perhaps Coleman is unique is his ability to express force in short time frames and achieve the effective acceleration.

The variation in the separate phases of the block clearance across the finalists stress the message for coaches that it is not always appropriate to coach being quick from the blocks. The quality of a sprinter's start should be considered based upon their resultant acceleration phase. The fact that the athlete that finished in second place recorded the 6th fastest total block time underlines the importance for coaches to avoid isolating the block clearance skill from that of the first three steps of acceleration. Coaches' should therefore consider the transferability of activities used to teach the block clearance carefully. For example, decontextualized pushing or reaction style practices from the blocks that require no acceleration may be limited in their transfer to the skills required in the competitive environment.

Step length data offers coaches a practical intervention to design practice tasks with athletes. The range of step lengths beyond the starting line (0.41 – 0.66 m beyond line; 1.08 – 1.29 m 1st step length) highlights a need for coaches to make sense of such data to scale practice tasks to an individual athlete's characteristics and abilities. Interestingly, Coleman's flight time from the blocks was the longest in the final, resulting in being ranked 3rd at first foot contact. This feasibly suggests one reason why he did not get closer to the world record on this occasion, despite it being the second fastest ratified 60 m time in history. Again, this underlines Coleman's potential to be even faster in the future and the complexity of bringing all the elements of starting and acceleration together in the moment.

Joint angles whilst in the set position pose an interesting challenge for coaches as a one size fits all approach perhaps does not answer each individual athlete's needs and capabilities. The observation that the lower ranked athletes displayed extreme trunk angles suggests that block positioning is a significant area for intervention by the coach. Intuitively, coaches are aware that they need to set athletes up to be capable of pushing from the set position, something this data supports. The coaching eye combined with rule of thumb values of 90° (lead knee) and 120° (rear knee) correlate with the data set. Those who fall most outside of these parameters are the shorter Coleman, and taller Volko, again reinforcing the need to scale coaching to the individual athlete.

Surprisingly, no athletes displayed full extension on the lead knee or hip on block exit. This possibly goes against coaching experience to cue full extension or drive from the blocks. It would be interesting in future research to perhaps combine athletes' personal accounts and responses to questions of their intentions when executing a start. An insight from elite athletes would offer a unique opportunity for coaches to glean specific knowledge about an athlete's intentions to act when in the blocks and when performing a start. This coupled with the kinematic data would then offer coaches a more complete knowledge of the skill, thus enabling them to design more representative practice tasks when teaching these skills with developing athletes.

Whilst the leading three athletes at first foot contact did not achieve full hip or knee extension at toe-off, they were the closest to achieving this. The potential link between the intention to fully extend the hip and subsequent first foot contact may provide coaches with clues as to the verbal cues practically support athletes learning and discovery when faced with starting practice tasks. As is expected the foot contact times decrease the further out from the start, which corresponds with the principle that contact time reduces as the athlete approaches upright running postures. What is perhaps interesting is the relative jump between the contact times in the first two steps and third across the athletes in this final. The concept of applying force, and therefore requiring longer contact times, is an indication that the best in the world are very accomplished at being patient during their execution of the first three steps. This is also inferred via the reduction in frequency observed on second step, suggesting the athlete is pushing in contrast to a reactive fast stepping away from the blocks. Setting up the correct joint angles and points of contact with the ground appears to be an overwhelming feature of good acceleration.

The time to 10 m presented as a percentage of overall 60 m performance is an interesting concept for coaches to use in analysis of the athletes' performance. It would appear that high level male sprinters achieve a 10 m time in less than 30% of their total time. Therefore, for developing athletes this bench mark could be used as an indicator for the potential to make gains either focusing on acceleration or the speed maintenance phase of the race. It should be noted that whilst the top speed component of the 60 m is significant it does not influence the acceleration phase. However, the acceleration phase will influence the top speed of an athlete significantly.

Perhaps the most significant finding for coaches is that the eventual winner displayed the highest step frequency in combination with significant step length. This suggests that superior starters have the ability to produce horizontal forces in very short time frames. Coupled to the relatively uniform pattern of acceleration demonstrated by Coleman's progressive increase in frequency and step length aligned to the progressive shift in shin and trunk angles make for an ideal recipe for effective display of the acceleration skill. Coaches should note however that there are individual solutions to the problem of projecting the body forward from the blocks and the subsequent first three steps in acceleration. A key principle however is that all athletes achieve a situation where their centre of mass is either ideally ahead or directly above foot contact on the first step. So, despite variations in trunk angle on block exit and the subsequent steps, they maintain the ability to push in this phase of the race.

World class starters in the men's 60 m indoor sprint are not necessarily the fastest from the blocks, however they will certainly display close to optimal characteristics in acceleration through a combination of horizontal projection achieved in a timely manner. Superior starters are those who can achieve the unique situation of being extremely fast in the block phase, whilst also achieving the required horizontal projection and step frequency increases seen in this evidence. This combination of abilities and skill make for a powerful start and acceleration phase of sprinting worthy of a world record holder.

Historical analysis and coaching commentary – Pierre-Jean Vazel

For the first time ever, a comprehensive biomechanical is published on men's 60 m, 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.

Technical features of the 2018 World Indoor medallists

The Birmingham's final was exceptionally fast, with the new world record (6.34 s) holder Christian Coleman setting the second best performance ever with 6.42 s in front of Su Bingtian who became the fifth fastest sprinter ever with 6.41 s. Ronnie Baker completed the podium with 6.44 s, the fastest time ever for a third place in a 60 m race.

Christian Coleman (1.75 m) was the one who stayed the shortest time on the blocks of all the finalists, just like women's 60 m winner Murielle Ahouré. This is the expression of very high neuromuscular abilities as well as a very efficient use of the starting-blocks. His sprinting action is characterised by a very high heel position during ground contacts and a pronounced forward lean of the upper body at full speed.

Su Bingtian (1.72 m) made significant improvement during the indoor season lowering the Chinese record from 6.50 s to 6.42 s, through training gains in power-speed and modifications of his starting blocks position. In the "set" command, he has now both knees at the same level, instead of having the rear leg's one lower, and he has now his shin parallel. This position seems to be more conducive for him to apply force in the optimum direction. He had the second shortest double-leg block time of the finalists, but this was followed by the second longest single leg block time. This slow extension of the front leg to exit the blocks is where he lost ground to Coleman. While Coleman's free leg is coming forward very early in the first three steps, Su must carry it for a longer time. However, after the third step, Coleman's running style changes abruptly with a much higher heel recovery, while Su's knees are gradually lifting higher because of more aggressive pushes against the ground. Both sprinters are almost side to side until the 15 m where Coleman gets into the upright position with a less pronounced back side heel recovery.

Ronnie Baker (1.78 m) uses a pronounced forward lean in the set position, like Ahouré, but this is not followed by a forward-orientated motion, as his trunk angle at first touch-down is the largest amongst all the competitors and remains the largest throughout the first three steps. Baker may be the first to touch the ground but his sub-optimal motion is measured by a drop in the velocity of the second step. By the third step, Baker is the second fastest of the finalists, showing that he is now in a better position to accelerate.

While Coleman, Su and Baker produced some of the best times ever at 60 m, the biomechanical analysis indicates that they still have some shortcoming either in their action on the blocks or during the first three steps, having the potential to shave some hundredths to their times. They were already leading the race at 10 m, with Coleman in 1.856 s, from Baker 1.866 s and Su 1.887 s. To the best of our knowledge, the fastest 10m time ever recorded is 1.80 s during a 10.27 s race into a 2.5 m/s wind by Japanese Ryota Yamagata in Hiroshima in 2016 (personal best 10.00 s in 2017). This supports the idea that the three medallists in Birmingham have the potential to go even faster by improving their start.

CONTRIBUTORS

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Matthew is a Lecturer in Athletics and Sports Coaching at Cardiff Metropolitan University. He is a level three qualified athletics coach with experience of working with athletes from grassroots to major age group championships in sprints and hurdles and has been responsible for the fledgling careers of athletes across all the athletic disciplines. Matthew has research interests working with developing coaches on their application of the principles of nonlinear pedagogy to enhance the retention and transition of youth athletes.

Pierre-Jean Vazel is a sprint and throws coach at Athlétisme Metz Métropole club in France. PJ is a 5th year graduate in Fine Arts and has covered 2 Olympics, 9 World Championships and over 300 meetings as a coach or chronicler for Le Monde and IAAF website. Since 2004 he coached national champions from six countries including Olu Fasuba to the 100 m African Record (9.85 s) and 60 m world indoor title. PJ is co-author of the ALTIS Foundation course and has done many lectures on the history of sprint science and training.