IAAF World Championships
LONDON 2017

BIOMECHANICAL REPORT

FOR THE

IAAF World Championships
LONDON 2017

400 m Men's

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INTRODUCTION

On Tuesday 8th August Wayde van Niekerk underlined his iconic status with a successful defence of his world 400 m title, claiming gold in 43.98 s. Despite an empty lane outside him, because of the absence of Botswana's Isaac Makwala, van Niekerk started strongly from lane six and lead from start to finish. Despite the race for gold being over at 300 m, the battle for the silver medal was very much on. It appeared that Botswana would win a medal as 20-year-old Baboloki Thebe ran the quickest bend of all (10.82 s) from the outside lane. However, Thebe faded with 40 m to go and 21-year-old Bahamian Steven Gardiner produced another strong performance to secure the silver in 44.41 s. Interestingly, if Gardiner had replicated his semi-final performance two days earlier, whereby he lowered his own national record to 43.89 s, van Niekerk may have faced a greater challenge. Thebe was also denied the bronze medal as the fast-finishing Abdalelah Haroun of Qatar crossed the line in a season's best time of 44.48 s. Despite being last at 340 m, Haroun carved through the field over the final 60 m to become the first Asian 400 m medallist at a World Championships.

IAAF World Championships London 4-13 August 2017

RESULTS

400 Metres Men - Final

RECORDS	RESULT	NAME	COUNTRY	AGE	VENUE	DATE
World Record WR	43.03	Wayde VAN NIEKERK	RSA	24	Rio de Janeiro (Estádio Olímpico)	14 Aug 2016
Championships Record CR	43.18	Michael JOHNSON	USA	32	Sevilla (La Cartuja)	26 Aug 1999
World Leading WL	43.62	Wayde VAN NIEKERK	RSA	25	Lausanne (Pontaise)	6 Jul 2017

Area Record AR National Record NR Personal Best PB Season Best SB

8 August 2017 21:54 START TIME 19° C TEMPERATURE 56 % HUMIDITY

PLACE	NAME	COUNTRY	DATE of BIRTH	LANE	RESULT		REACTION	Fn
1	Wayde VAN NIEKERK	RSA	15 Jul 92	6	43.98		0.157	
2	Steven GARDINER	BAH	12 Sep 95	4	44.41		0.188	
3	Abdalelah HAROUN	QAT	1 Jan 97	3	44.48	SB	0.190	
4	Baboloki THEBE	BOT	18 Mar 97	9	44.66		0.182	
5	Nathon ALLEN	JAM	28 Oct 95	5	44.88		0.158	
6	Demish GAYE	JAM	20 Jan 93	8	45.04		0.179	
7	Fred KERLEY	USA	7 May 95	2	45.23		0.142	
	Isaac MAKWALA	BOT	29 Sep 86	7	DNS			

Timing and Measurement by SEIKO AT-400-M-f--1--.RS1..v1 Issued at 21:57 on Tuesday, 08 August 2017

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METHODS

Eleven vantage locations for camera placement were identified and secured. Six of these were dedicated to the home straight and the additional five were strategically positioned around the stadium (Figure 1). Each of the home straight locations had the capacity to accommodate up to five cameras placed on tripods in parallel. Five locations were situated on the broadcasting balcony along the home straight (from the 300 m line to the 390 m line) whilst the sixth location was located within the IAAF VIP outdoor area overlooking the finish line from a semi-frontal angle. Two separate calibration procedures were conducted before and after each competition. First, a series of nine interlinked training hurdles were positioned every 10 m along the home straight ensuring that the crossbar of each hurdle, covered with black and white tape, was aligned with the track's transverse line (Figure 2). These hurdles were also positioned across all nine lanes on the track markings for the 100, 200 and 300 m intervals. Second, a rigid cuboid calibration frame was positioned on the running track between the 347-metre mark and the 355.5-metre mark (from the starting line) multiple times over discrete predefined areas along and across the track to ensure an accurate definition of a volume within which athletes were achieving high running speeds (Figure 3). This approach produced a large number of non-coplanar control points per individual calibrated volume and facilitated the construction of bi-lane specific global coordinate systems.

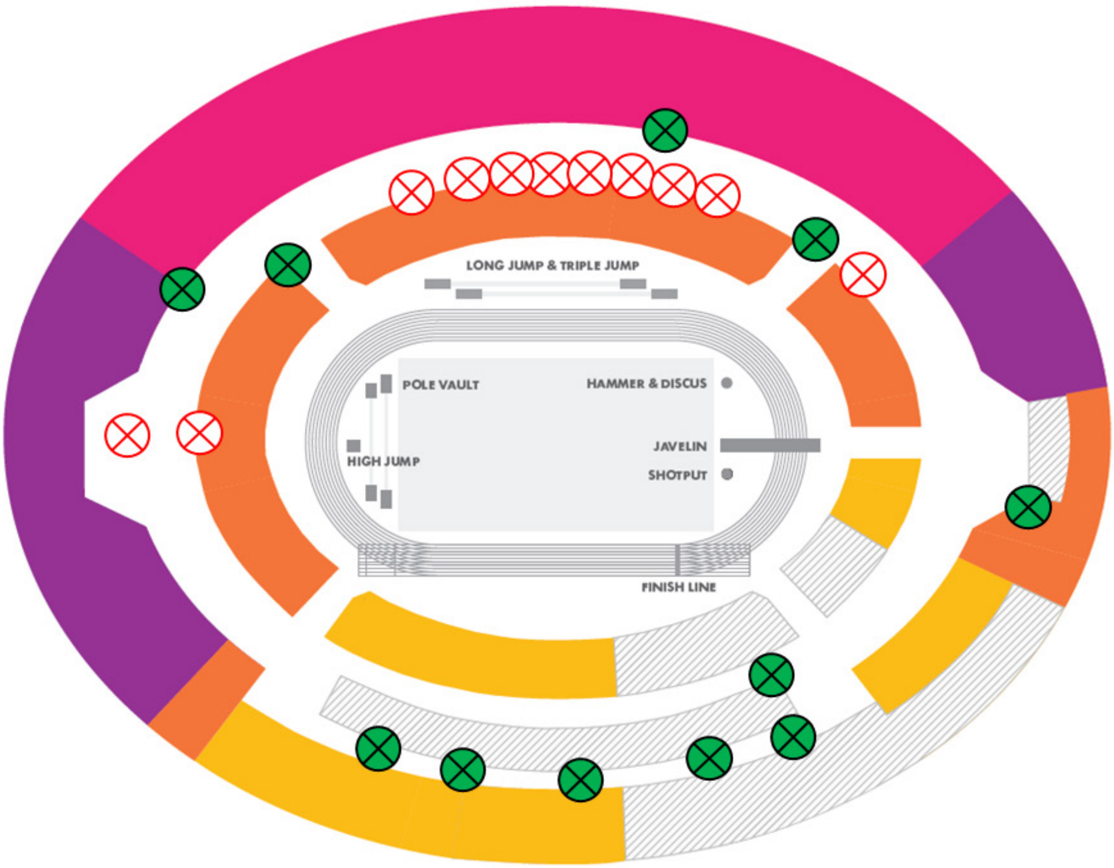

Figure 1. Camera layout within the stadium for the men's 400 m indicated by green in-filled circles.

A total of 20 cameras were employed to record the action during the 400 m semi-finals and finals. Five Sony RX10 M3 cameras operating at 100 Hz (shutter speed: 1/1250; ISO: 1600; FHD: 1920x1080 px) were positioned strategically along the home straight with their optical axes perpendicular to the running direction in order to capture motion in the sagittal plane and provide footage for the analysis of the split times. Five Sony PXW-FS7 cameras operating at 150 Hz (shutter speed: 1/1250; ISO: 1600; FHD: 1920x1080 px) were used to capture the motion of athletes as they were moving through the calibrated middle section. Each of the five 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. To provide footage for the analysis of the initial 300 m, five Canon EOS 700D cameras operating at 60 Hz (shutter speed: 1/1250; ISO: 1600; SHD: 1280x720 px) were used.

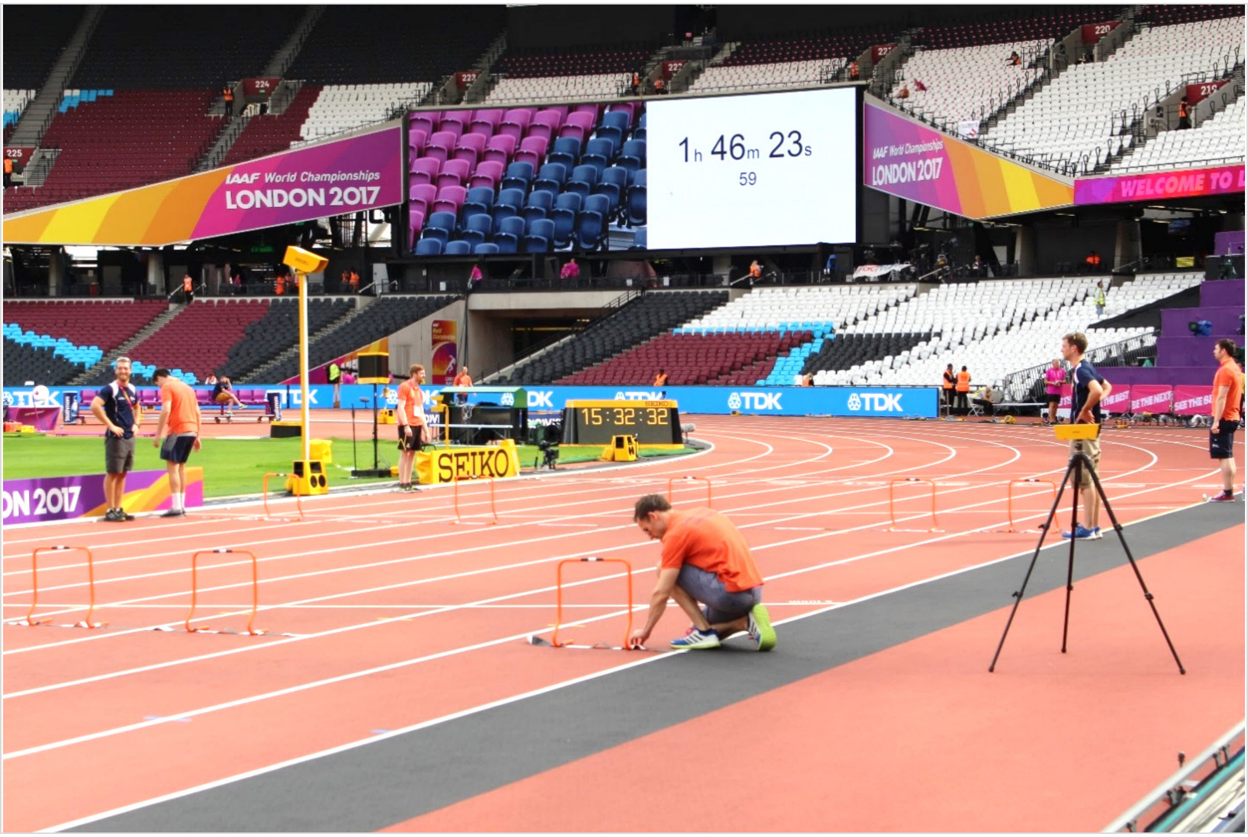

Figure 2. Set-up of the hurdle calibration system used to determine split intervals.

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. Because of greater variability of performance across athletes during the middle calibration volume, compared to the shorter sprints, the digitising process centred upon critical events (e.g., touchdown and toe-off) rather than an analysis of the full sequence throughout the calibration volume. Each file was first 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 repeated digitising of one sprint running stride 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.

Figure 3. The calibration frame was constructed and filmed before and after the competition.

De Leva's (1996) body segment parameter models were used to obtain data for the whole body centre of mass. A recursive second-order, low-pass Butterworth digital filter (zero phase-lag) was employed to filter the raw coordinate data. The cut-off frequencies were calculated using residual analysis. Split times and kinematic characteristics were processed through SIMI Motion by using the 60, 100 and 150 Hz footage respectively. Where available, athletes' heights were obtained from 'Athletics 2017' (edited by Peter Matthews and published by the Association of Track and Field Statisticians), and online sources.

Figure 4. Action from the 400 m men's final.

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

Variable	Definition
Positional analysis	Position of each athlete at each 100 m interval during the race. Also, throughout the home straight, the position at each 10 m interval (final), and for each 20 m interval (semi-finals).
Individual split times	Split time for each athlete based on the positional analysis above.
Mean speed	Mean speed for each athlete based on the individual split times.
Completed steps	Total recorded steps (e.g., right foot to left foot) during each 100 m interval.
Mean step length (split data)	Mean absolute length of each step during each 100 m interval and the relative value, based on an athlete's height, of each step during these intervals. The value of 1 relates to an athlete's height.
Step length	The distance covered from toe-off on one foot to toe-off on the other foot.
Relative step length	Step length as a proportion of the athlete's height (body height = 1.00).
Step rate	The number of steps per second (Hz).
Contact time	The time the foot is in contact with the ground.

Flight time	The time from toe-off (TO) of one foot to touchdown (TD) of the other foot.
Step time	Contact time + flight time.
Step velocity	Step length divided by step time.
Swing time	The time that the foot is not in contact with the ground during one full stride.
DCM TD	The horizontal distance between the ground contact point (foot tip) at TD and the CM.
DCM TO	The horizontal distance between the ground contact point (foot tip) at TO and the CM.
Trunk angle (α)	The angle of the trunk relative to the horizontal and considered to be 90° in the upright position.
Knee angle (β)	The angle between the thigh and lower leg and considered to be 180° in the anatomical standing position.
Contact leg hip angle (γ)	The shoulder-hip-knee angle of the contact side.
Swing leg hip angle (δ)	The shoulder-hip-knee angle of the swing side. ***Note:*** *angle taken at toe-off only.*
Contact thigh angle (ε)	The angle between the thigh of the contact leg and the vertical.
Swing thigh angle (ζ)	The angle between the thigh of the swing leg and the vertical.
Thigh separation angle (η)	The angle between the thighs of the contact and swing legs. This has been calculated as the difference between ε and ζ.
Shank angle (θ)	The angle of the lower leg relative to the running surface and considered to be 90° when the shank is perpendicular to the running surface.
Ankle angle (ι)	The angle between the lower leg and the foot and considered to be 90° in the anatomical standing position.

Note: *CM = Centre of mass.*

RESULTS – Final

Performance data

The tables below display the season's (SB) and personal best (PB) times of each athlete competing in the final before the World Championships, and their performance during the semi-finals (Table 2). These values are then compared to their performance in the final itself (Table 3).

Table 2. Individual season's (SB) and personal bests (PB), and performance during the semi-final (SF).

Athlete	SB	*rank*	PB	*rank*	SF	*rank*	*notes*
VAN NIEKERK	43.62 s	*1*	43.03 s	*1*	44.22 s	*3*	
GARDINER	44.26 s	*5*	44.26 s	*5*	43.89 s	*1*	*NR*
HAROUN	45.15 s	*8*	44.27 s	*6*	44.64 s	*8*	*SB*
THEBE	44.02 s	*4*	44.02 s	*4*	44.33 s	*5*	
ALLEN	44.52 s	*6*	44.52 s	*7*	44.19 s	*2*	*PB*
GAYE	44.64 s	*7*	44.64 s	*8*	44.55 s	*7*	*PB*
KERLEY	43.70 s	*2*	43.70 s	*2*	44.51 s	*6*	
MAKWALA	43.84 s	*3*	43.72 s	*3*	44.30 s	*4*	

Key: *SB = season's best, PB = personal best, SF = semi-final, NR = national record.*

Table 3. Comparison of athletes' performance during the final compared to PB, SB and semi-finals (SF).

Athlete	FINAL	*notes*	vs. SF	vs. SB	vs. PB
VAN NIEKERK	43.98 s		–0.24 s	0.36 s	0.95 s
GARDINER	44.41 s		0.52 s	0.15 s	0.15 s
HAROUN	44.48 s	*SB*	–0.16 s	–0.67 s	0.21 s
THEBE	44.66 s		0.33 s	0.64 s	0.64 s
ALLEN	44.88 s		0.69 s	0.36 s	0.69 s
GAYE	45.04 s		0.49 s	0.40 s	0.40 s
KERLEY	45.23 s		0.72 s	1.53 s	1.53 s
MAKWALA	-		-	-	-

Key: *SB = season's best, PB = personal best, SF = semi-final.*

Positional analysis

Figure 5 shows the relative position of each athlete at each 100 m split throughout the race. A more detailed overview of the relative positions at each 10 m split throughout the home straight is presented in Figure 6.

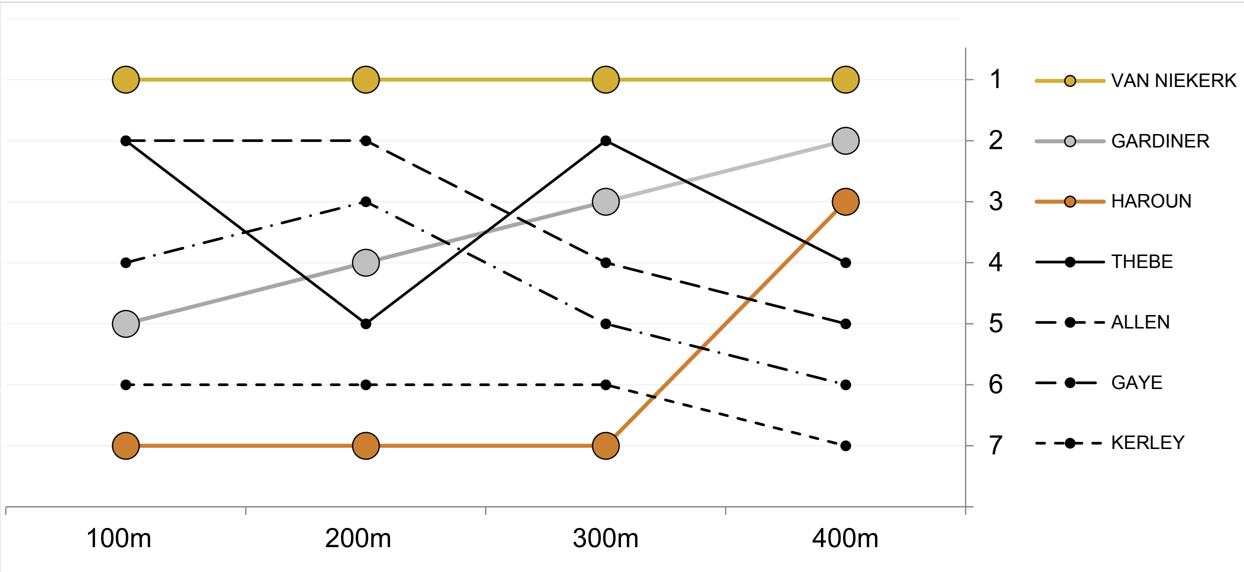

Figure 5. Positions at the end of each 100 m split.

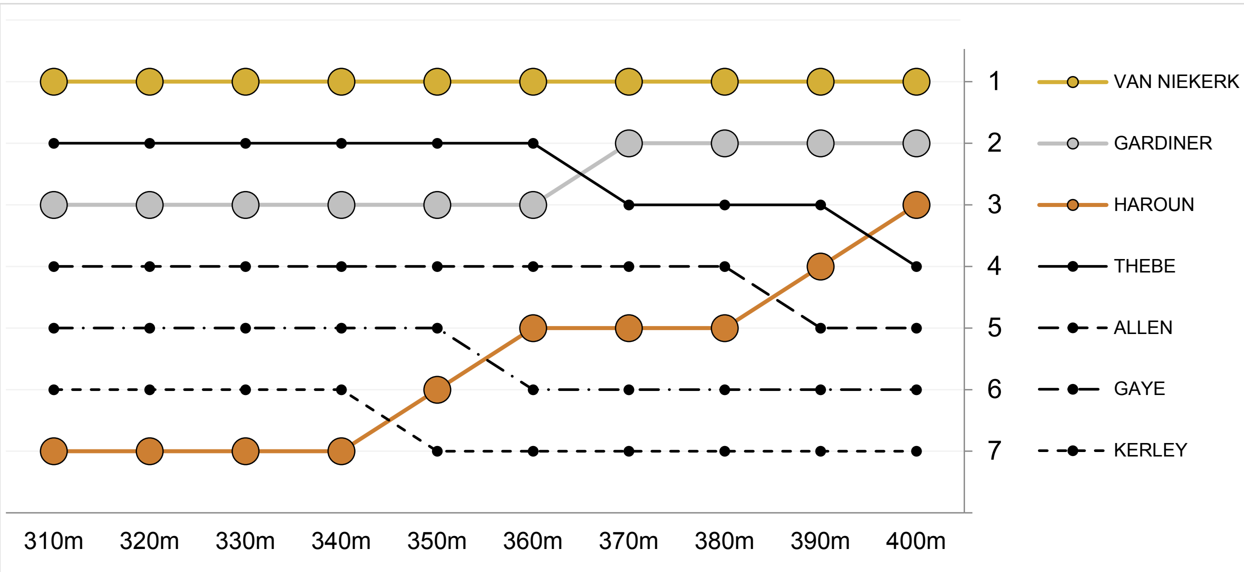

Figure 6. Positions at the end of each 10 m split throughout the home straight.

Individual split times

The following graphs display the split times of all athletes over each: 200 m split (Figures 7 and 8), consecutive 100 m splits (Figure 9; note: 0-100 m is displayed without the reaction time) and consecutive 10 m splits throughout the home straight (Figures 9 and 10). The mean speed over consecutive 10 m splits throughout the home straight is presented in Figure 11. Please note that split times have been rounded mathematically to two decimal places throughout this report. However, the official result is always rounded up in accordance with the IAAF Competition Rules – this causes some instances where our total race times differ by 0.01 seconds. Any instances of this are highlighted in the notes section of the performance tables by an asterisk (*).

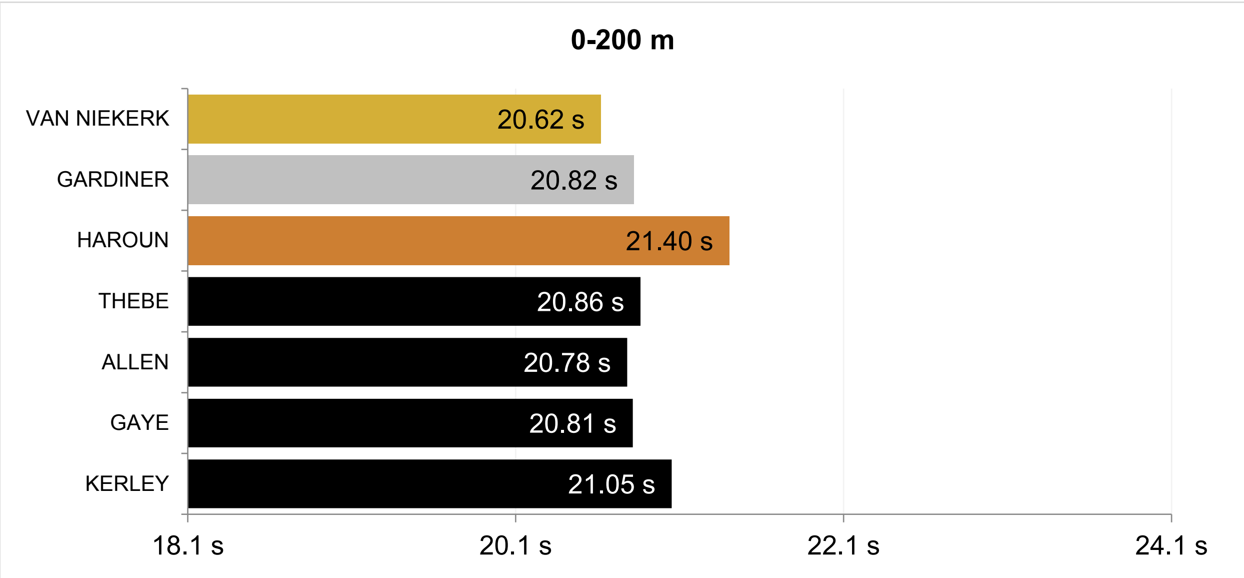

Figure 7. Individual 0-200 m split times (minus reaction time).

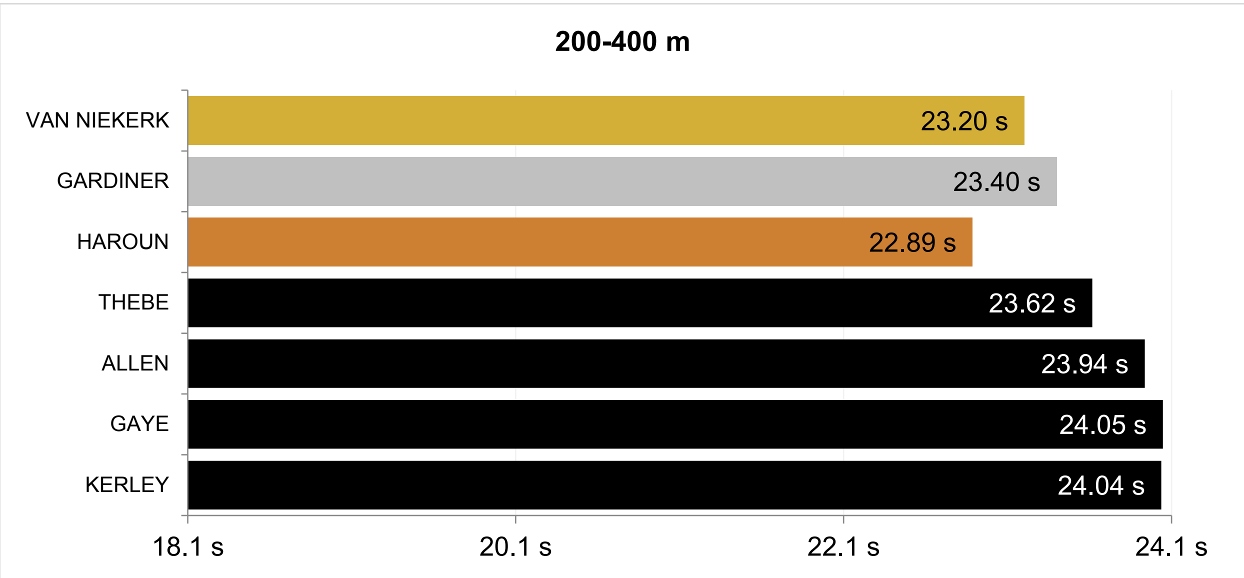

Figure 8. Individual 200-400 m split times.

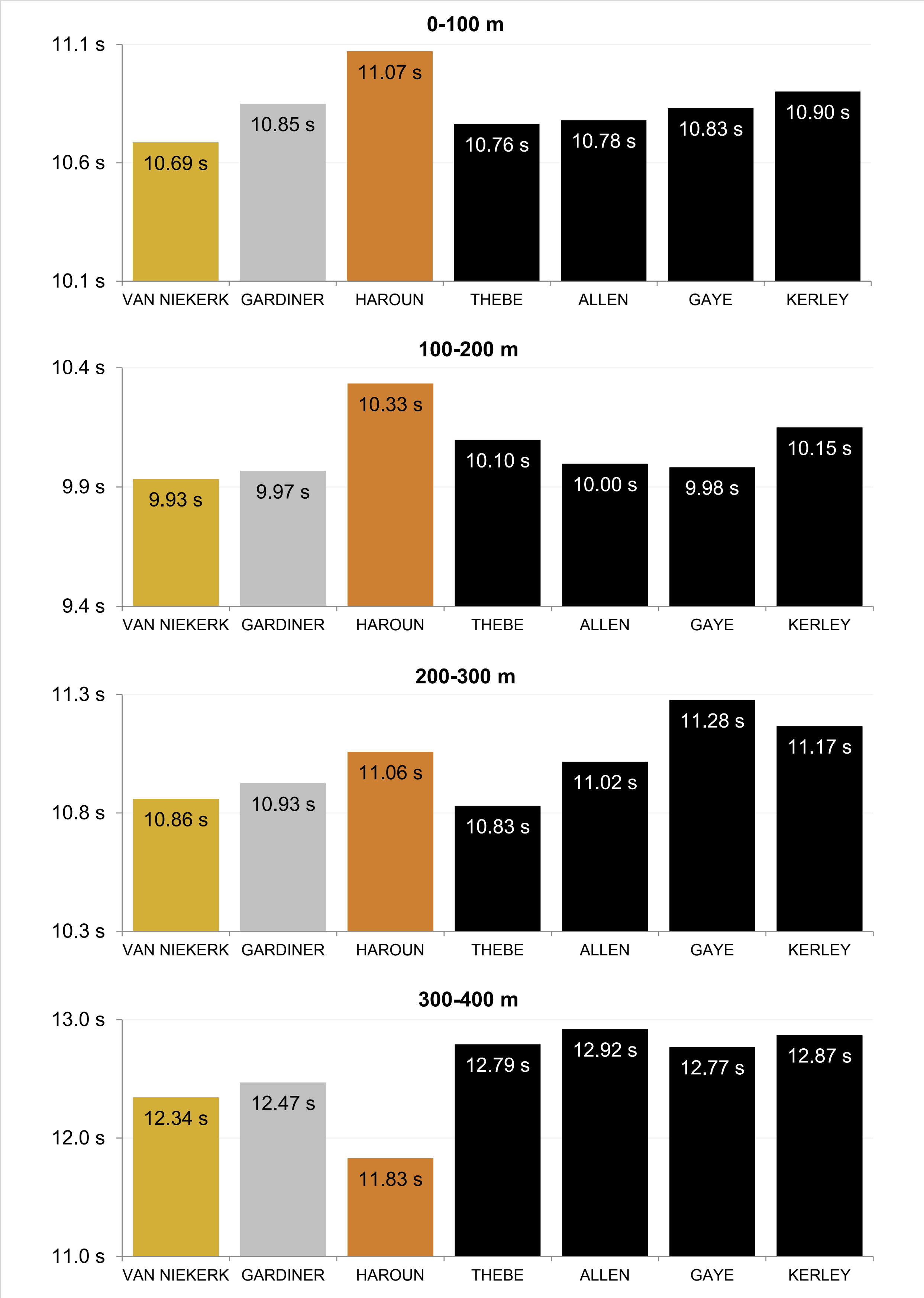

Figure 9. Individual consecutive 100 m split times (0-100 m minus reaction time).

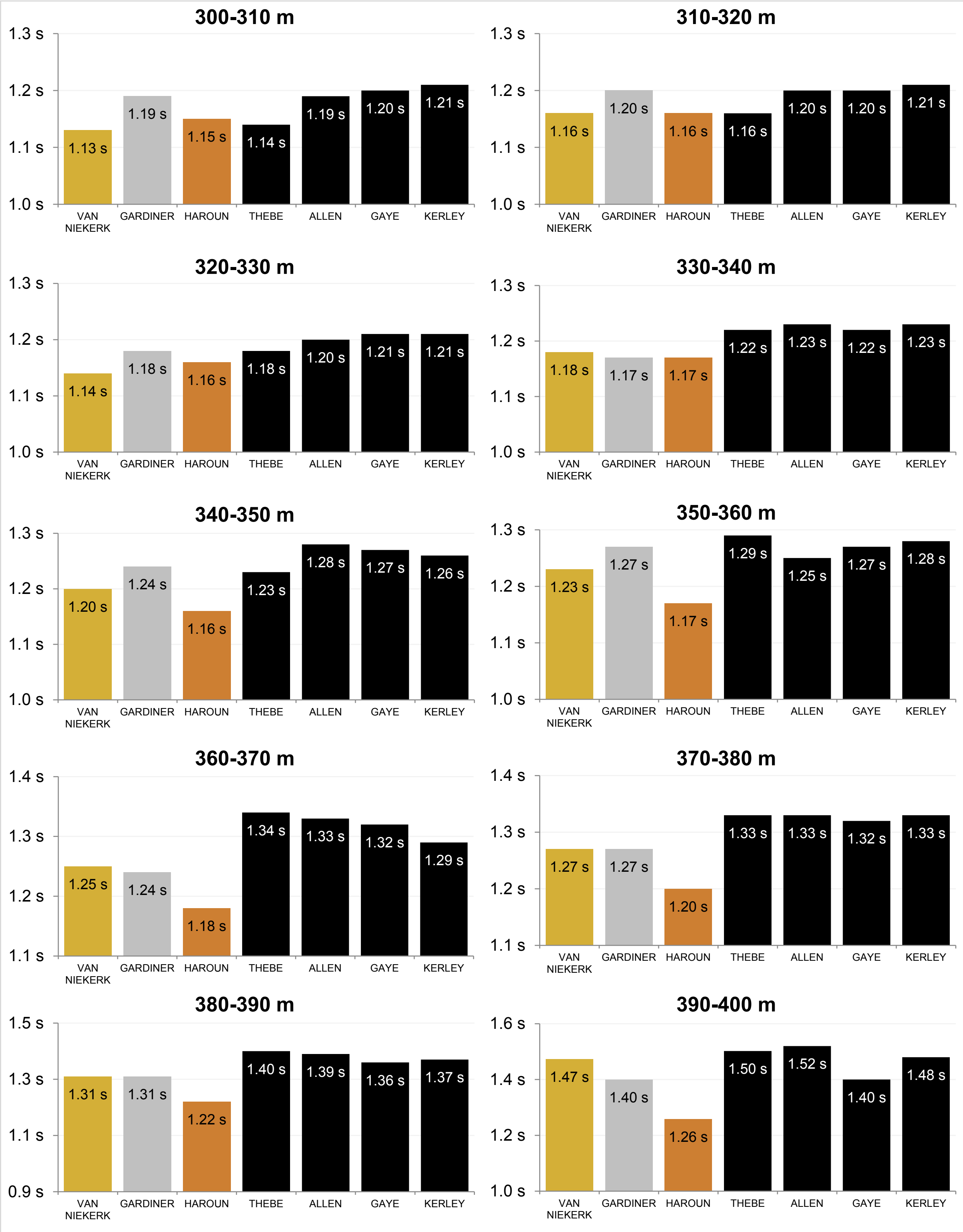

Figure 10. Individual consecutive 10 m split times throughout the home straight.

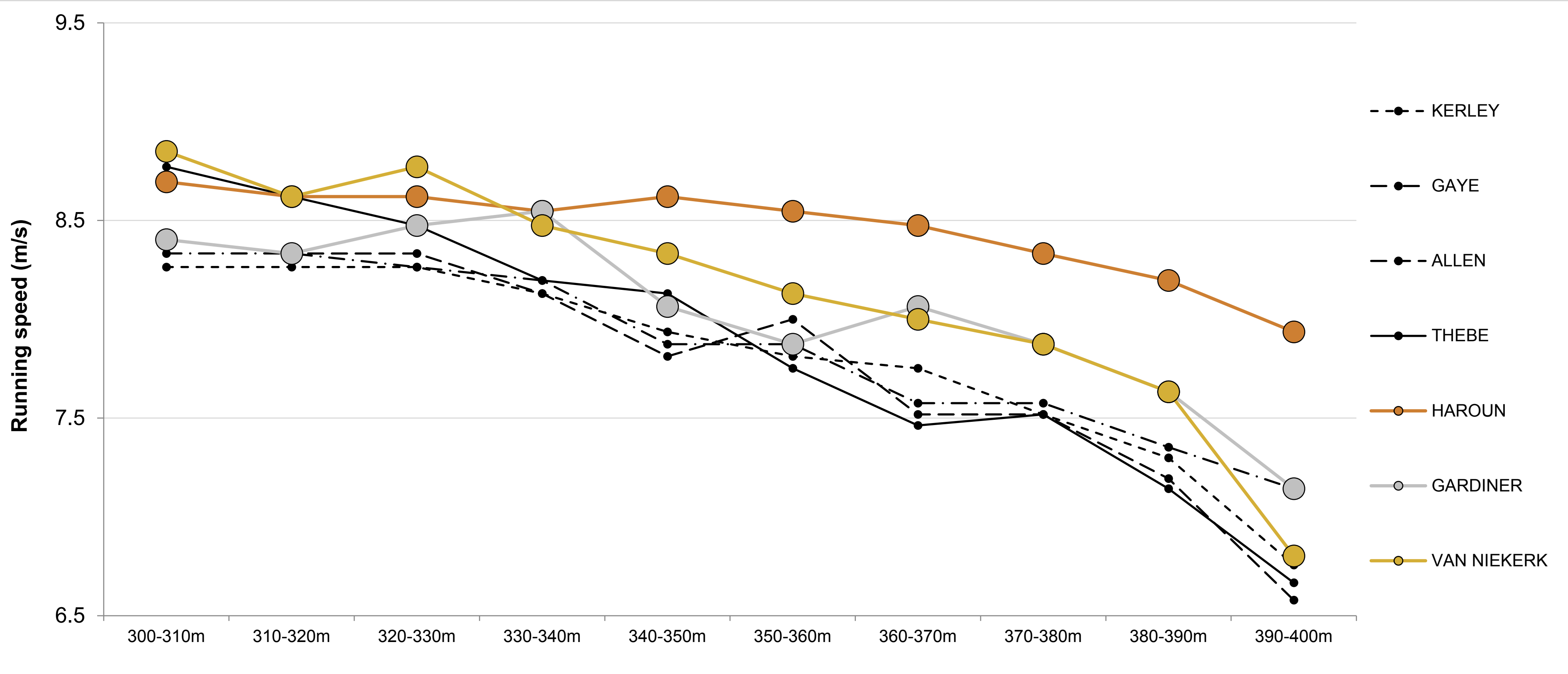

Figure 11. Mean running speed during each 10 m split throughout the home straight.

Completed steps and step length

The following graphs show step information of individual athletes over progressive 100 m splits for the mean step length and relative to each athlete's stature (Figure 12). The total completed steps for the race and during each 100 m split for each athlete is presented in Figure 13.

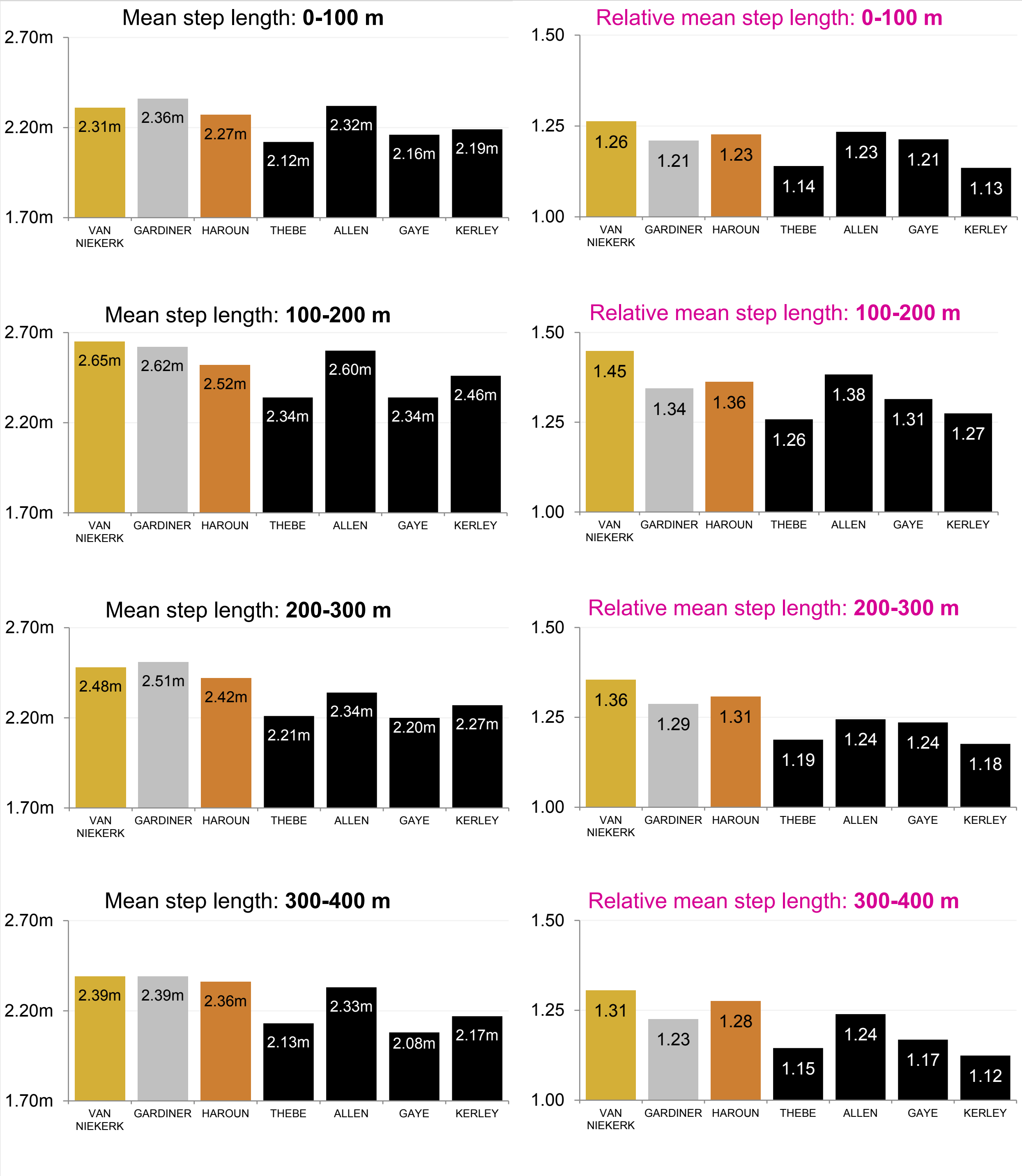

Figure 12. Mean and relative (height) step length during each 100 m split.

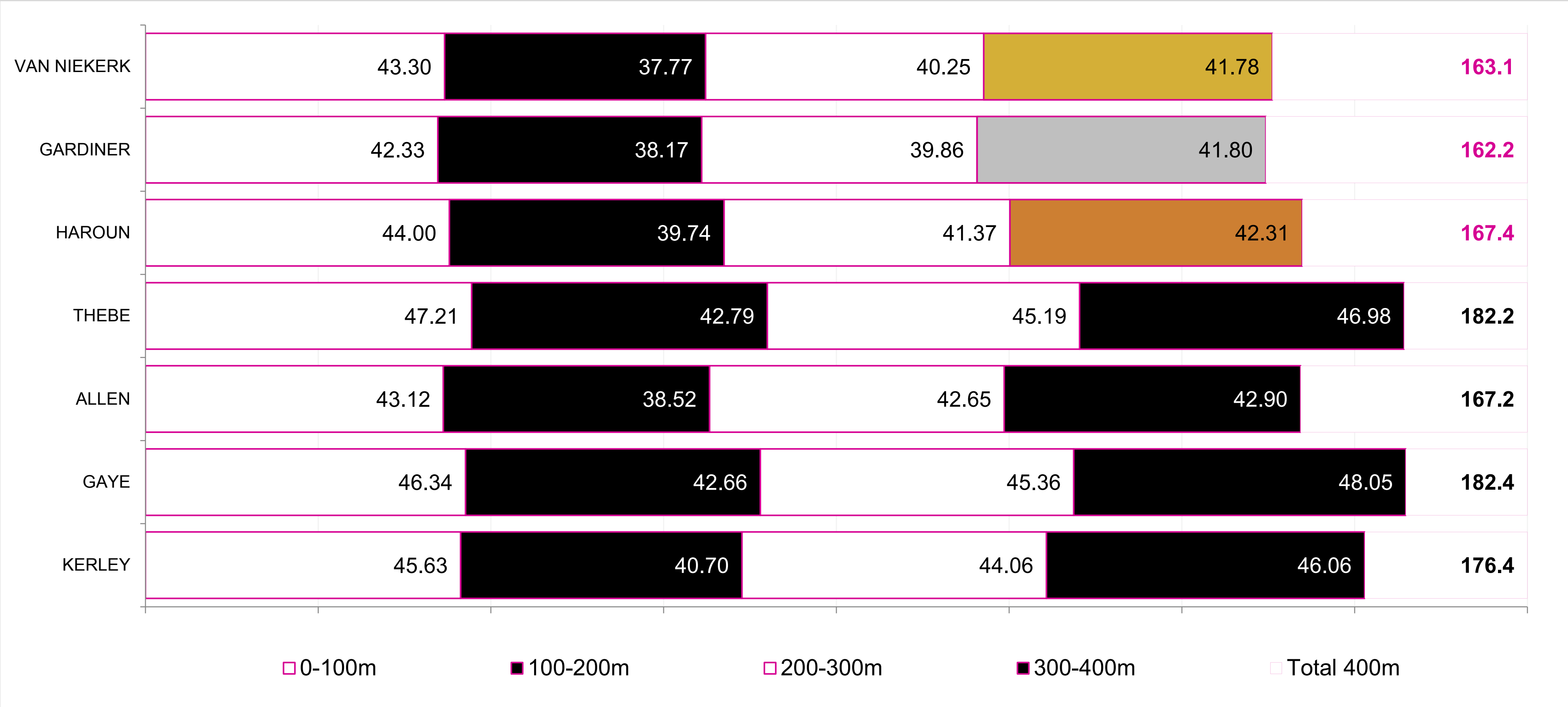

Figure 13. Total completed steps during the race and throughout each consecutive 100 m split.

GOLD MEDALLIST: Wayde van Niekerk

	RT	100 m	200 m	300 m	RESULT
Final	0.157 s	10.85 s	20.78 s	31.64 s	**43.98 s**
Rank	*2nd*	*1st*	*1st*	*1st*	***1st***
vs. silver	–0.031 s	–0.20 s	–0.23 s	–0.30 s	–0.43 s
vs. bronze	–0.033 s	–0.42 s	–0.82 s	–1.01 s	–0.50 s
Semi-Final	0.168 s	10.91 s	20.99 s	32.12 s	**44.22 s**
Rank	*11th*	*=1st*	*5th*	*8th*	***1st***

	0-100 m	100-200 m	0-200 m	200-300 m	300-400 m	200-400 m
Final	10.69 s	9.93 s	20.62 s	10.86 s	12.34 s	23.20 s
Rank	*1st*	*1st*	*1st*	*2nd*	*2nd*	*2nd*
vs. silver	–0.16 s	–0.03 s	–0.20 s	–0.07 s	–0.13 s	–0.20 s
vs. bronze	–0.38 s	–0.40 s	–0.78 s	–0.20 s	+0.51 s	+0.32 s
Semi-Final	10.74 s	10.08 s	20.82 s	11.13 s	12.10 s	23.23 s
Rank	*5th*	*9th*	*5th*	*12th*	*2nd*	*3rd*

Kinematic characteristics

This section presents the results from the digitised data within the calibration zone (i.e., around 350 m) along the home straight. All variables have been described previously (Table 1).

Table 4. Mean step rate, step velocity and step length for each finalist around 350 m.

	Step velocity (m/s)	Step rate (Hz)	Step length (m)	#*relative*
VAN NIEKERK	8.23	3.33	2.47	1.35
GARDINER	8.26	3.37	2.45	1.26
HAROUN	8.59	3.66	2.35	1.27
THEBE	8.03	3.75	2.14	1.15
ALLEN	8.04	3.41	2.36	1.26
GAYE	8.15	3.85	2.12	1.19
KERLEY	7.73	3.66	2.11	1.09

Note: *Step velocity calculated from step length and step time; # relative step length based on athlete's height.*

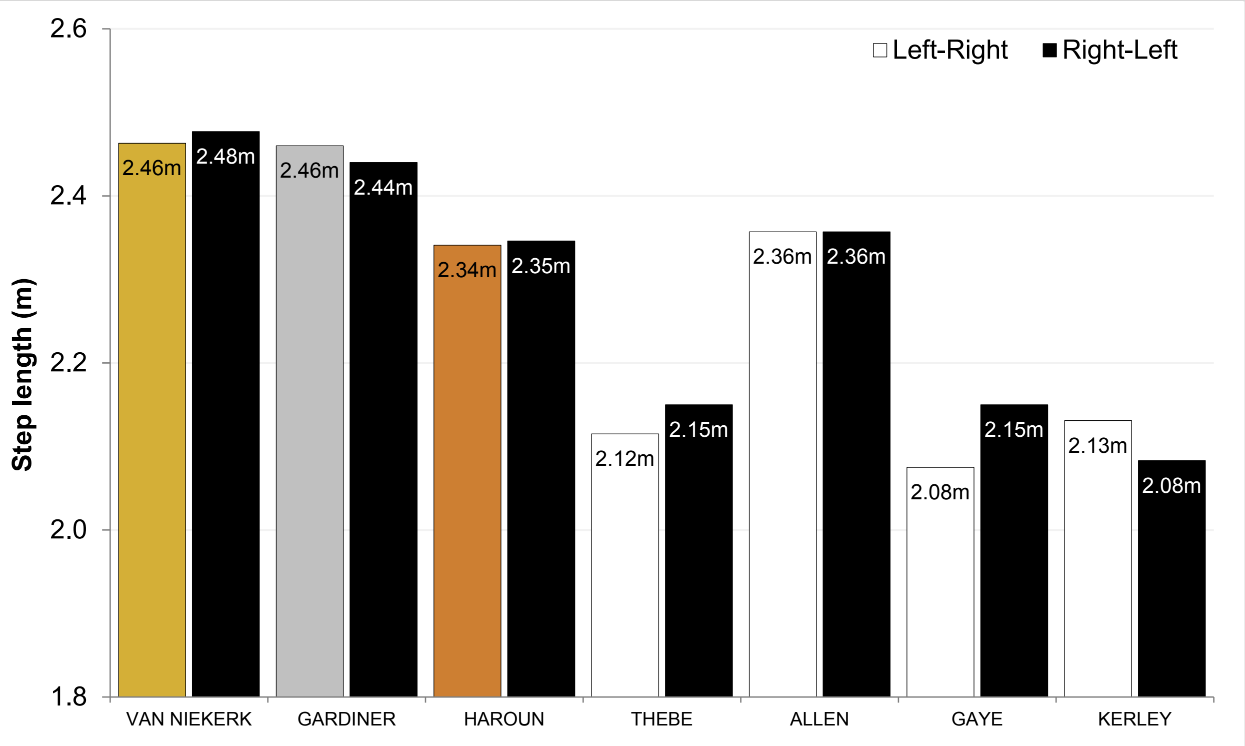

Figure 14. Step lengths for each of the finalists around 350 m.

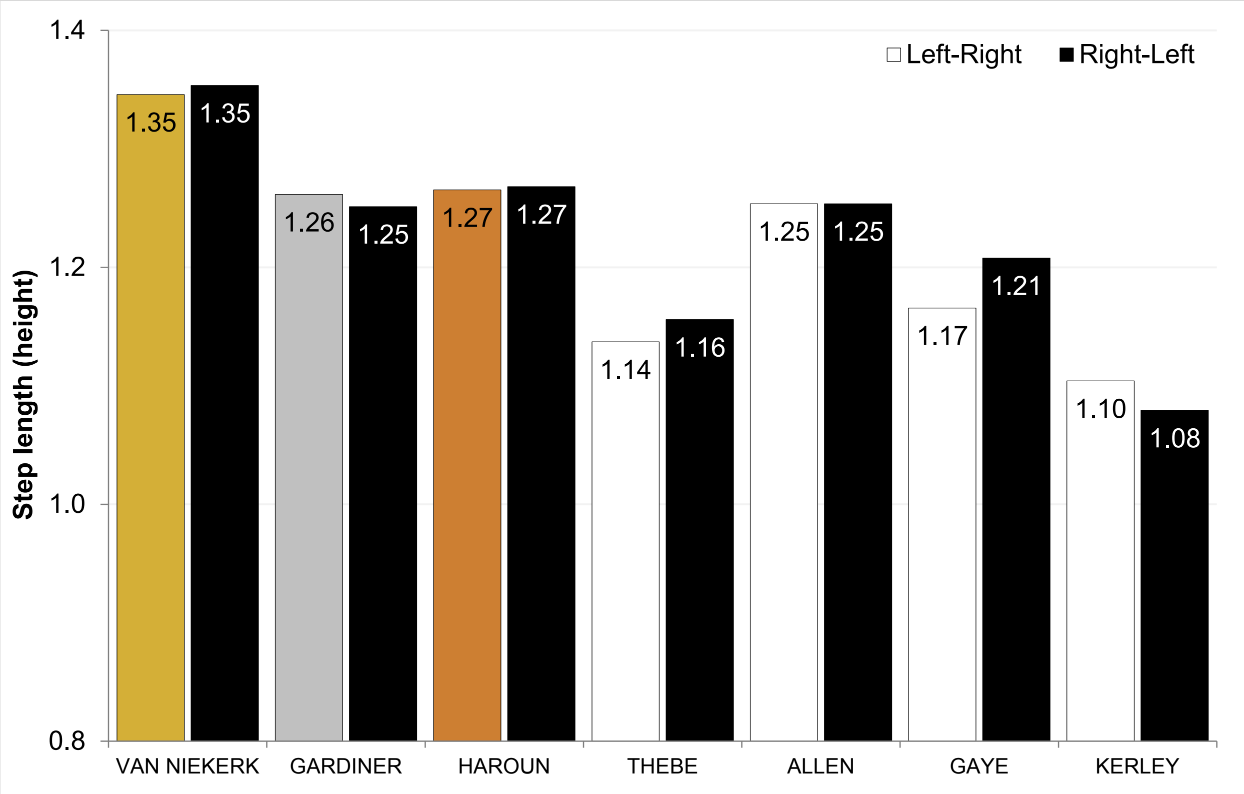

Figure 15. Relative (height) step lengths for each of the finalists around 350 m.

Note: *Van Niekerk's and Haroun's steps appear to be different because of rounding.*

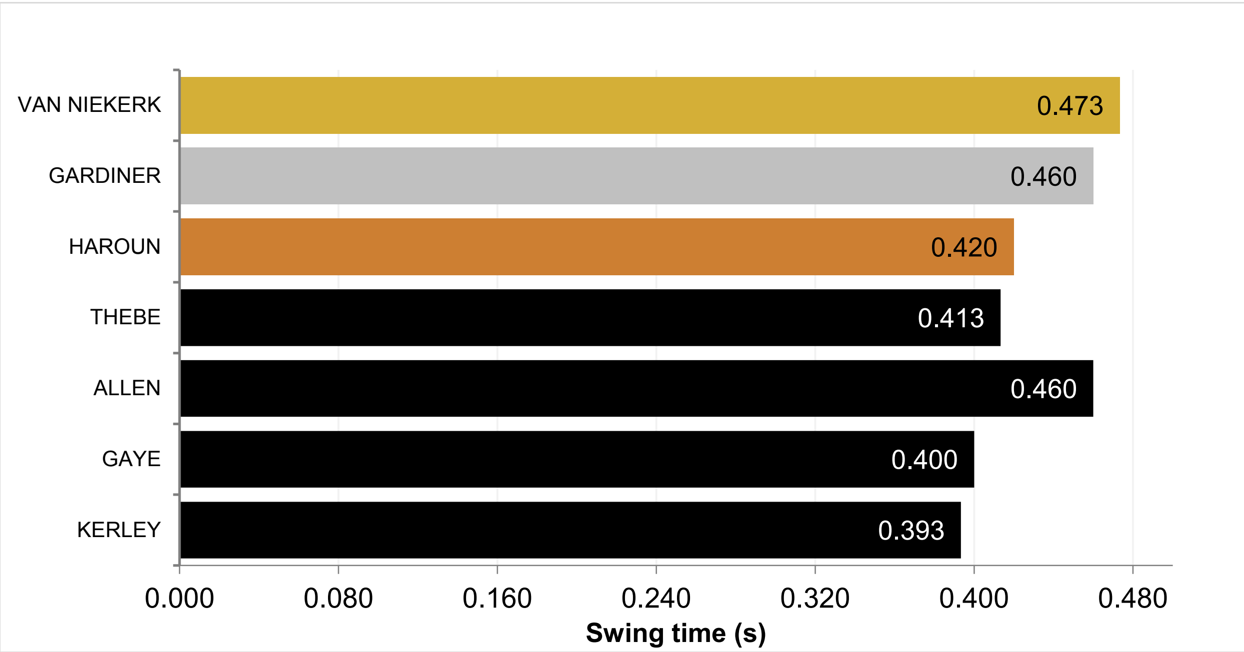

Figure 16. Swing times for each of the finalists around 350 m.

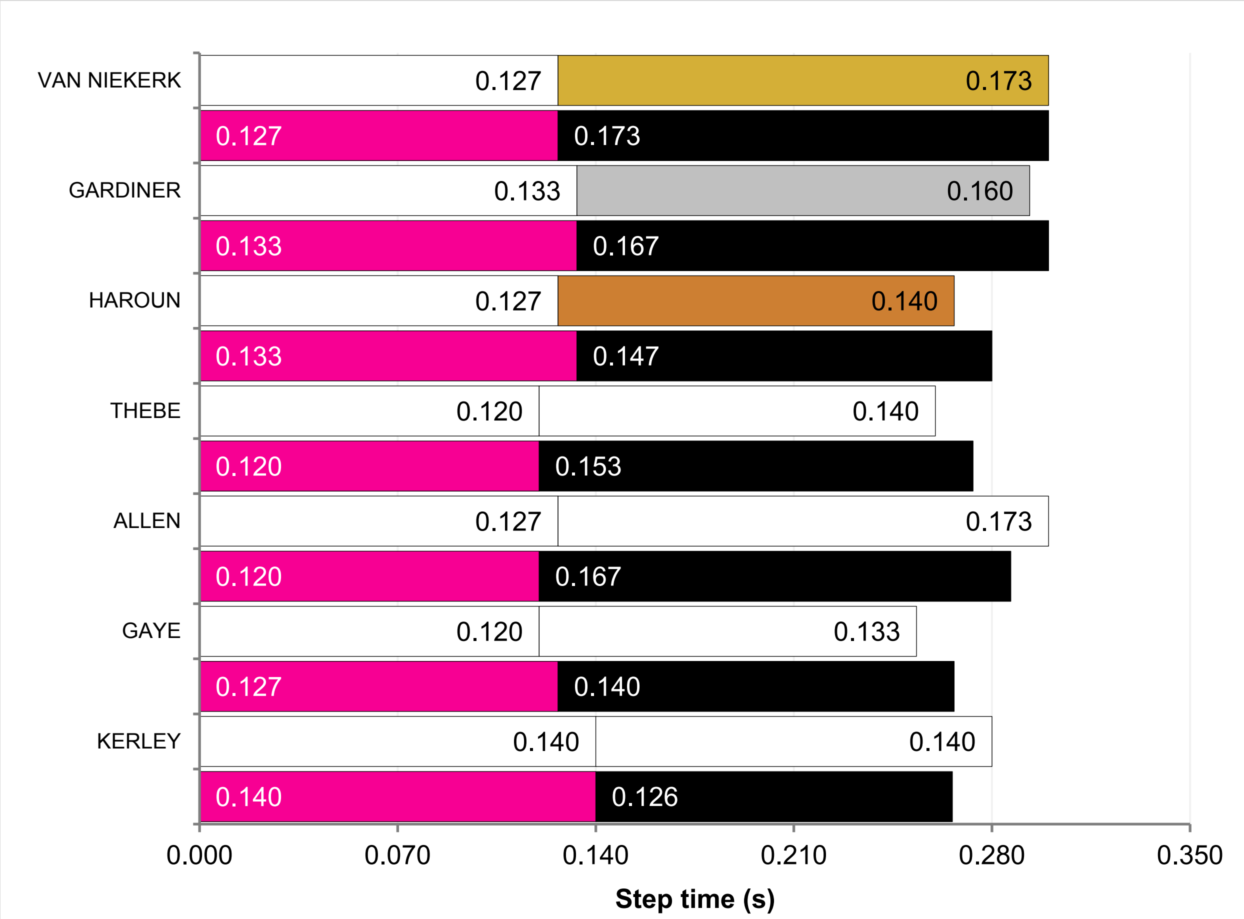

Figure 17. Individual contact and flight times for each of the finalists around 350 m. For each athlete, the top column (black text) represents the left foot contact and left-to-right flight time, and the bottom column (white text) represents the right foot contact (pink shading) and right-to-left flight time (black shading).

Table 5. Horizontal distance to the centre of mass (DCM) at touchdown (TD) and toe-off (TO).

	DCM TD (m / % body height)		DCM TO (m / % body height)	
	Left	Right	Left	Right
VAN NIEKERK	0.46 / 25	0.48 / 26	0.53 / 29	0.53 / 29
GARDINER	0.45 / 23	0.42 / 21	0.56 / 29	0.50 / 26
HAROUN	0.50 / 27	0.53 / 29	0.54 / 29	0.50 / 27
THEBE	0.40 / 22	0.46 / 25	0.47 / 25	0.44 / 24
ALLEN	0.45 / 24	0.41 / 22	0.54 / 29	0.54 / 29
GAYE	0.42 / 24	0.43 / 24	0.51 / 29	0.45 / 25
KERLEY	0.51 / 26	0.45 / 23	0.45 / 23	0.61 / 31

Note: *Data displayed as an absolute distance and as a percentage of the athletes' heights. Percentage values have been rounded to the nearest integer.*

Angular kinematics

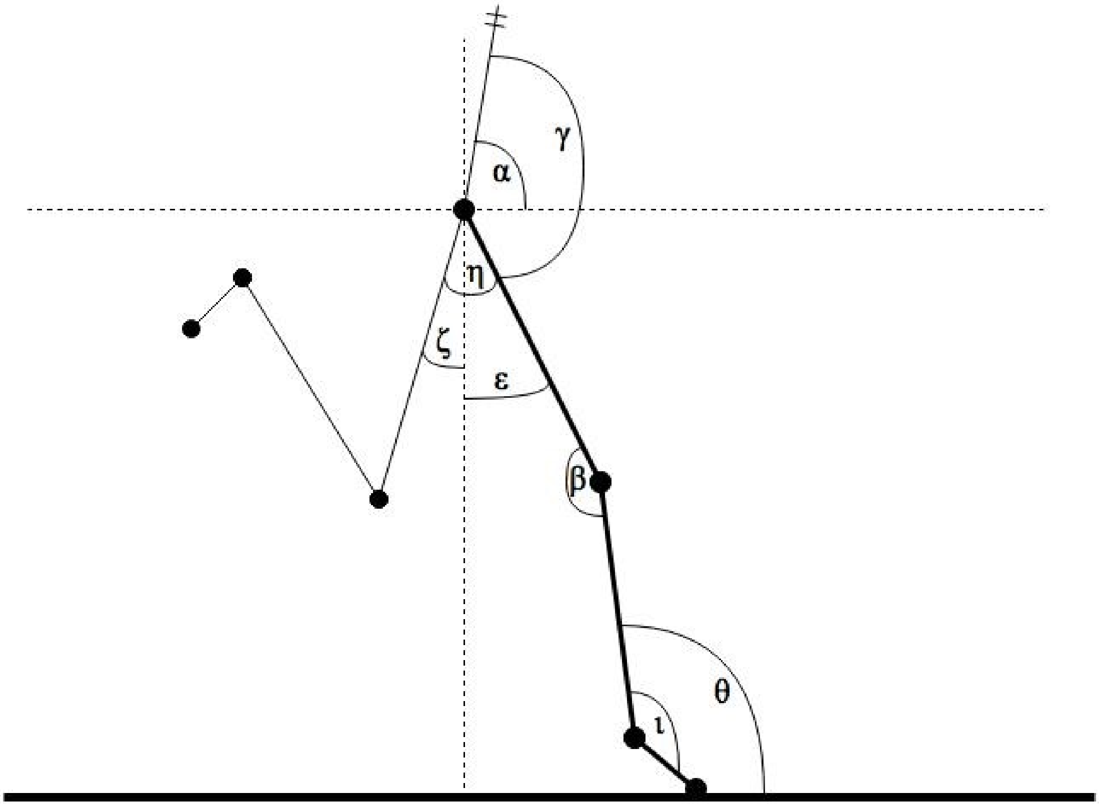

Figure 18. Body schematic denoting joint angles measured at touchdown. This does not represent any athlete's posture but is merely for illustration purposes.

Table 6. Joint angles at touchdown for the medallists.

	VAN NIEKERK		GARDINER		HAROUN	
	Left (°)	Right (°)	Left (°)	Right (°)	Left (°)	Right (°)
α	85.9	79.5	85.0	87.6	85.2	82.1
β	162.5	154.7	161.0	155.2	163.8	161.9
γ	156.6	148.6	166.8	155.4	154.6	153.0
ε	24.7	29.8	23.6	24.9	26.5	30.1
ζ	–2.1	–2.3	–4.6	–3.6	–15.3	–22.8
η	–26.8	–32.1	–28.2	–28.5	–41.8	–52.9
θ	100.5	97.7	96.0	92.7	101.7	102.2
ι	121.2	110.4	121.5	111.4	112.4	110.2

Note: *For angles* **ε** *and* **ζ***, a positive value indicates that the thigh segment was in front of the vertical axis. For angle* **η***, a negative value indicates that the swing leg is behind the touchdown at the point of contact, whereas a positive value indicates the swing thigh is in front of the contralateral thigh segment. The 2-D schematic should not be used as a model to combine angles as different landmarks have been used for defining certain angles.*

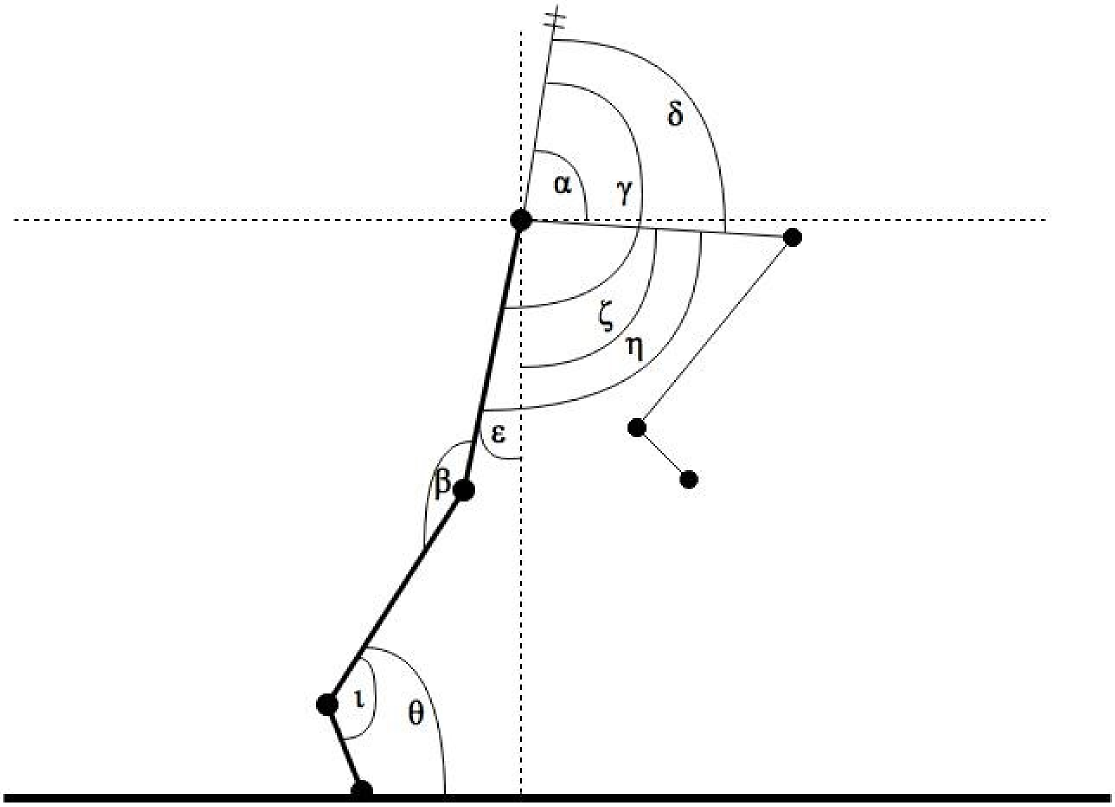

Figure 19. Body schematic denoting joint angles measured at toe-off. This does not represent any athlete's posture but is merely for illustration purposes.

Table 7. Joint angles at toe-off for the medallists.

	VAN NIEKERK		GARDINER		HAROUN	
	Left (°)	Right (°)	Left (°)	Right (°)	Left (°)	Right (°)
α	87.4	83.8	84.9	87.8	86.8	84.8
β	159.0	160.6	165.4	173.8	170.8	166.4
γ	202.7	209.1	207.0	206.5	203.3	206.9
δ	125.4	127.0	126.2	130.6	133.2	132.8
ε	–26.0	–26.9	–27.8	–28.4	–31.6	–29.4
ζ	58.5	53.5	62.3	53.0	49.5	51.4
η	84.5	80.4	90.1	81.4	81.1	80.8
θ	43.5	45.0	48.1	55.9	49.4	47.1
ι	135.0	130.0	127.8	137.1	138.1	115.1

Note: *For angles* **ε** *and* ζ*, a positive value indicates that the thigh segment was in front of the vertical axis. For angle* **η***, a negative value indicates that the swing leg is behind the touchdown leg at the point of contact, whereas a positive value indicates the swing thigh is in front of the contralateral thigh segment. The 2-D schematic should not be used as a model to combine angles as different landmarks have been used for defining certain angles.*

Table 8. Joint angles at touchdown for the remaining four finalists.

	THEBE		ALLEN		GAYE		KERLEY	
	Left (°)	Right (°)	Left (°)	Right (°)	Left (°)	Right (°)	Left (°)	Right (°)
α	86.9	84.4	84.9	80.9	85.9	84.2	86.2	82.8
β	157.6	154.6	167.5	158.4	156.4	156.9	155.2	144.0
γ	153.5	153.6	158.5	150.7	151.8	152.8	152.3	149.6
ε	24.3	28.3	18.9	23.4	25.1	25.8	25.2	28.3
ζ	2.4	–8.4	0.1	3.6	13.4	16.5	–16.4	–1.1
η	–21.9	–36.7	–18.8	–19.8	–11.7	–9.3	–41.6	–29.4
θ	99.3	94.0	106.2	95.8	96.0	94.1	105.5	103.5
ι	80.7	108.1	118.3	110.1	114.3	109.6	111.4	102.2

***Note**: For angles* ε *and* ζ*, a positive value indicates that the thigh segment was in front of the vertical axis. For angle* η*, a negative value indicates that the swing leg is behind the touchdown leg at the point of contact, whereas a positive value indicates the swing thigh is in front of the contralateral thigh segment. The 2-D schematic should not be used as a model to combine angles as different landmarks have been used for defining certain angles.*

Table 9. Joint angles at toe-off for the remaining four finalists.

	THEBE		ALLEN		GAYE		KERLEY	
	Left (°)	Right (°)	Left (°)	Right (°)	Left (°)	Right (°)	Left (°)	Right (°)
α	85.6	86.5	85.5	84.3	88.1	86.3	86.1	86.4
β	156.7	157.1	166.5	159.7	161.8	159.4	158.1	161.7
γ	194.7	199.5	201.5	197.7	198.0	203.4	202.2	204.1
δ	129.4	129.3	120.5	120.3	127.7	116.3	140.5	133.7
ε	–22.0	–19.3	–28.6	–23.1	–25.4	–25.2	–27.8	–30.0
ζ	53.7	51.0	62.2	60.1	56.9	63.4	43.7	46.9
η	75.7	70.3	90.8	83.2	82.3	88.6	71.5	76.9
θ	45.0	47.8	48.3	46.9	46.5	44.6	44.5	43.1
ι	127.4	128.4	140.5	142.2	135.0	140.3	99.0	123.1

***Note**: For angles* ε *and* ζ*, a positive value indicates that the thigh segment was in front of the vertical axis. For angle* η*, a negative value indicates that the swing leg is behind the touchdown leg at the point of contact, whereas a positive value indicates the swing thigh is in front of the contralateral thigh segment. The 2-D schematic should not be used as a model to combine angles as different landmarks have been used for defining certain angles.*

RESULTS – Semi-Final 1

Performance data

Table 10 below displays the ranking of each athlete before the World Championships across all athletes qualifying for the semi-finals, based on their season's (SB) and personal best (PB) times, and a comparison to their semi-final time.

Table 10. Athletes' ranking based on SB and PB, and comparison to their semi-final performance.

Athlete	*SB rank*	*PB rank*	SEMI-FINAL	*notes*	vs. SB	vs. PB
GARDINER	*7*	*6*	43.89 s	*Q NR*	–0.37 s	–0.37 s
ALLEN	*12*	*8*	44.19 s	*Q PB*	–0.33 s	–0.33 s
KERLEY	*3*	*2*	44.51 s	*q*	0.81 s	0.81 s
BORLÉE	*14*	*11*	45.10 s		0.31 s	0.54 s
LONDON III	*10*	*7*	45.12 s		0.65 s	0.65 s
HUSILLOS	*20*	*18*	45.16 s	*PB*	–0.06 s	–0.06 s
OMELKO	*19*	*19*	45.37 s		0.14 s	0.23 s
COWAN	*22*	*21*	45.96 s		0.60 s	0.60 s

Key: *Q = automatic qualifier, q = secondary qualifier, SB = season's best, PB = personal best, NR = national record.*

Positional analysis

Figure 20 shows the relative position of each athlete at each 100 m split throughout the race.

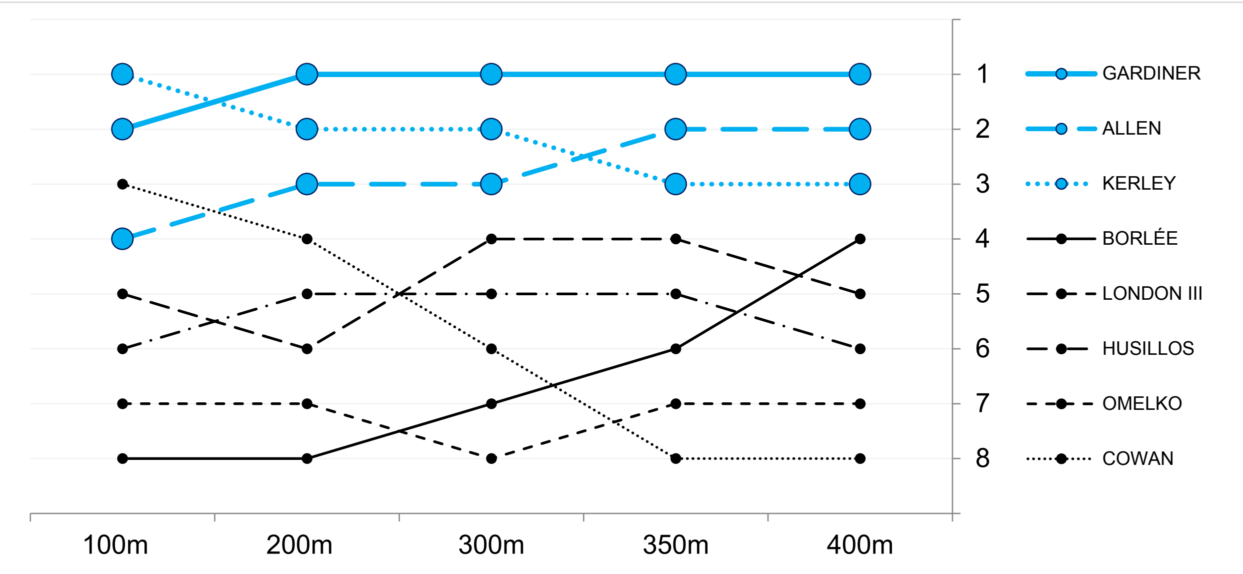

Figure 20. Positions at the end of each 100 m split.

Individual split times

The following graphs display the split times of all athletes over each: 200 m split (Figures 21 and 22), consecutive 100 m splits (note: 0-100 m is displayed without the reaction time) including consecutive 50 m splits during the home straight (Figure 23). The mean speeds over progressive 100 m (from 0-300 metres) and 50 metre (from 300-400 metres) splits are presented in Figure 24.

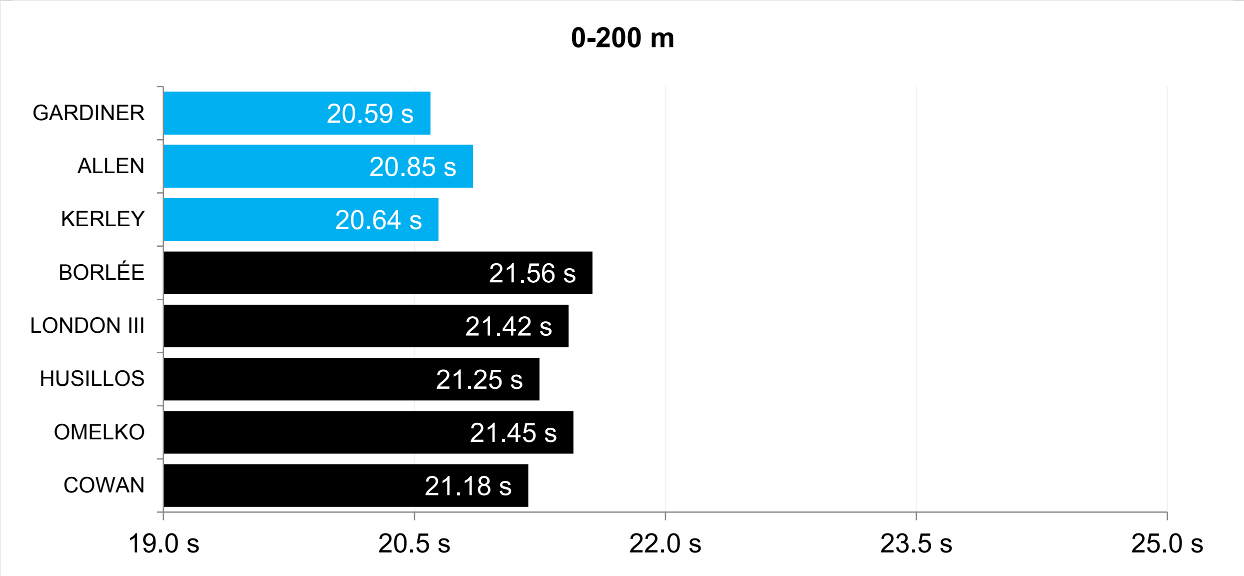

Figure 21. Individual 0-200 m split times (minus reaction time).

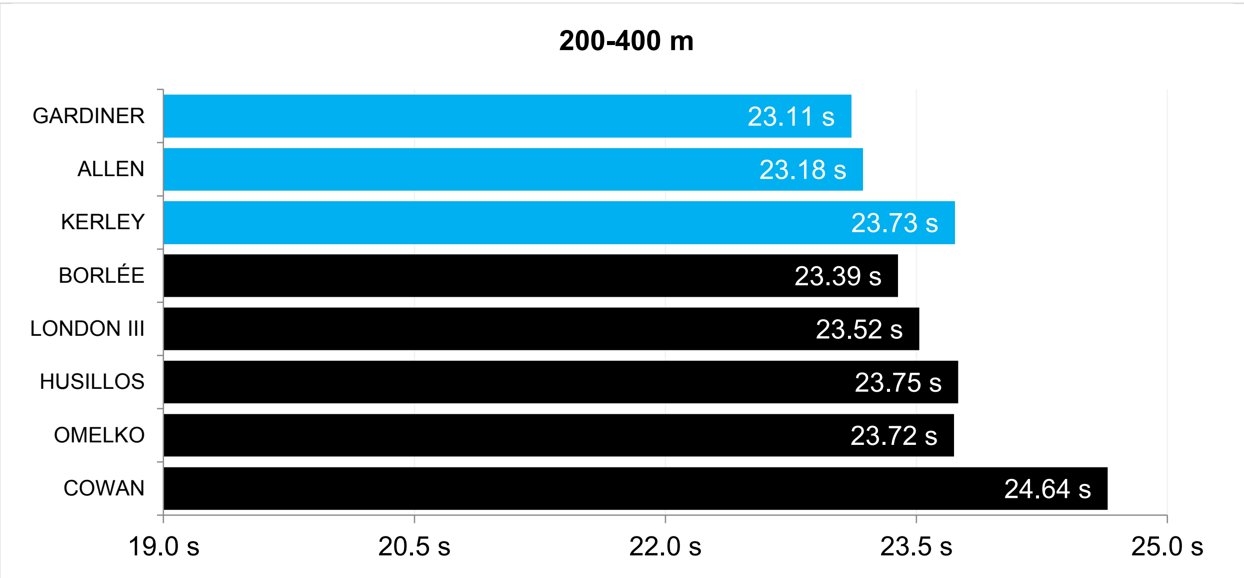

Figure 22. Individual 200-400 m split times.

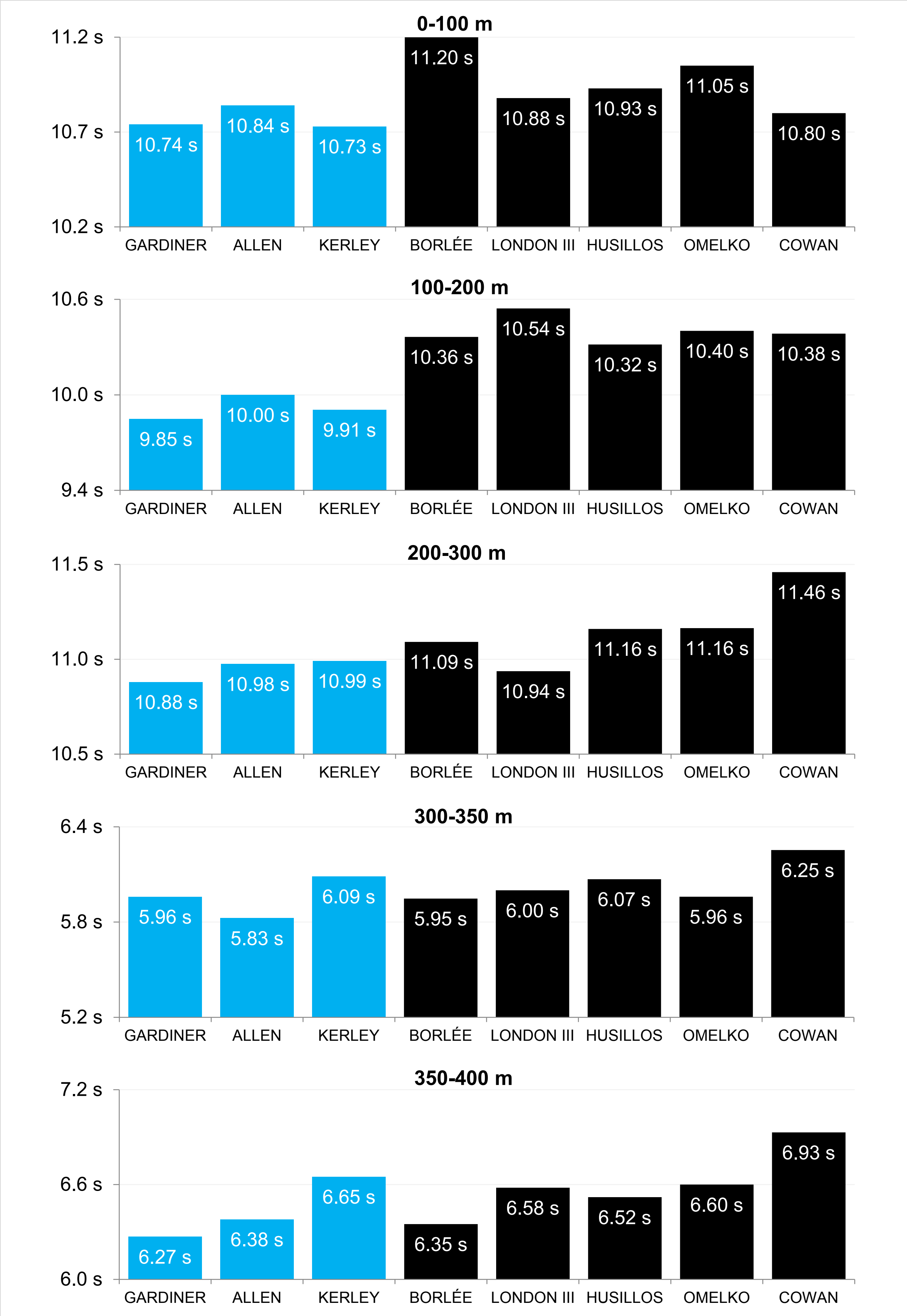

Figure 23. Individual consecutive 100 m split times, and both 50 m times during the home straight.

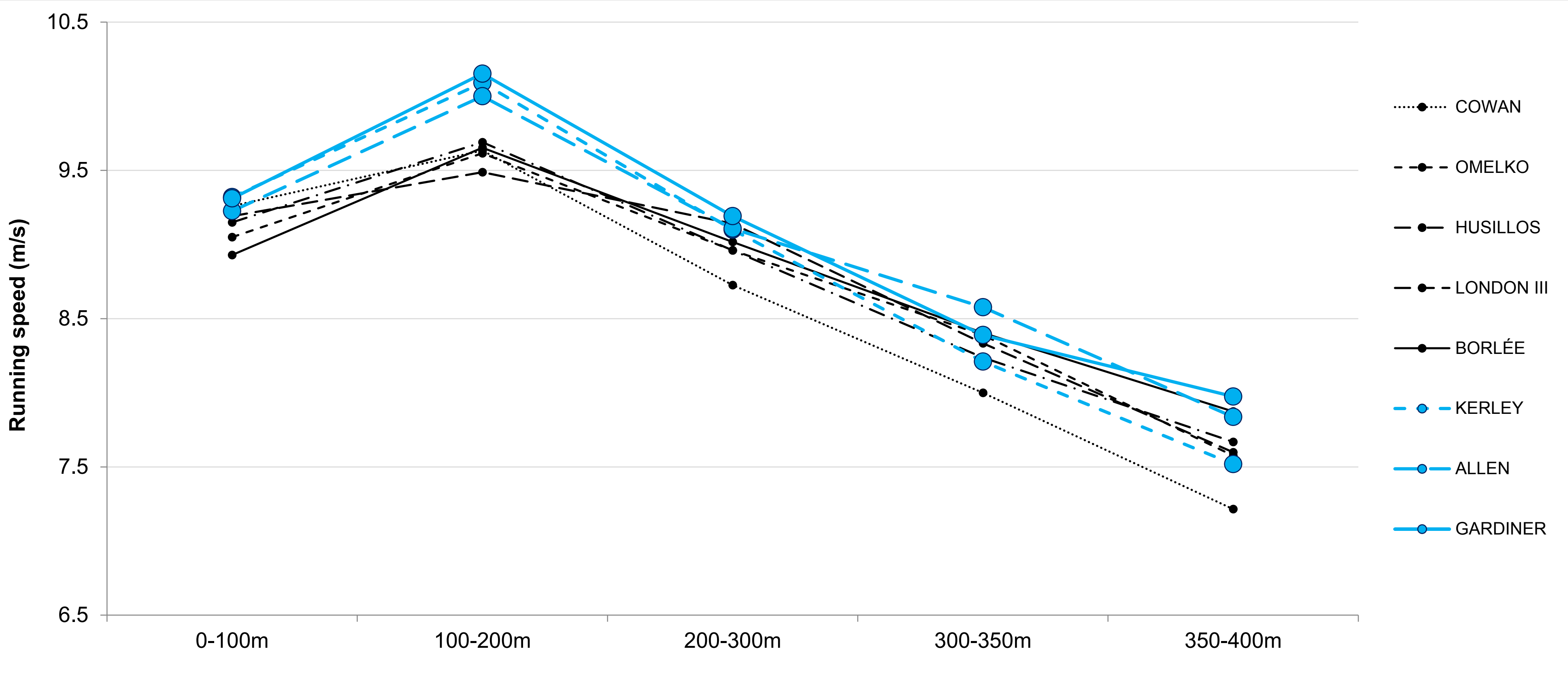

Figure 24. Mean running speed during each consecutive 100 m split, and each 50 m split during the home straight.

Completed steps and step length

The following graphs show step information of individual athletes over progressive 100 m splits for the mean step length and relative to each athlete's stature (Figure 25). The total completed steps for the race and during each 100 m split for each athlete is presented in Figure 26.

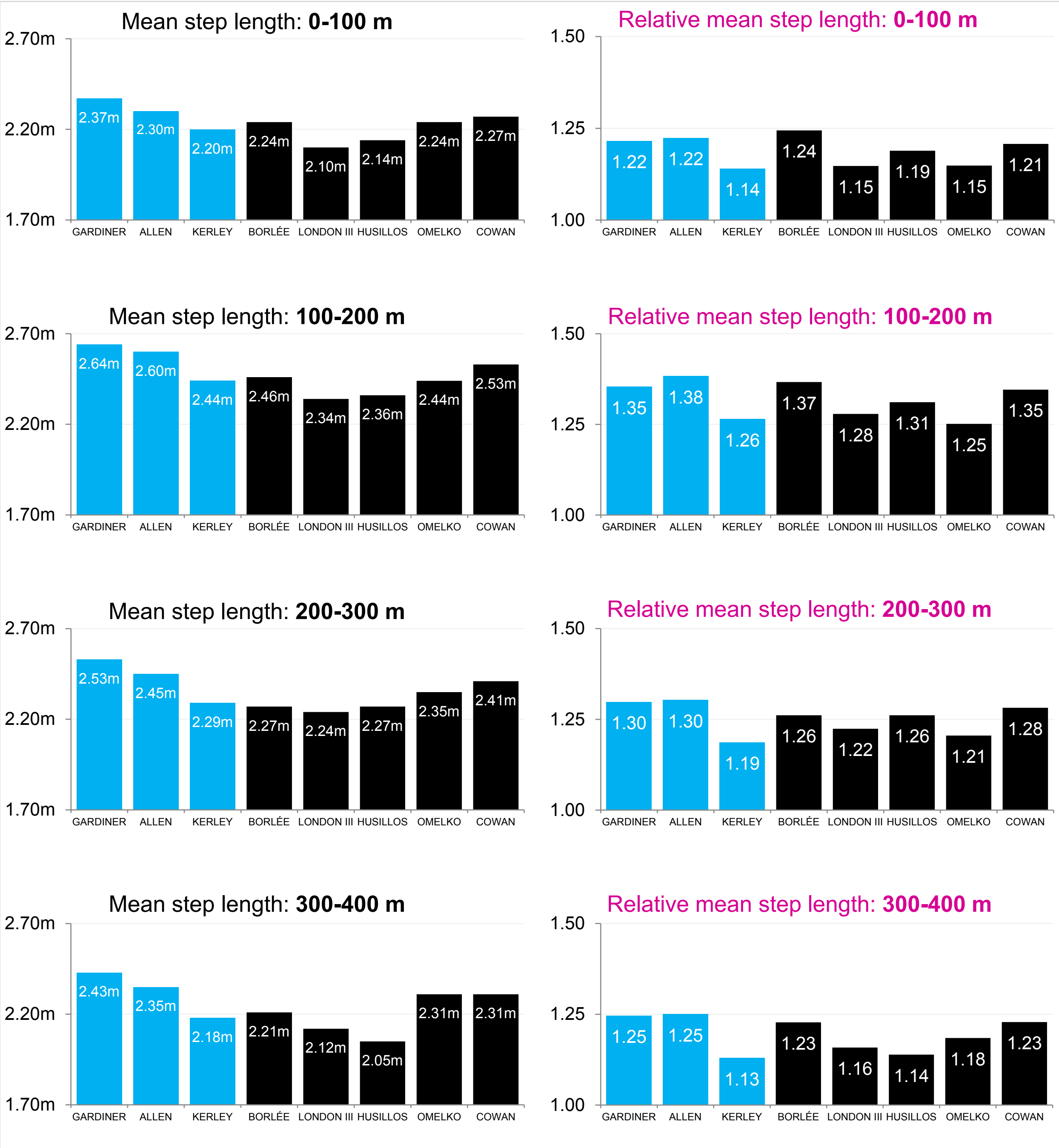

Figure 25. Mean and relative (height) step length during each 100 m split.

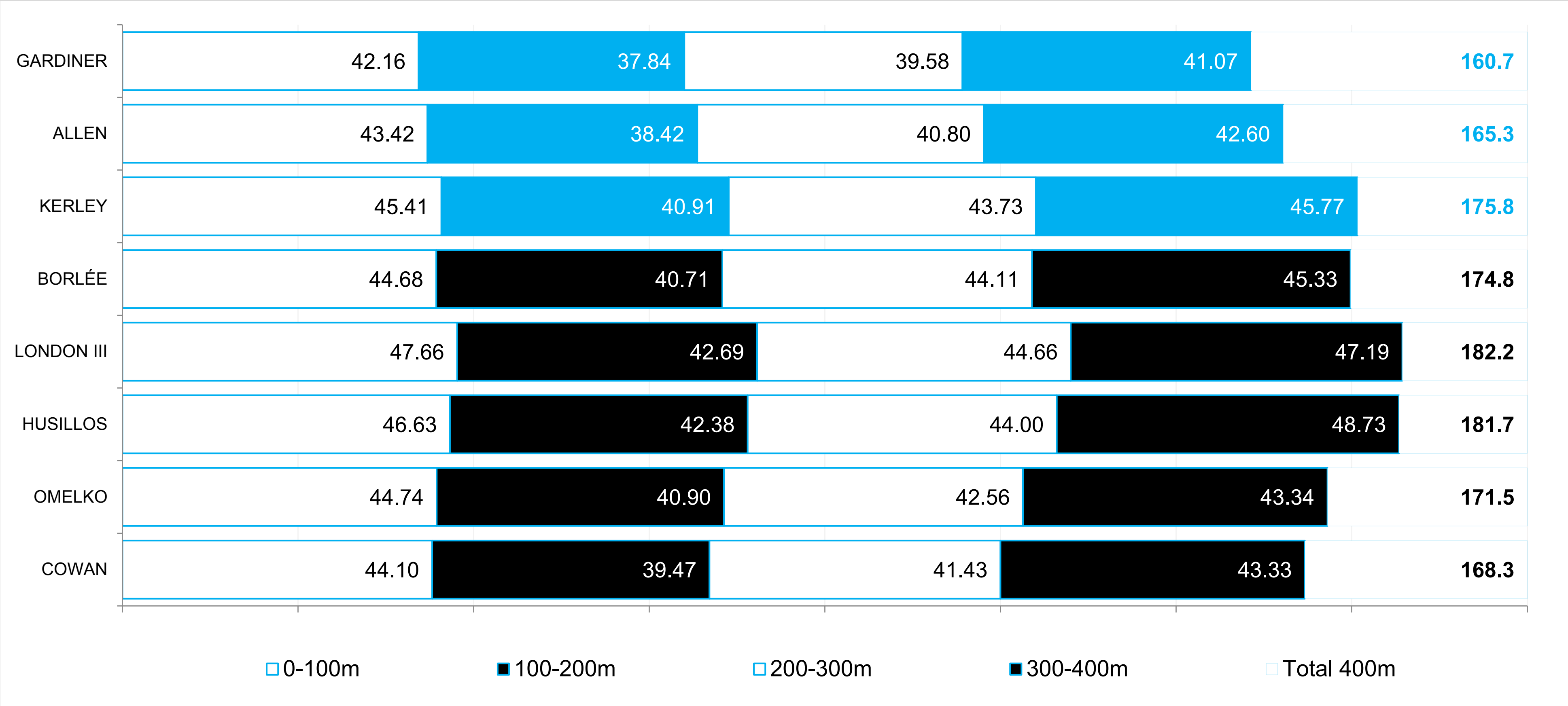

Figure 26. Total completed steps during the race and throughout each consecutive 100 m split.

RESULTS – Semi-Final 2

Performance data

Table 11 below displays the ranking of each athlete before the World Championships across all athletes qualifying for the semi-finals, based on their season's (SB) and personal best (PB) times, and a comparison to their semi-final time.

Table 11. Athletes' ranking based on SB and PB, and comparison to their semi-final performance.

Athlete	*SB rank*	*PB rank*	SEMI-FINAL	*notes*	vs. SB	vs. PB
VAN NIEKERK	*1*	*1*	44.22 s	*Q*	0.60 s	1.19 s
THEBE	*4*	*6*	44.33 s	*Q*	0.31 s	0.31 s
HAROUN	*18*	*9*	44.64 s	*q SB*	–0.51 s	0.37 s
HUDSON-SMITH	*13*	*12*	44.74 s	*SB*	–0.25 s	0.26 s
GORDON	*15*	*13*	45.20 s		0.18 s	0.68 s
GREGAN	*21*	*22*	45.42 s		0.16 s	0.16 s
MERRITT	*10*	*2*	45.52 s		0.74 s	1.87 s
MWERESA	*24*	*19*	45.93 s		0.51 s	0.92 s

Key: *Q = automatic qualifier, q = secondary qualifier, SB = season's best, PB = personal best.*

Positional analysis

Figure 27 shows the relative position of each athlete at each 100 m split throughout the race.

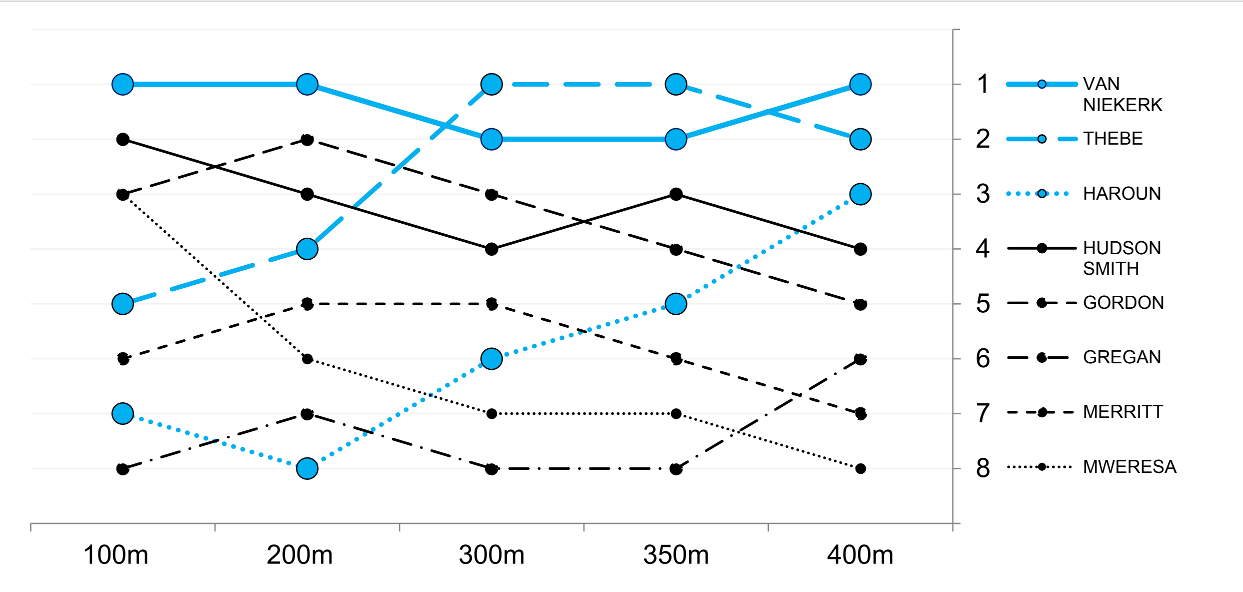

Figure 27. Positions at the end of each 100 m split.

Individual split times

The following graphs display the split times of all athletes over each: 200 m split (Figures 28 and 29), consecutive 100 m splits (note: 0-100 m is displayed without the reaction time) including consecutive 50 m splits during the home straight (Figure 30). The mean speeds over progressive 100 m (from 0-300 metres) and 50 metre (from 300-400 metres) splits are presented in Figure 31.

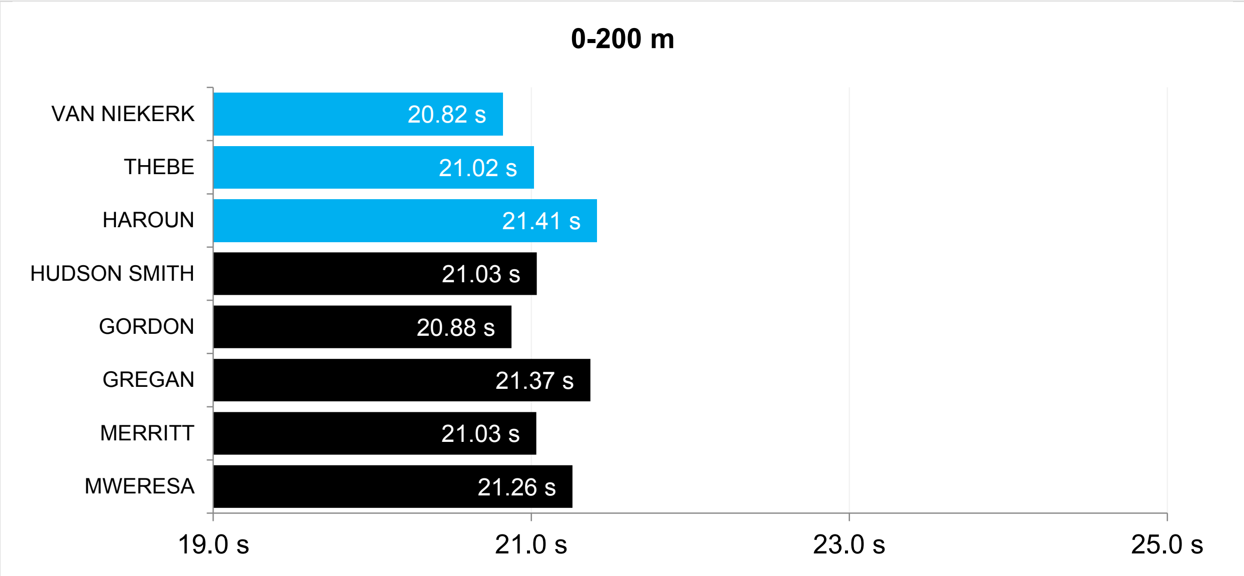

Figure 28. Individual 0-200 m split times (minus reaction time).

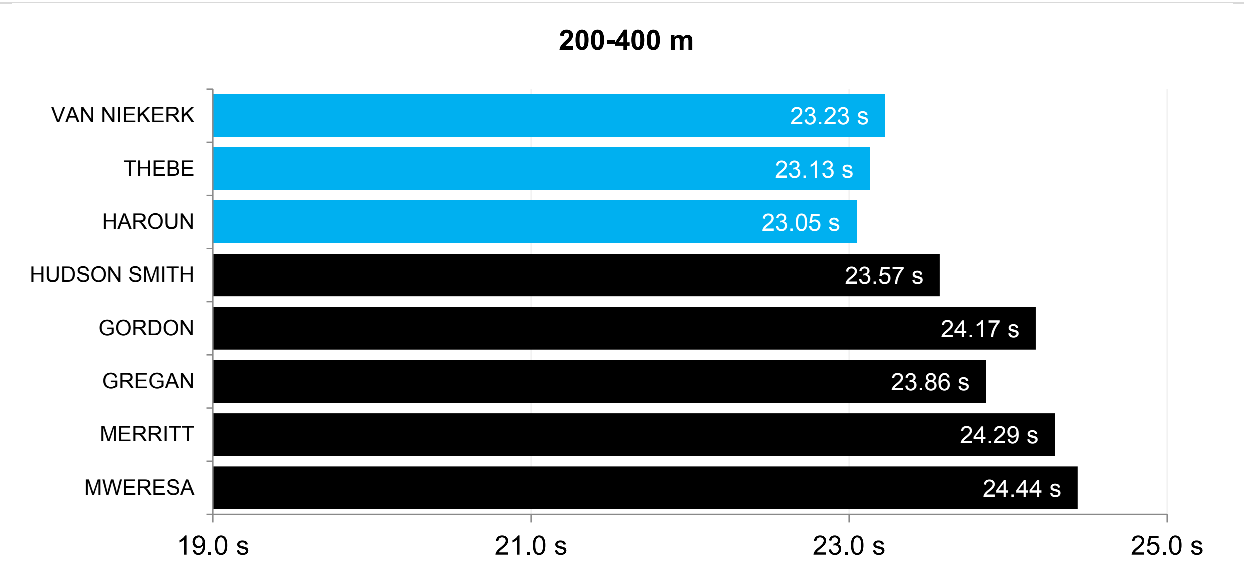

Figure 29. Individual 200-400 m split times.

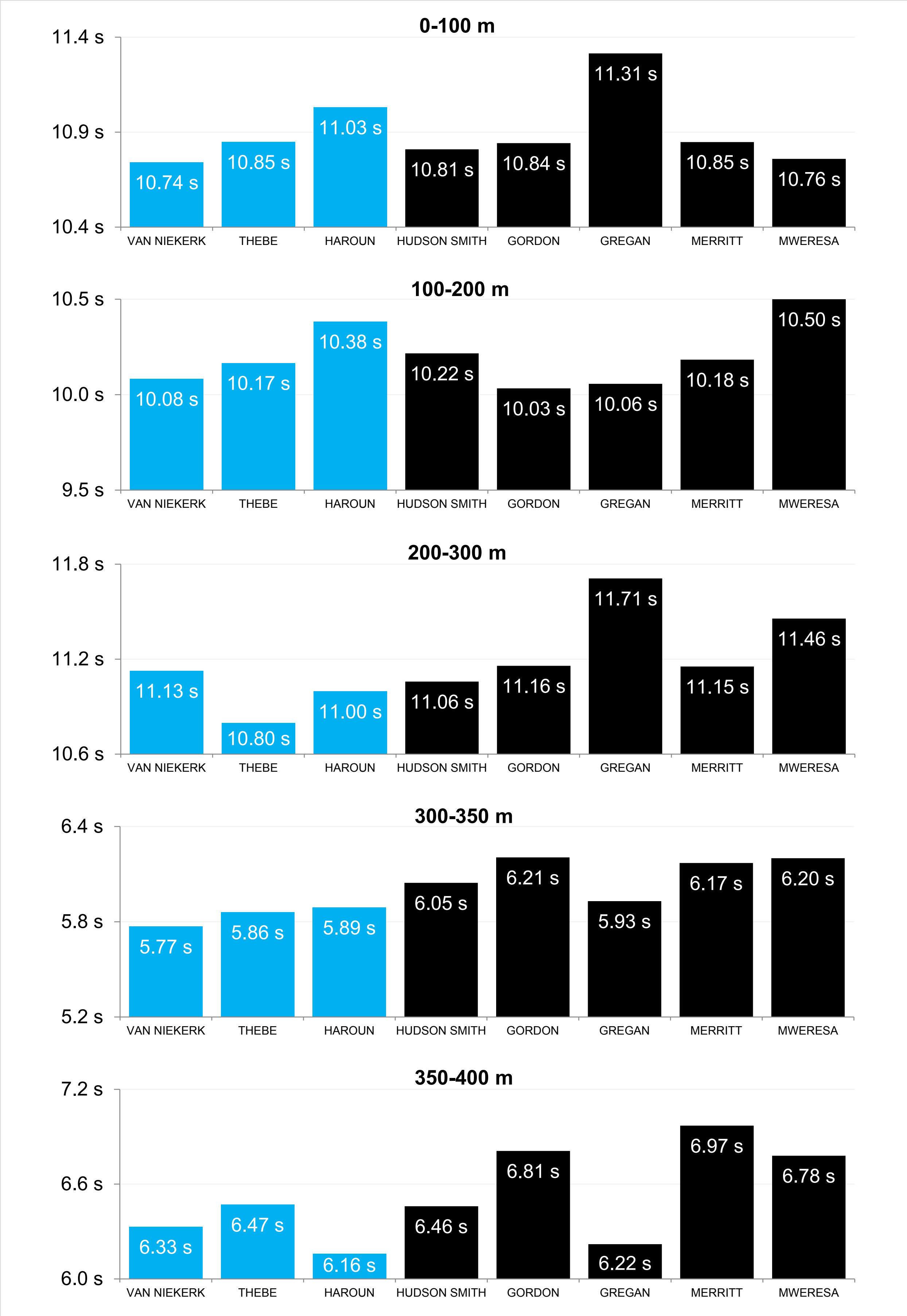

Figure 30. Individual consecutive 100 m split times, and both 50 m times during the home straight.

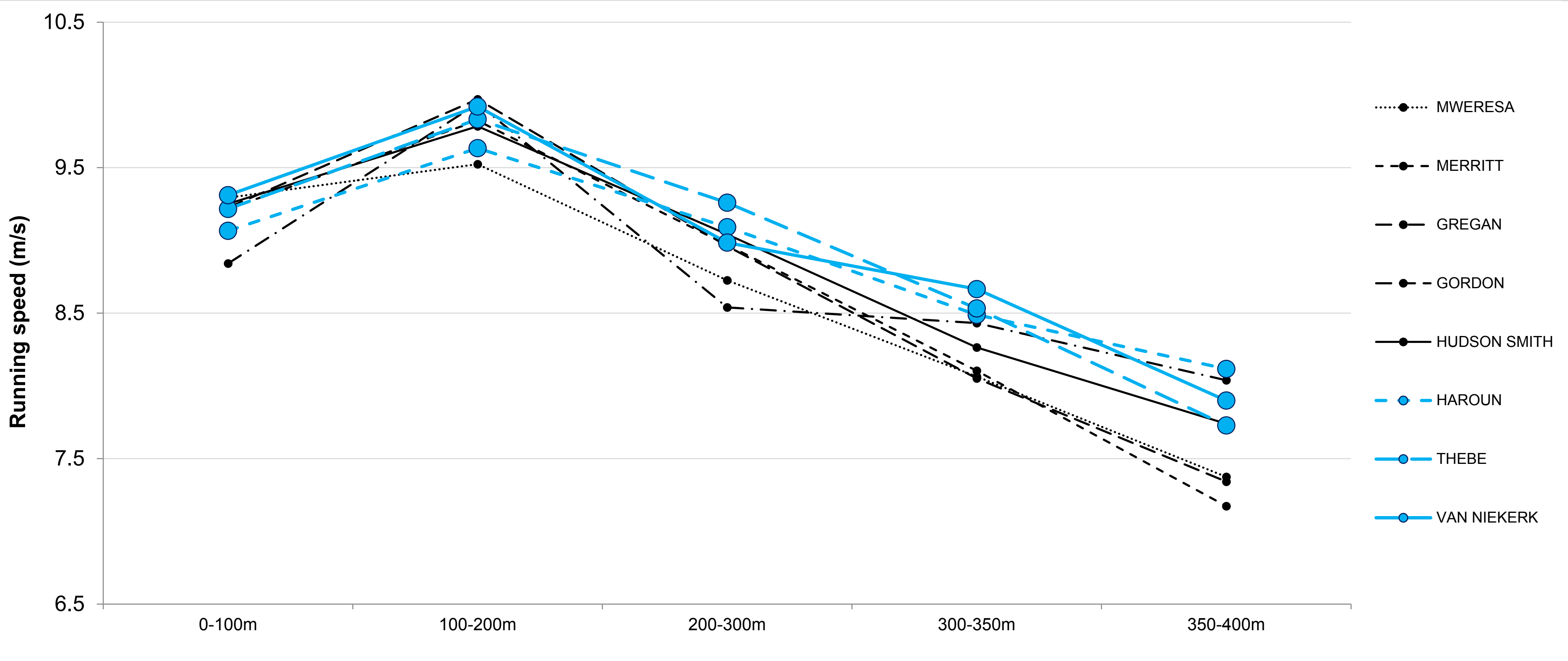

Figure 31. Mean running speed during each consecutive 100 m split, and each 50 m split during the home straight.

Completed steps and step length

The following graphs show step information of individual athletes over progressive 100 m splits for the mean step length and relative to each athlete's stature (Figure 32). The total completed steps for the race and during each 100 m split for each athlete is presented in Figure 33.

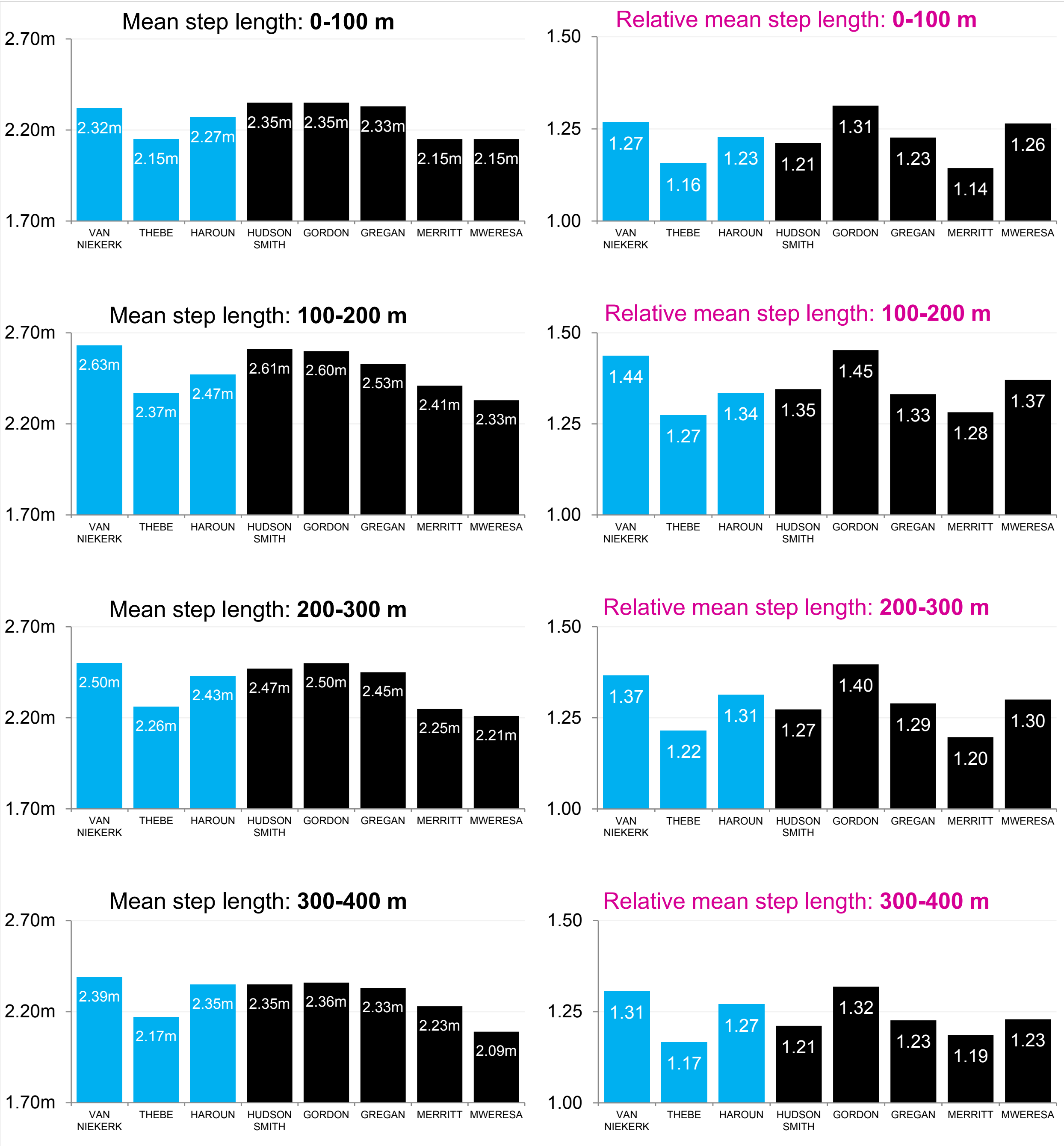

Figure 32. Mean and relative (height) step length during each 100 m split.

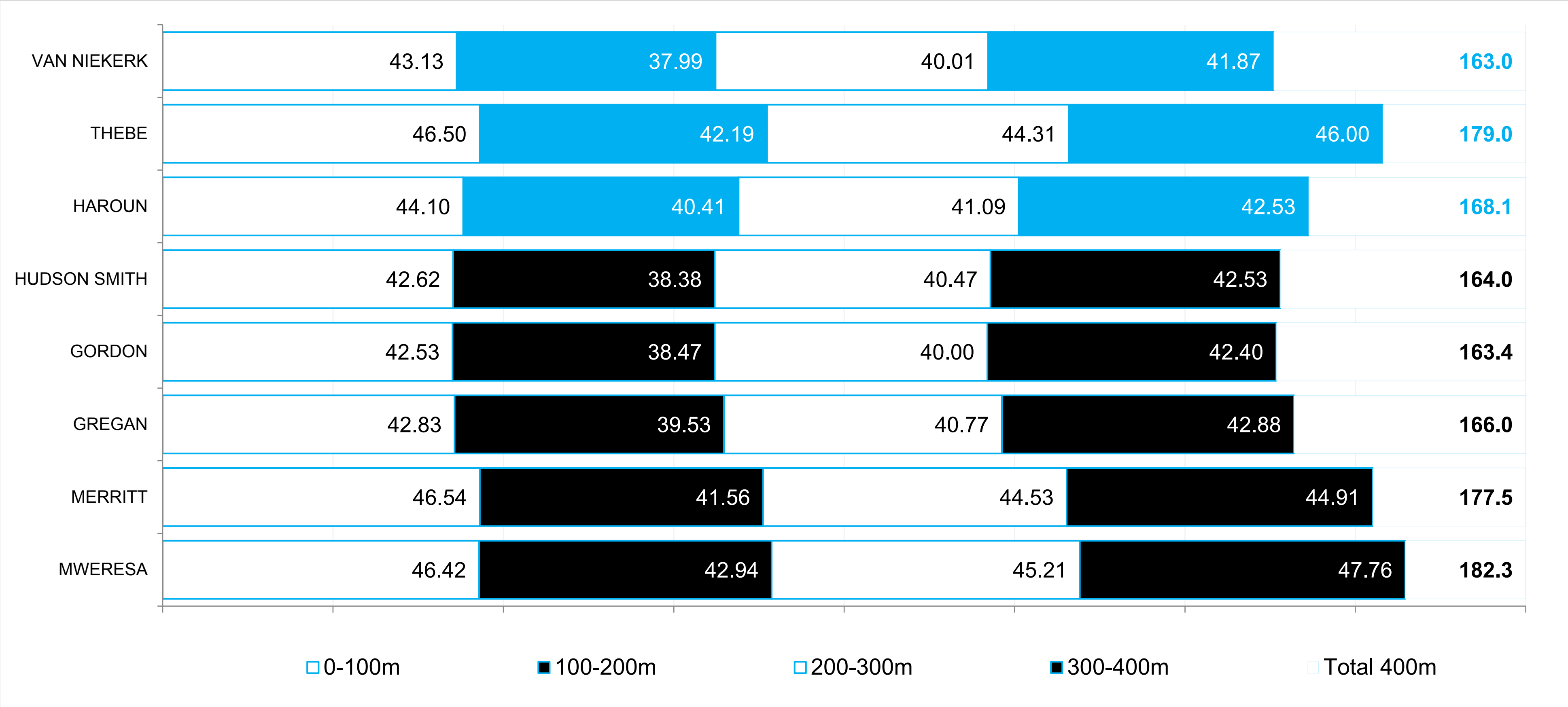

Figure 33. Total completed steps during the race and throughout each consecutive 100 m split.

RESULTS – Semi-Final 3

Performance data

Table 12 below displays the ranking of each athlete before the World Championships across all athletes qualifying for the semi-finals, based on their season's (SB) and personal best (PB) times, and a comparison to their semi-final time.

Table 12. Athletes' ranking based on SB and PB, and comparison to their semi-final performance.

Athlete	*SB rank*	*PB rank*	SEMI-FINAL	*notes*	vs. SB	vs. PB
MAKWALA	*3*	*4*	44.30 s	*Q*	0.46s	0.58 s
GAYE	*9*	*16*	44.55 s	*Q PB*	–0.09 s	–0.09 s
ROBERTS	*5*	*7*	44.84 s		0.62 s	0.62 s
WALTON	*13*	*18*	45.16 s		0.17 s	0.17 s
BORLÉE	*16*	*10*	45.23 s		0.14 s	0.80 s
MASLÁK	*17*	*17*	45.24 s		0.41 s	0.45 s
CEDENIO	*12*	*5*	45.91 s		1.01 s	1.90 s
RE	*23*	*24*	45.95 s		0.55 s	0.55 s

Key: *Q = automatic qualifier, q = secondary qualifier, SB = season's best, PB = personal best.*

Positional analysis

Figure 34 shows the relative position of each athlete at each 100 m split throughout the race.

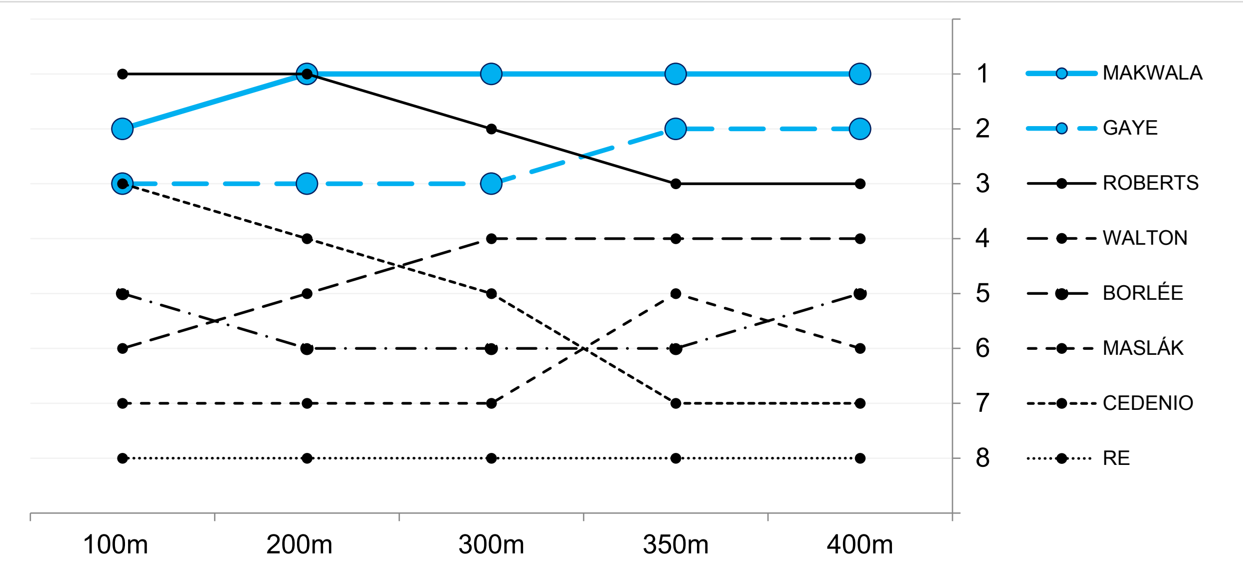

Figure 34. Positions at the end of each 100 m split.

Individual split times

The following graphs display the split times of all athletes over each: 200 m split (Figures 35 and 36), consecutive 100 m splits (note: 0-100 m is displayed without the reaction time) including consecutive 50 m splits during the home straight (Figure 37). The mean speeds over progressive 100 m (from 0-300 metres) and 50 metre (from 300-400 metres) splits are presented in Figure 38.

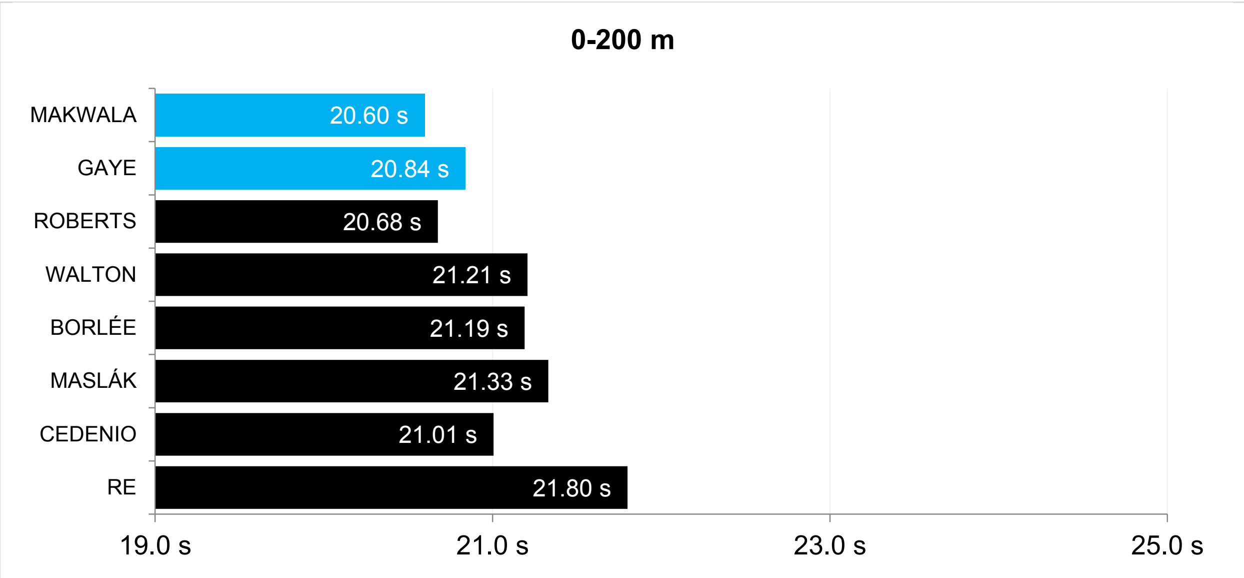

Figure 35. Individual 0-200 m split times (minus reaction time).

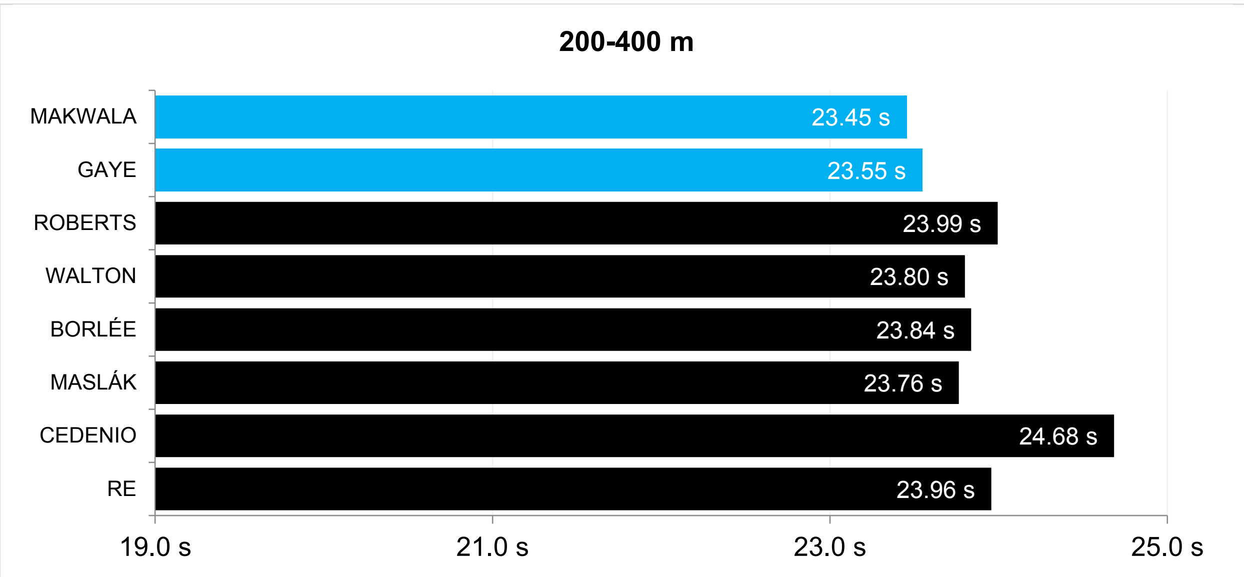

Figure 36. Individual 200-400 m split times.

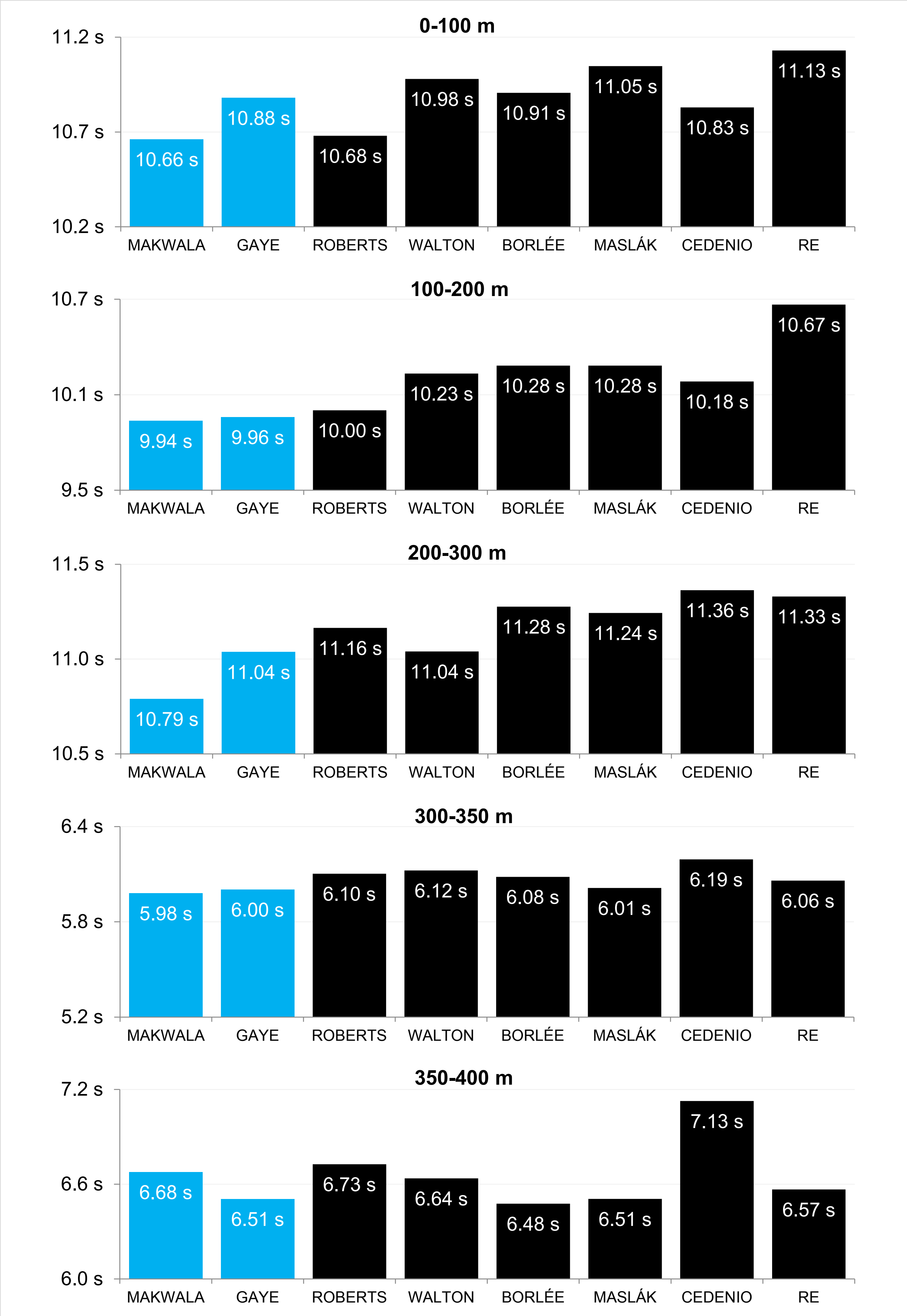

Figure 37. Individual consecutive 100 m split times, and both 50 m times during the home straight.

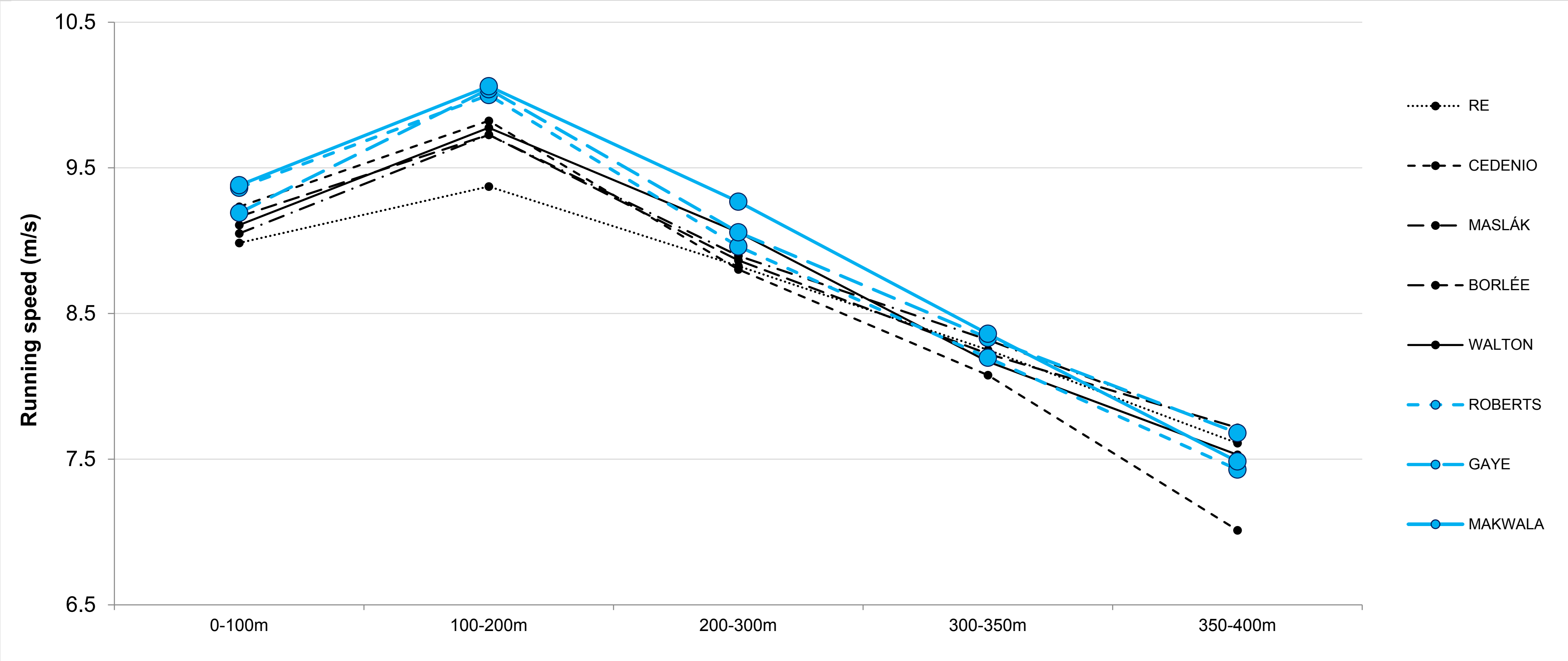

Figure 38. Mean running speed during each consecutive 100 m split, and each 50 m split during the home straight.

Completed steps and step length

The following graphs show step information of individual athletes over progressive 100 m splits for the mean step length and relative to each athlete's stature (Figure 39). The total completed steps for the race and during each 100 m split for each athlete is presented in Figure 40.

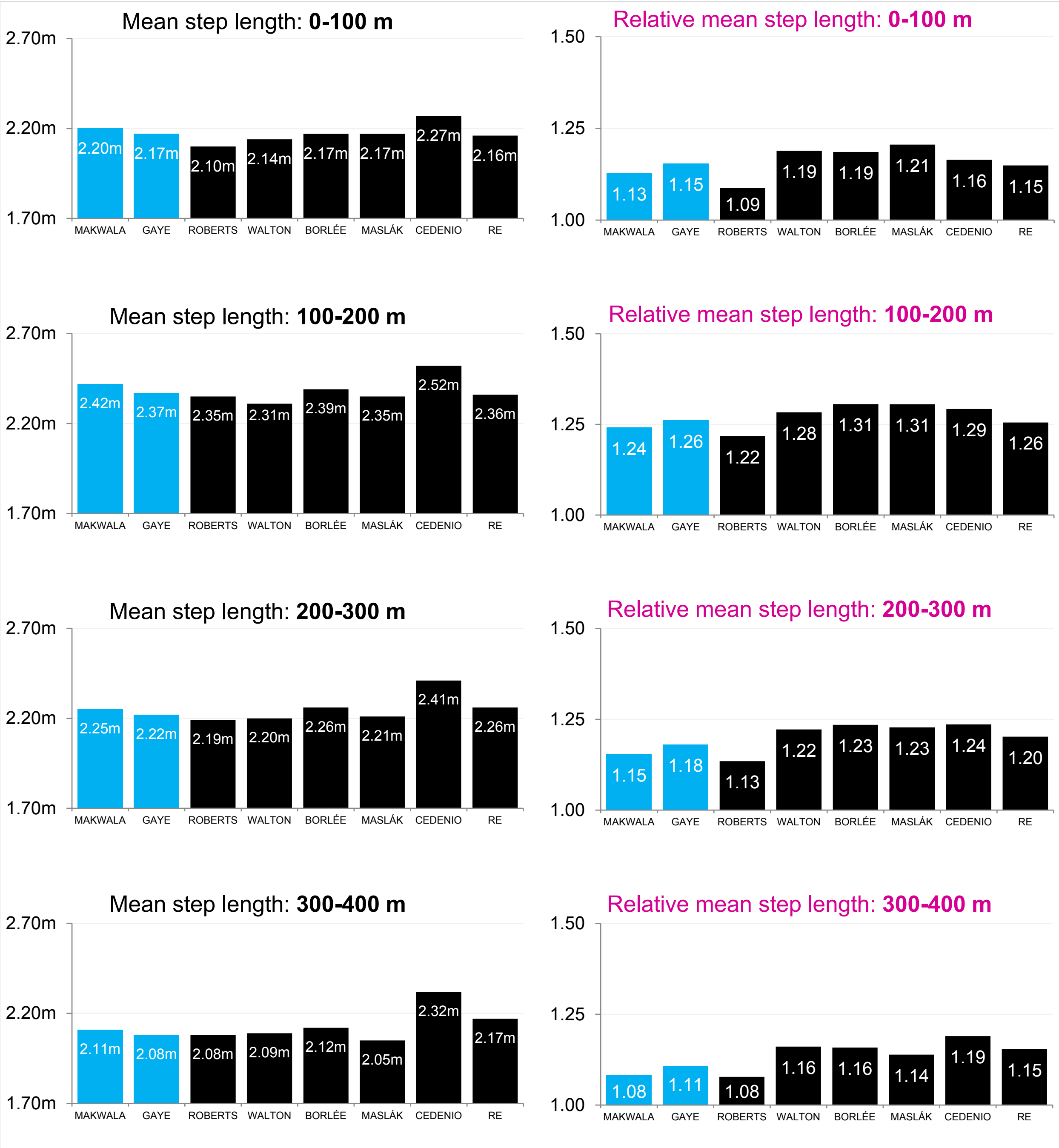

Figure 39. Mean and relative (height) step length during each 100 m split.

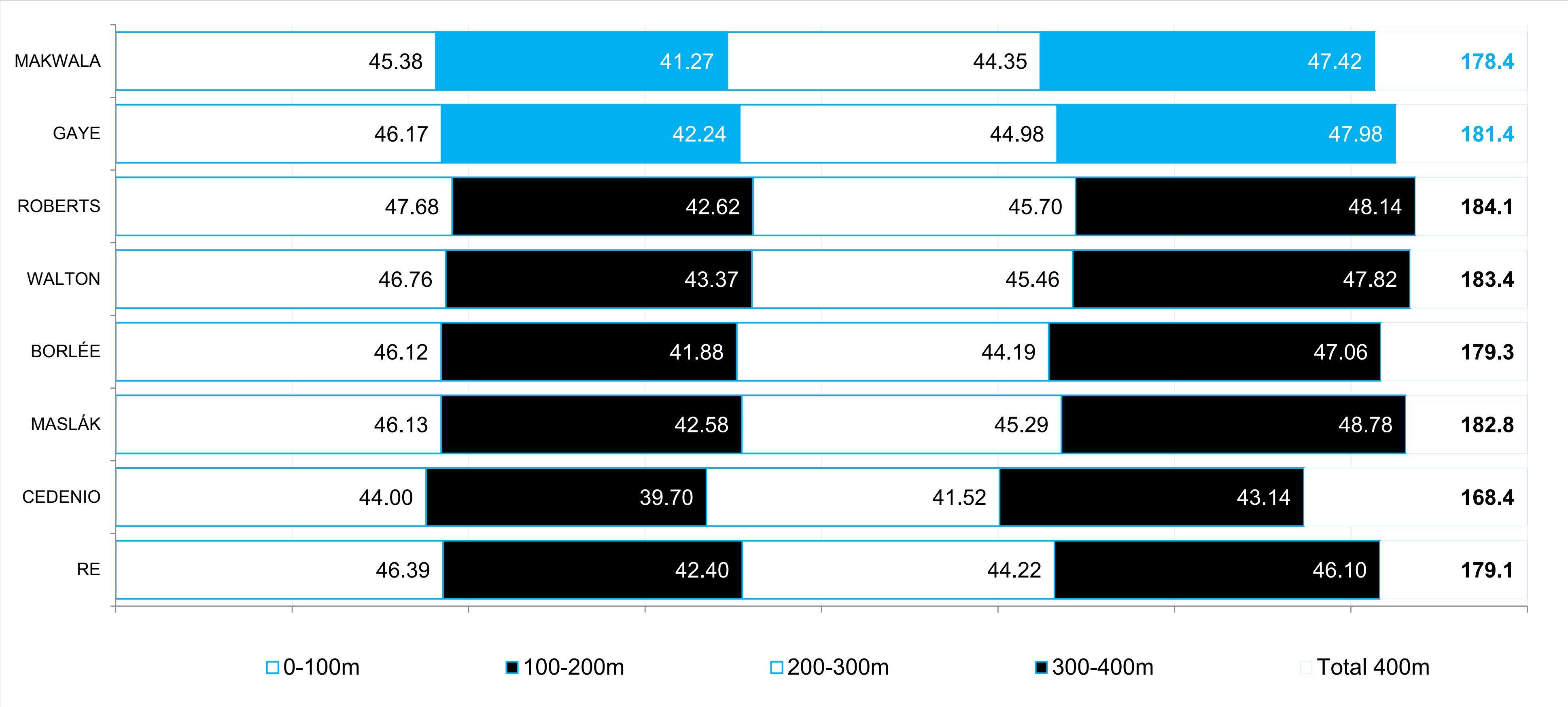

Figure 40. Total completed steps during the race and throughout each consecutive 100 m split.

COACH'S COMMENTARY

Historical analysis and coaching commentary – Pierre-Jean Vazel

This commentary will draw a profile for each of the 400 m medallists, from the review of selected results of the most relevant parameters that are characteristics of their technique, with historical insights of the research on this event.

Wayde van Niekerk (RSA)

Born: 1992. Height: 1.83 m. Mass: 73 kg. Personal bests: 100 m: 9.94 s (2017); 200 m: 19.84 s (2017); 300 m: 30.81 s (2017); 400 m: 43.03 s (world record; 2016). SE index: 2.17.

Being the only athlete to have run under the symbolic barriers of the three sprint races (sub-10 s at 100 m, sub-20 s at 200 m and sub-44 s at 400 m), van Niekerk obviously has a sprint profile. Quarter-milers are traditionally classified into "sprint" or "endurance" type (Nett, 1950). They were either coming from 200 m or 800 m but nowadays, fewer and fewer elite 400 m runners can successfully line-up in middle distances whereas in London, two athletes were finalists at both 400 m and 200 m. Thus, an objective marker to classify athletes in either group is no longer to look at 800 m personal bests but to use a Speed Endurance (SE) index, which is 400 m result, divided by the 200 m personal or season best. Interestingly, there is no relationship between SE index and 400 m times, meaning both groups are equally successful at 400 m. With an index over 2.157, athletes belong to the sprint type group, like van Niekerk (2.17), and it is up to the coach to determine how much SE training is necessary to do, without affecting the athlete's speed, which is his main strength. The progression of his split times over 100 m section of his 400 m year after year (Yamamoto, 2015, 2016) shows that most of his improvement occurred in the last half of the race indeed, especially in the 200-300 m section, probably indicating a shift in his training towards specific endurance. This 200-300 m section is also the most correlated with 400 m time when hundreds of performance and pooled in (Vazel, 2010).

100 m split analysis (all times include reaction times; times are eventually rounded to the closest tenth when 0.01 s accuracy could not be obtained).

Meet	Result (s)	0-100 m (s)	100 -200 m (s)	200-300 m (s)	300-400 m (s)
2017 London WC	43.98	10.85	9.93	10.86	12.34
2016 Rio OG	43.03	10.77	9.81	10.48	11.97
2015 Beijing WC	43.48	10.73	10.03	10.60	12.12
2014 New York	44.38	10.9	10.2	10.9	12.4
2013 Ostrava	45.09	11.2	10.1	11.2	12.6

Intermediate time analysis.

Meet	100 m (s)	200 m (s)	300 m (s)	Result (s)
2017 London WC	10.85	20.78	31.64	43.98
2016 Rio OG	10.77	20.58	31.06	43.03
2015 Beijing WC	10.73	20.76	31.36	43.48
2014 New York	10.9	21.1	32.0	44.38
2013 Ostrava	11.2	21.3	32.5	45.09

London’s 400 m and 200 m reports give a rare opportunity to compare the adaptations of the running mechanics with fatigue for the athletes that took part to both events. Van Niekerk’s kinematic parameters were studied at 150 m during the 200 m and 350 m during the 400 m. As his velocity went from 10.40 m/s to 8.23 m/s, his step length decreased from 2.60 to 2.47 m, but a greater decline was found in step frequency, which is in line with previous studies (Letzetler, 1979, Schäffer, 1989), from 4.00 to 3.33 Hz. This lower step rate was mainly explained by longer contact times, from 0.100 to 0.127 s and flight times, from 0.150 to 0.173 s. Indeed, in Rio 2016 for the world record (43.03 s), he covered the last 100 m faster than in London, in 11.97 vs. 12.34 s due to a higher mean step rate of 3.50 vs. 3.39 Hz, while mean step length was about the same (2.38 and 2.39 m). In 2014, he only needed 160 steps to run his ten-personal best of 44.38 s in New York, which was second only at the elite level to former world record holder Butch Reynolds (159.8 steps for his 43.29 s in 1988). Being already at the extreme end of the current human limits regarding step length (2.65 m and relative SL of 1.45 for a 1.83 m body height), van Niekerk has improved by decreasing it slightly, in favour for a significant improvement on step frequency over the years.

Step length progression during 400 m.

Meet	Result (s)	0-100 m (m)	100 -200 m (m)	200-300 m (m)	300-400 m (m)
2017 London WC	43.98	2.31	2.65	2.48	2.39
2016 Rio OG	43.03	2.34	2.62	2.49	2.38

Step frequency progression during 400 m.

Meet	Result (s)	0-100 m (Hz)	100 -200 m (Hz)	200-300 m (Hz)	300-400 m (Hz)
2017 London WC	43.98	4.05	3.80	3.71	3.39
2016 Rio OG	43.03	3.98	3.90	3.81	3.50

As expected with higher fatigue, comparing van Niekerk's body angles at 150 m during 200 m and 350 m during 400 m, the angle between thighs at touchdown is larger (about 16 to 30°) and the knee lift at toe-off is lower (58-66° to 53-58°). This is further demonstrated around the knee joint as its flexion at touchdown and toe-off are about the same during his 200 m and 400 m. Yet, his technique is highly effective for short sprint events but may not be suited to the adaptation constraints at 400 m. The last 100 m is indeed not van Niekerk's strong part, against all odds. Of all the personal best 400 m races analysed, and to the best of our knowledge, van Niekerk holds the second fastest first 100 m section (10.77 s), the fastest ever being 10.7 s by Tyson Gay (for 44.89 s in 2010). He also has the fastest ever second 100 m section (9.81 s), the fourth fastest ever third 100 m section (10.48 s) behind Tyree Washington's 10.4 s (for 44.29 s in 1998 – his lifetime best 44.28 s in 2001 couldn't be analysed), 10.44 s by Michael Johnson (43.18 s in 1999) and Alvin Harrison's 10.47 s (44.09 s in 1996). His 11.97 s for the last 100 m section doesn't rank him in the all-time top 50, far behind the 11.2 s run by Tommie Smith (44.5 s in 1967) and Butch Reynolds (43.29 s in 1988). However, van Niekerk ran 11.4 s during a 43.96 s race in 2016, after a very conservative pace of 21.9 s at half way, giving almost two seconds of speed reserve.

Over the years, van Niekerk has mainly improved the last 100 m in reducing the inevitable drop of step frequency. He probably managed to do so in improving his leg spring stiffness, which is related to step frequency but not step length (Hobara, 2010). However, in spite of these constant improvements, this section of the race is still where the more room for improvement lies. From these observations, adapting his metabolism and running technique to the requirements of the 400 m while still improving his 100 m and 200 m personal bests in order not to lose his exceptional speed reserve is the paradoxical task for van Niekerk on his road to the 42 s 400 m.

<u>*Steven Gardiner (BAH)*</u>

Born: 1995. Height: 1.88 m. Mass: 75 kg. Personal bests: 200 m: 19.75 (2018); 400 m: 43.89 (2017). SE index: 2.22.

The Bahamian was the fastest in London with 43.89 s, but it was while winning his semi-final. In the final, he could not duplicate his race and ran 44.41 s for the silver medal. Gardiner was slower in each of the 100 m segments of the 400 m race, the largest difference being in the last straight.

100 m split analysis.

Meet	Result (s)	0-100 m (s)	100-200 m (s)	200-300 m (s)	300-400 m (s)
2017 WC final	44.41	11.04	9.97	10.93	12.47
2017 WC semi-final	43.89	10.93	9.85	10.88	12.23

Intermediate time analysis.

Meet	100 m (s)	200 m (s)	300 m (s)	Result (s)
2017 WC final	11.04	21.01	31.94	44.41
2017 WC semi-final	10.93	20.78	31.66	43.89

Regarding tactics, a marker to look at is the “Speed Reserve (SR)” (Chomenkov, 1953). It is the difference between the 200 m intermediate time during 400 m and their 200 m lifetime or season best. Like SE index, there is no relationship with 400 m time and the mean SR for sub-45 s runners is 0.84. However, the lower the SR (meaning that the athlete reached the half way of his 400 m closer to his 200 m PB), the slower they will run the second half of the race relative to the first one (Vazel, 2010). Gardiner had a PB of 20.63 s but in spring 2018, he ran 19.75 s, which is more representative of his true ability in London. As he reached the 200 m mark during the 400 m in 20.78 s, he had a SR of 1.03. That is above average but “sprint types” tend to cover the first half slower than “endurance types” relatively to their 200 m personal best. During the final, he had a SR of 1.26 but he could not run the second 200 m faster than what he did in the semis. Since there seems to be no tactical mistake made, his slower time might be attributed to a lack of time to recovery although there was a rest day in between the final two rounds. The comparison in his step structure between the two races shows that his slower time is mainly explained by shorter steps rather than step rate.

Step length progression during 400 m.

Meet	Result (s)	0-100 m (m)	100-200 m (m)	200-300 m (m)	300-400 m (m)
2017 WC final	44.41	2.36	2.62	2.51	2.39
2017 WC semi-final	43.89	2.37	2.64	2.53	2.43

Step frequency progression during 400 m.

Meet	Result (s)	0-100 m (Hz)	100 -200 m (Hz)	200-300 m (Hz)	300-400 m (Hz)
2017 WC final	44.41	3.91	3.83	3.65	3.36
2017 WC semi-final	43.89	3.86	3.85	3.64	3.36

Yet, in the semi-final and final, the progressive drop in step rate was excessively high, and like van Niekerk, Gardiner should be able to run the last 100 m under 12 s by increasing his leg spring stiffness under fatigue. Both athletes had the longest steps and flight times of the finalists, which prevents a high stride rate through a tendency to crash and jump over their leg (Mann, 2013). Reynolds, the fastest ever in the home straight (11.2 s), also had extremely long steps, but his rate remained almost even through the race.

Analysis of Butch Reynolds' 43.29 s race in Zurich (1988).

	Result	0-100 m	100-200 m	200-300 m	300-400 m
Time (s)	43.29	11.3	10.1	10.7	11.2
Step length		2.43	2.65	2.50	2.45
Step frequency		3.65	3.74	3.74	3.64

<u>Abdalelah Haroun (QAT)</u>

Born: 1997. Height: 1.78 m. Mass: 73 kg. Personal bests: 200 m: 21.16 s (2018); 400 m: 44.27 s (2015). SE index: 2.09.

With the lowest SE index of all the finalists, the bronze medallist Haroun has an endurance profile, as he never ran under 21 s at 200 m while holding the world indoor best at 500 m. He was also the slowest in the first half and the fastest in the last half of the 400 m final. This cautious approach suited him well as he was the only finalist to run a season best in 44.48 s, with the smallest margin (0.21 s) from his personal best (44.27 s).

In London's final, Haroun ran on the pace of his PB in the first 100 m, ran slower the middle 200 m section, but finished better in the home straight, as we was the only finalist to run the last 100 m under 12 s.

100 m split analysis

Meet	Result (s)	0-100 m (s)	100-200 m (s)	200-300 m (s)	300-400 m (s)
2017 London WC	44.48	11.26	10.33	11.06	11.83
2015 La Chaux	44.27	11.3	10.1	10.8	12.1

Intermediate time analysis

Meet	100 m (s)	200 m (s)	300 m (s)	Result (s)
2017 London WC	11.26	21.59	32.65	44.48
2015 La Chaux	11.3	21.4	32.2	44.27

The kinematic findings confirm that his steps are not well suited to fast sprinting, with one of the biggest knee angles (β) at toe-off and angles between thighs (η) at touchdown of the other seven finalists. This indicates that the swing leg is not coming up fast enough to prepare the next step and will lead to an excessively high folding of the shin and a curved trajectory of the foot below the buttocks during the contact phase (Tiupa, 1991). Although this technique may be inefficient to produce world-class times at 100 m or 200 m, it suits well to the last stages of the 400 m races, with a more economical way for the swing leg (see women's 400 m report commentary for details). With contact times of about 0.130 s and flight times around 0.143 s, Haroun displays an ideal ratio for sprinting under fatigue, with a contact time long enough to produce a large enough impulse as force went down, and a flight time short enough to promote step rate.

For further improvements that could lead to sub-44 s times, Haroun should find ways to adapt his mechanics to improve his basic speed to get closer to 20 s at 200 m and tap more into his speed reserve. That is what the most famous endurance-type 400 m runner, Alberto Juantorena did.

Juantorena's 100 m split analysis.

	Result	0-100 m	100-200 m	200-300 m	300-400 m
1972 OG	45.96	12.2	10.8	11.0	12.0
1976 OG	44.26	11.6	10.0	10.7	12.0

In 1972, Juantorena reached the half way mark in 23.0 s, with a two-second speed reserve as his 200 m PB was 21.0 s. By 1976, he was now a 400 m and 800 m specialist, winning both events at the Olympic Games. He also slightly improved his 200 m PB with 20.7 s, but during his 400 m, he passed at midway in 21.6 s, which only gave 0.9 as speed reserve. However, his new-trained speed endurance allowed him to tap more into his reserve whilst finishing as fast as before. To sum-up, while improving greatly his endurance (800 m) and slightly his speed (200 m), Juantorena managed to start faster without suffering excessive fatigue towards the end of the 400 m race. Workouts for speed (improving times at 80 m or flying 30 m), specific endurance (glycolytic mobilisation and accumulation as found in the highest lactate readings and results in workouts simulating 400 m fatigue) and fundamental endurance (expression of aerobic level) are crucial questions for 400 m. However, these three parameters cannot be improved concurrently at the same rate indefinitely, and eventually will conflict each other as shown in the experience of 400 m training in East Germany (Hess, 1997). Training for 400 m is a science and an art where coaches need to take in account biomechanical and physiological limitations and strengths of the athletes, and come up with the subtle balance between all its elements for a given athlete. Individualisation and optimisation seems to be the way to go after trial and error following the path of training volume increase and models during the past century.

Baboloki Thebe (BOT)

Born: 1997. Height: 1.78 m. Mass: 68 kg. Personal bests: 200 m: 20.21 s (2016); 400 m: 44.02 s (2017). SR index: 2.18.

100 m split analysis.

Meet	Result (s)	0-100 m (s)	100-200 m (s)	200-300 m (s)	300-400 m (s)
2017 London WC	44.66	10.94	10.10	10.83	12.79
2017 Lausanne	44.02	10.9	10.2	10.9	12.0

Intermediate time analysis.

Meet	100 m (s)	200 m (s)	300 m (s)	Result (s)
2017 London WC	10.94	21.04	31.87	44.66
2015 La Chaux	10.9	21.1	32.0	44.02

Nathon Allen (JAM)

Born: 1995. Height: 1.78 m. Mass: 68 kg. Personal bests: 200 m: 20.70 s (2016); 400 m: 44.19 s (2017). SR index: 2.13.

100 m split analysis.

Meet	Result (s)	0-100 m (s)	100-200 m (s)	200-300 m (s)	300-400 m (s)
2017 London WC	44.88	10.94	10.00	11.02	12.92
2017 London WC SF	44.19	11.00	10.00	10.98	12.21

Intermediate time analysis.

Meet	100 m (s)	200 m (s)	300 m (s)	Result (s)
2017 London WC	10.94	20.94	31.96	44.88
2017 London WC SF	11.00	21.00	31.98	12.21

Demish Gaye (JAM)

Born: 1993. Height: 1.88 m. Mass: 77 kg. Personal bests: 200 m: 20.48 s (2017); 400 m: 44.55 s (2017). SR index: 2.18.

100 m split analysis.

Meet	Result (s)	0-100 m (s)	100-200 m (s)	200-300 m (s)	300-400 m (s)
2017 London WC	45.04	11.01	9.98	11.28	12.77
2017 London WC SF	44.55	11.04	9.96	11.04	12.51

Intermediate time analysis.

Meet	100 m (s)	200 m (s)	300 m (s)	Result (s)
2017 London WC	11.01	20.99	32.27	45.04
2017 London WC SF	11.04	21.00	32.04	44.55

Fred Kerley (USA)

Born: 1995. Height: 1.91 m. Mass: 93 kg. Personal bests: 200 m: 20.24 s (2017); 400 m: 43.70 s (2017). SR index: 2.16.

100 m split analysis.

Meet	Result (s)	0-100 m (s)	100-200 m (s)	200-300 m (s)	300-400 m (s)
2017 London WC	45.23	11.04	10.15	11.17	12.87
2017 Austin	43.70	11.0	10.1	10.9	11.8

Intermediate time analysis.

Meet	100 m (s)	200 m (s)	300 m (s)	Result (s)
2017 London WC	11.04	21.19	32.36	45.23
2017 Austin	11.0	21.1	31.9	43.70

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Coaching commentary – Ralph Mouchbahani

In analysing the men's 400 m compared to the women's 400 m, it is interesting to note that proper running mechanics and hence the quality of the technical model plays a very different role.

In the men's event, relative step length appears to play a major role. The podium finishers all have a relative step length consistently over 1.20 throughout the race. This translated to them having the highest step velocity along the home straight. Fifth-placed Allen also had a high relative step length, but fell short due to an inferior step frequency, leading to a lower step velocity. The sixth-ranked finisher, Gaye, missed out because his stride velocity was below average. The stride efficiency and the maintenance of proper mechanics in time and movement patterns depends on the mastery of all three factors (step length, step rate and step velocity).

The efficiency and the usage of the energy sources is reflected in the comparisons and interpretations of the race strategy. All three medallists averaged the second half of the race at 90%, whereas the remaining finalists were at around 87%. When taking the step velocity into account it explains what matters and what needs to be addressed in training. The podium performers could on average cover the second 200 m faster and hence maintain the speed better than the remaining finalists (4th-8th). This shows that mastering the technique, being more efficient in controlling the rhythm allows athletes to master mechanics better when getting tired. This reflects on speed ability, coordination and technique addressed in training. We experience that 400 m sprinters begin working on speed endurance before mastering proper mechanics, hence become less efficient when getting tired. The data collected reinforces this observation. It is commonly adopted to schedule training components with endurance (general conditioning) preceding strength and speed. Whereas, getting strong and fast (proper mechanics) should be mastered first, before moving to advance endurance components.

Recommendations for training

1. Speed work before endurance.
2. Endurance becomes effective when proper running mechanics are mastered.
3. Speed endurance is intensity- and not quantity-based.
4. Intensity is strongly related to the mastery of sprint mechanics in proper time and movement patterns.
5. Special endurance must be trained in proper mechanics as well, although its main emphasis is the cardiovascular system as this will result in efficiency of the mechanics and the energy sources available.

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