IAAF World Championships
LONDON 2017

BIOMECHANICAL REPORT

FOR THE

IAAF World Championships
LONDON 2017

Marathon Men's

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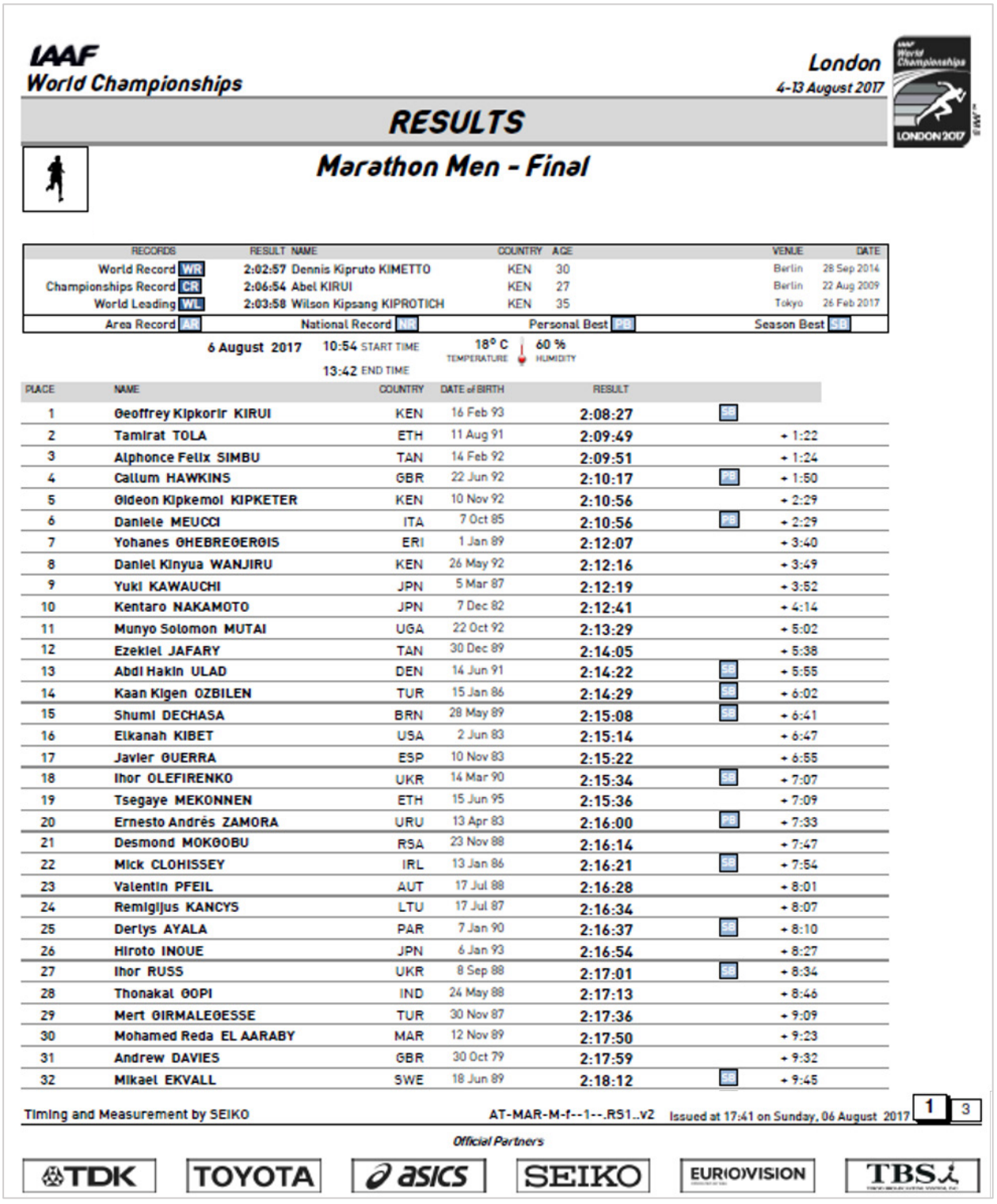
Table of Contents

Figures

Tables

INTRODUCTION

The men's marathon took place on August 6th in the City of London. The race started and finished at Tower Bridge, with most of the distance covered using four loops of approximately 10 km each. The weather conditions were relatively mild with cloud cover at times. The lead men stayed together in a pack until roughly halfway. The results for the first 32 finishers are shown below.



IAAF World Championships — London 4-13 August 2017

RESULTS

Marathon Men - Final

RECORDS	RESULT	NAME	COUNTRY	AGE	VENUE	DATE
World Record WR	2:02:57	Dennis Kipruto KIMETTO	KEN	30	Berlin	28 Sep 2014
Championships Record CR	2:06:54	Abel KIRUI	KEN	27	Berlin	22 Aug 2009
World Leading WL	2:03:58	Wilson Kipsang KIPROTICH	KEN	35	Tokyo	26 Feb 2017

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

6 August 2017 — 10:54 START TIME — 13:42 END TIME — 18° C TEMPERATURE — 60 % HUMIDITY

PLACE	NAME	COUNTRY	DATE of BIRTH	RESULT		
1	Geoffrey Kipkorir KIRUI	KEN	16 Feb 93	2:08:27	SB	
2	Tamirat TOLA	ETH	11 Aug 91	2:09:49		+ 1:22
3	Alphonce Felix SIMBU	TAN	14 Feb 92	2:09:51		+ 1:24
4	Callum HAWKINS	GBR	22 Jun 92	2:10:17	PB	+ 1:50
5	Gideon Kipkemoi KIPKETER	KEN	10 Nov 92	2:10:56		+ 2:29
6	Daniele MEUCCI	ITA	7 Oct 85	2:10:56	PB	+ 2:29
7	Yohanes GHEBREGERGIS	ERI	1 Jan 89	2:12:07		+ 3:40
8	Daniel Kinyua WANJIRU	KEN	26 May 92	2:12:16		+ 3:49
9	Yuki KAWAUCHI	JPN	5 Mar 87	2:12:19		+ 3:52
10	Kentaro NAKAMOTO	JPN	7 Dec 82	2:12:41		+ 4:14
11	Munyo Solomon MUTAI	UGA	22 Oct 92	2:13:29		+ 5:02
12	Ezekiel JAFARY	TAN	30 Dec 89	2:14:05		+ 5:38
13	Abdi Hakin ULAD	DEN	14 Jun 91	2:14:22	SB	+ 5:55
14	Kaan Kigen OZBILEN	TUR	15 Jan 86	2:14:29	SB	+ 6:02
15	Shumi DECHASA	BRN	28 May 89	2:15:08	SB	+ 6:41
16	Elkanah KIBET	USA	2 Jun 83	2:15:14		+ 6:47
17	Javier GUERRA	ESP	10 Nov 83	2:15:22		+ 6:55
18	Ihor OLEFIRENKO	UKR	14 Mar 90	2:15:34	SB	+ 7:07
19	Tsegaye MEKONNEN	ETH	15 Jun 95	2:15:36		+ 7:09
20	Ernesto Andrés ZAMORA	URU	13 Apr 83	2:16:00	PB	+ 7:33
21	Desmond MOKGOBU	RSA	23 Nov 88	2:16:14		+ 7:47
22	Mick CLOHISSEY	IRL	13 Jan 86	2:16:21	SB	+ 7:54
23	Valentin PFEIL	AUT	17 Jul 88	2:16:28		+ 8:01
24	Remigijus KANCYS	LTU	17 Jul 87	2:16:34		+ 8:07
25	Derlys AYALA	PAR	7 Jan 90	2:16:37	SB	+ 8:10
26	Hiroto INOUE	JPN	6 Jan 93	2:16:54		+ 8:27
27	Ihor RUSS	UKR	8 Sep 88	2:17:01	SB	+ 8:34
28	Thonakal GOPI	IND	24 May 88	2:17:13		+ 8:46
29	Mert GIRMALEGESSE	TUR	30 Nov 87	2:17:36		+ 9:09
30	Mohamed Reda EL AARABY	MAR	12 Nov 89	2:17:50		+ 9:23
31	Andrew DAVIES	GBR	30 Oct 79	2:17:59		+ 9:32
32	Mikael EKVALL	SWE	18 Jun 89	2:18:12	SB	+ 9:45

Timing and Measurement by SEIKO — AT-MAR-M-f--1--.RS1..v2 — Issued at 17:41 on Sunday, 06 August 2017 — 1 3

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METHODS

A position near the Bank of England was chosen for camera placement because it was near the end of each loop and allowed a clear view of the runners across a relatively wide street, which was straight and slightly uphill. Two Sony NXCAM cameras, operating at 50 Hz (shutter speed: 1/1250; ISO: variable; FHD: 1920x1080 px), were placed on a pavement on the side of the street furthest from the athletes' natural running line (marked on the road with blue paint). The cameras were angled approximately 45º and 135º to the plane of motion, with calibration procedures conducted before and after competition. This approach produced a large number of non-coplanar control points and facilitated the construction of specific global coordinate systems. In addition, two Casio Exilim high-speed cameras operating at 120 Hz (shutter speed: 1/1000; ISO: variable; 640x480 px) were positioned with their optical axes perpendicular to the running direction to capture sagittal plane motion for analysis of foot-strike patterns.

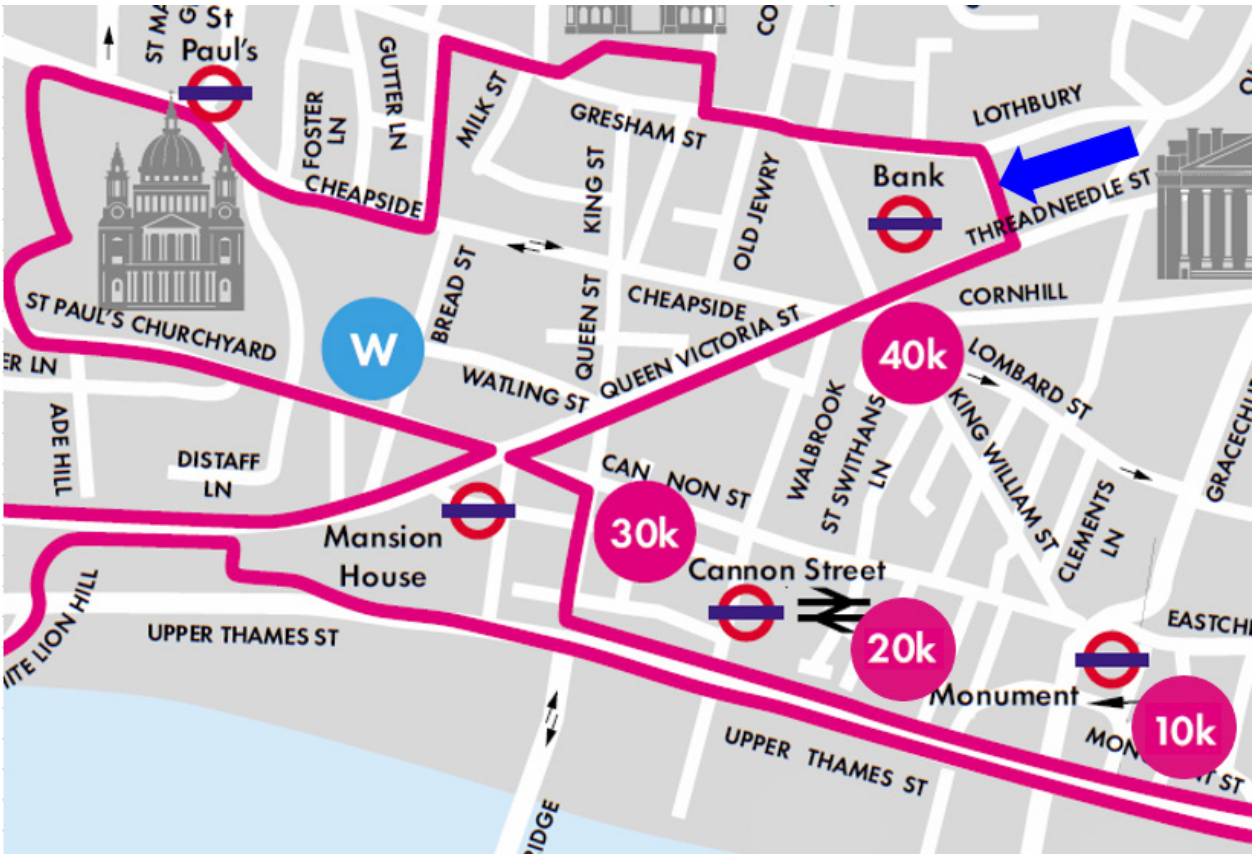

Figure 1. The cameras were placed near the end of each loop (location shown by the blue arrow).

The video files were imported into SIMI Motion (SIMI Motion version 9.2.2, Simi Reality Motion Systems GmbH, Germany) and 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. Digitising started 10 frames before the beginning of the stride and completed 10 frames after to provide padding during filtering. Each file was first digitised frame by frame and upon completion

Figure 2. Two Sony NXCAM cameras and two Casio Exilim cameras recorded the runners on each lap.

adjustments were made as necessary using the points over frame method, where each point was tracked through the entire sequence. The Direct Linear Transformation (DLT) algorithm was used to reconstruct the three-dimensional (3D) coordinates from individual camera's x and y image coordinates. Reliability of the digitising process was estimated by repeated digitising of one 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. 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. 3D still mode analysis was employed for some kinematic variables where digitising the whole body was not possible. The split data for each 5 km were provided by SEIKO as part of the official timing services. 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 3. The lead runners were packed closely together for most laps.

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

Variable	Definition
Running speed	The mean speed achieved during one complete running stride (i.e., two steps).
Step length	The distance covered from toe-off of one foot to toe-off of the other foot.
Relative step length	Step length as a proportion of the athlete's height (body height = 1.00).
Step length difference	The difference in step length between left-to-right and right-to-left steps. Positive values indicate a longer left-to-right step, and negative values longer right-to-left steps.
Step rate	The number of steps the athlete took per second (measured in Hz).
Contact time	The duration the athlete's foot was in contact with the ground.
Contact time %	The percentage of time per step spent in contact (the remainder is flight).
Flight time	The duration from toe-off of one foot to contact with the other foot.
Hip angle	The angle between the trunk and thigh segments and considered to be 0° in the anatomical standing position. Positive values indicate flexion, negative values indicate hyperextension.
Knee angle	The angle between the thigh and lower leg segments and considered to be 180° in the anatomical standing position.
Ankle angle	The angle between the lower leg and foot segments and calculated in a clockwise direction.
Shoulder angle	The angle between the trunk and upper arm and considered to be 0° in the anatomical standing position. Positive values indicate flexion, negative values indicate hyperextension.
Elbow angle	The angle between the upper arm and forearm and considered to be 180° in the anatomical standing position.
Footstrike pattern	The first position in which the foot makes contact with the ground; either rearfoot (the heel contacts the ground first), midfoot (the heel and midfoot contact the ground together) or forefoot (the forefoot contacts the ground first with a clear lack of heel contact until later in stance).

The joint angles were averaged between both sides of the body. In a few instances, only one side was measured because of obscured views or, in one instance, because the athlete was in an atypical position (wiping their nose). Footstrike patterns were obtained in nearly all cases using the Casio Exilim cameras that were positioned for this purpose, although on some occasions footage from the Sony NXCAM cameras had to be used instead.

RESULTS

Table 2 summarises the personal best (PB) and season's best (SB) times of each of the top eight finishers before the race and their ranking amongst all starters. Table 3 shows the comparison between their result in the race and their PB and SB times.

Table 2. Individual personal best (PB) and season's best (SB) times before the final.

	PB	Rank	SB	Rank
KIRUI	2:06:27	7	-	-
TOLA	2:04:11	1	2:04:11	1
SIMBU	2:09:10	16	2:09:10	7
HAWKINS	2:10:52	26	-	-
KIPKETER	2:05:51	5	2:05:51	3
MEUCCI	2:11:08	27	2:16:06	36
GHEBREGERGIS	2:08:14	9	2:08:14	5
WANJIRU	2:05:21	4	2:05:48	2

Table 3. Comparison between the final result and PB and SB times before the final.

	Result	Notes	vs PB (min:s)	vs SB (min:s)
KIRUI	2:08:27	SB	2:00	-
TOLA	2:09:49		5:38	5:38
SIMBU	2:09:51		0:41	0:41
HAWKINS	2:10:17	PB	–0:35	-
KIPKETER	2:10:56		5:05	5:05
MEUCCI	2:10:56	PB	–0:12	–5:10
GHEBREGERGIS	2:12:07		3:53	3:53
WANJIRU	2:12:16		6:55	6:28

Figure 4 shows the mean speeds for each of the top eight finishers during each 5 km segment. Because the athletes were so close together until after halfway, it was only possible to analyse them on Laps 3 and 4. Figure 5 shows that the men were slowing considerably in the last 20 km, whereas in general the women were speeding up, resulting in similar running speeds at the end.

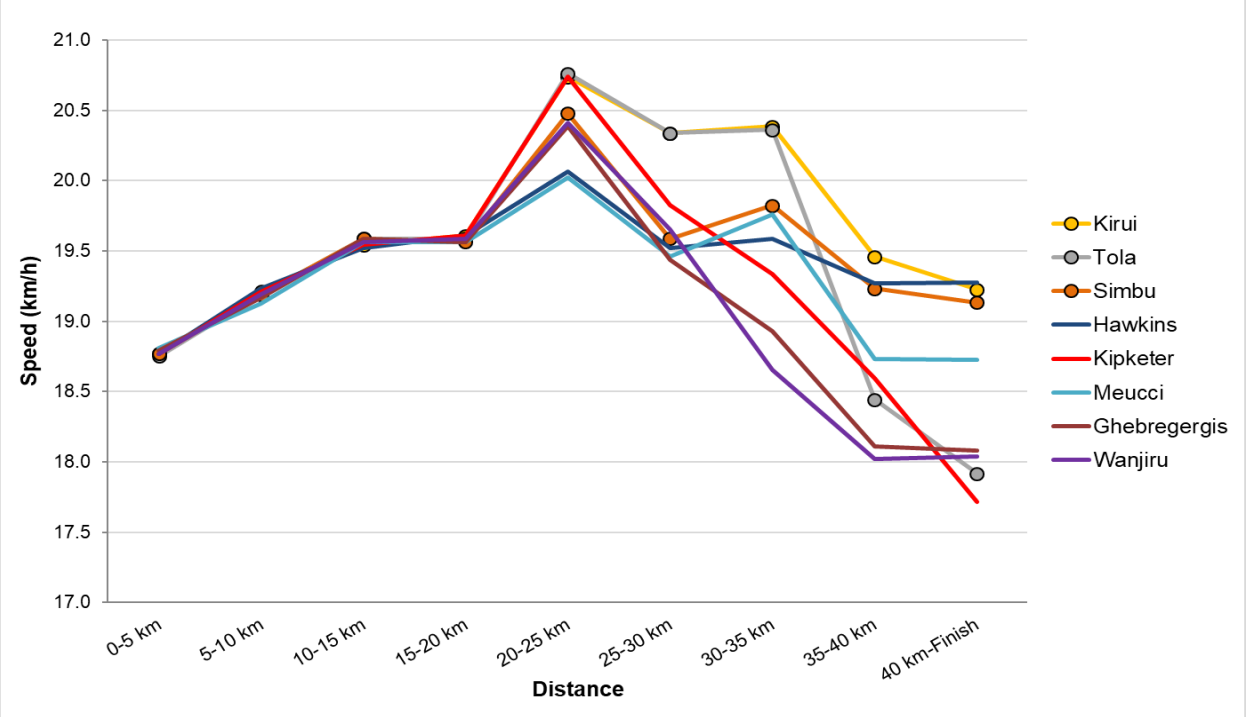

Figure 4. The mean speeds for each 5 km segment for the top eight finishers.

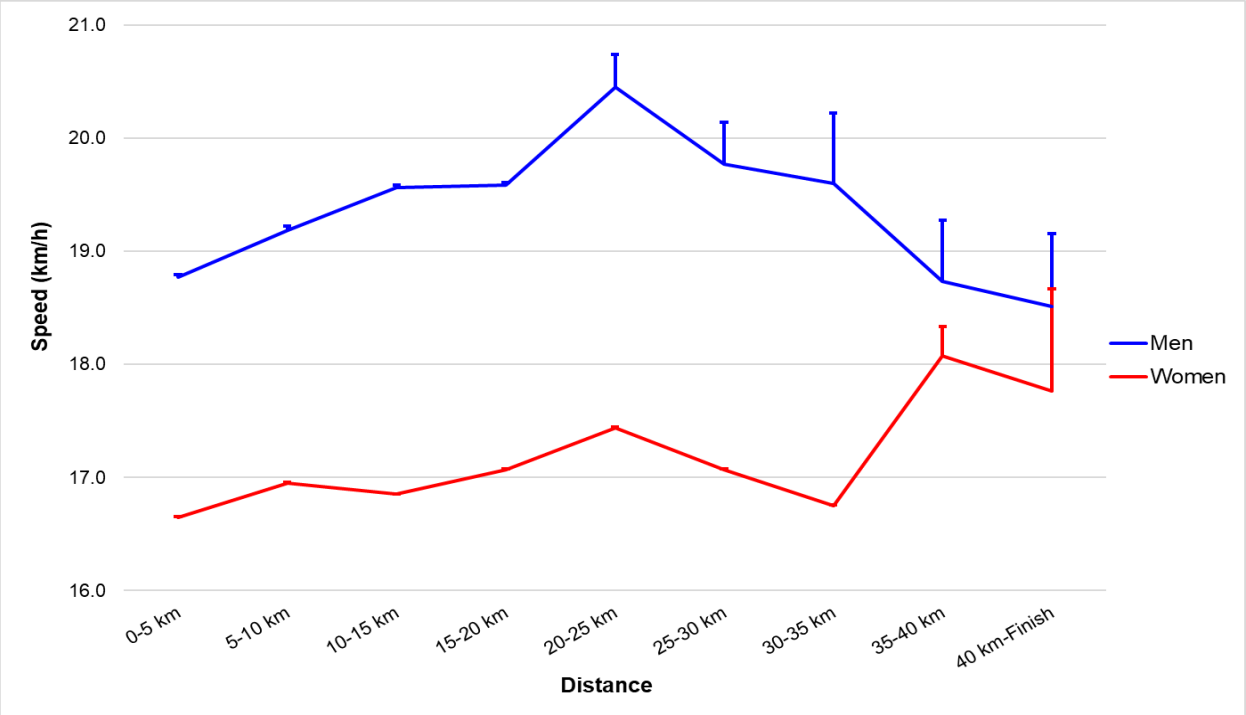

Figure 5. Mean speeds (+ SD) for each 5 km segment of the top eight finishers in the men's and women's marathons.

Figure 6 shows examples of footstrike patterns recorded during the race, with the description of each footstrike pattern for the top eight athletes shown in Table 4. It was possible to identify footstrikes on all four laps for these athletes, with the exception of Meucci on Lap 4.

Figure 6. Examples of rearfoot, midfoot and forefoot striking patterns from the race.

Table 4. Footstrike patterns for the top eight athletes on each lap.

	Lap 1	Lap 2	Lap 3	Lap 4
KIRUI	Rearfoot	Rearfoot	Rearfoot	Rearfoot
TOLA	Rearfoot	Rearfoot	Rearfoot	Rearfoot
SIMBU	Rearfoot	Rearfoot	Rearfoot	Rearfoot
HAWKINS	Rearfoot	Rearfoot	Rearfoot	Rearfoot
KIPKETER	Midfoot	Midfoot	Forefoot	Midfoot
MEUCCI	Midfoot	Midfoot	Midfoot	-
GHEBREGERGIS	Rearfoot	Midfoot	Rearfoot	Rearfoot
WANJIRU	Rearfoot	Rearfoot	Midfoot	Midfoot

Of the 70 finishers (out of 71) whose footstrike patterns were visible on Lap 4, 47 (67%) were rearfoot strikers, 21 (30%) were midfoot strikers and two (3%) were forefoot strikers.

Figure 7 shows the shows the mean values for spatiotemporal variables of the top eight athletes during Lap 3, whereas Table 5a shows the values for each individual runner (standing height data were not available for Simbu and Ghebregergis).

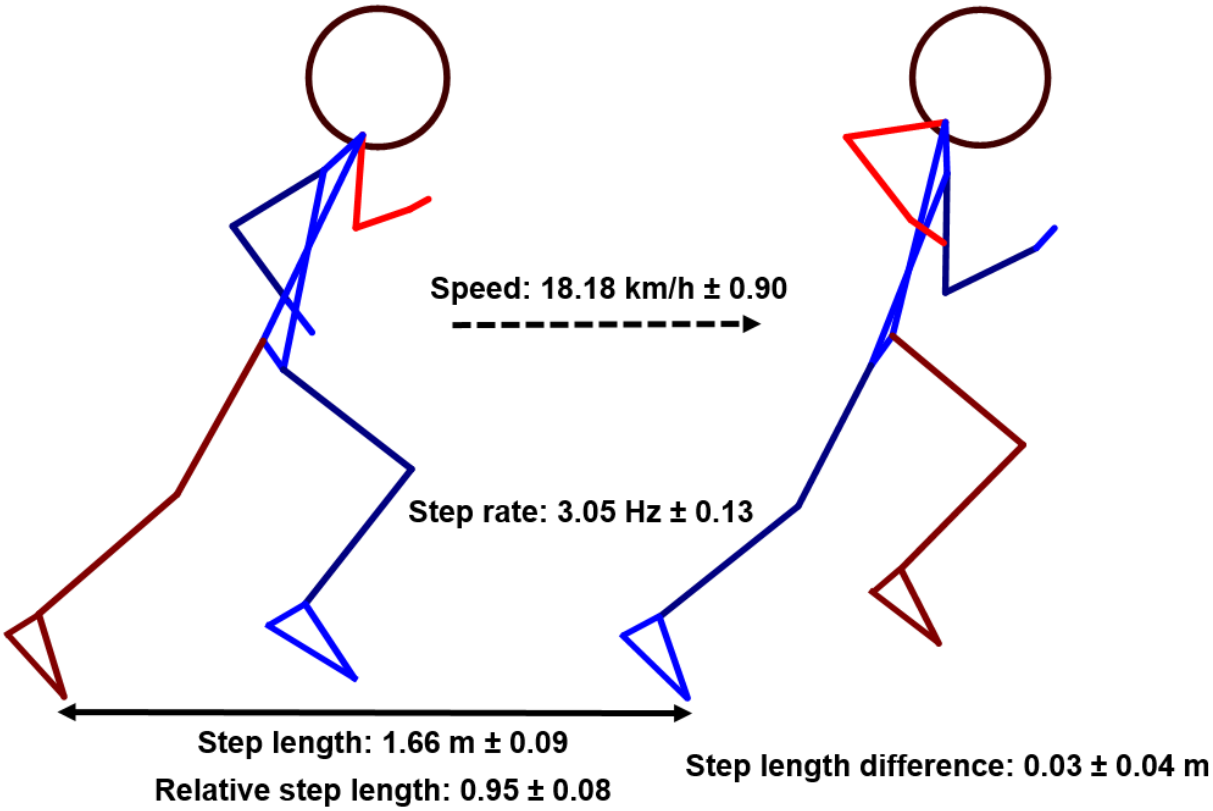

Figure 7. Mean running speed and spatiotemporal variables measured during Lap 3. Step length was measured as a percentage of standing height for six of the athletes.

Table 5. Speed and spatiotemporal values (Lap 3).

	Speed (km/h)	Step length (m)	Relative step length	Step length difference (m)	Step rate (Hz)
KIRUI	19.69	1.71	1.08	0.00	3.19
TOLA	19.44	1.77	0.98	0.00	3.05
SIMBU	18.03	1.72	-	0.04	2.91
HAWKINS	18.04	1.61	0.90	0.00	3.12
KIPKETER	17.64	1.72	0.97	0.01	2.85
MEUCCI	17.61	1.56	0.88	0.03	3.14
GHEBREGERGIS	17.21	1.61	-	0.06	2.96
WANJIRU	17.75	1.54	0.89	0.11	3.20

Figure 8 shows the mean values for spatiotemporal variables of the top eight athletes during Lap 4, whereas Table 6 shows the values for each individual runner (standing height data were not available for Simbu and Ghebregergis). It was not possible to obtain data for Meucci on Lap 4 as he ran outside the calibrated volume.

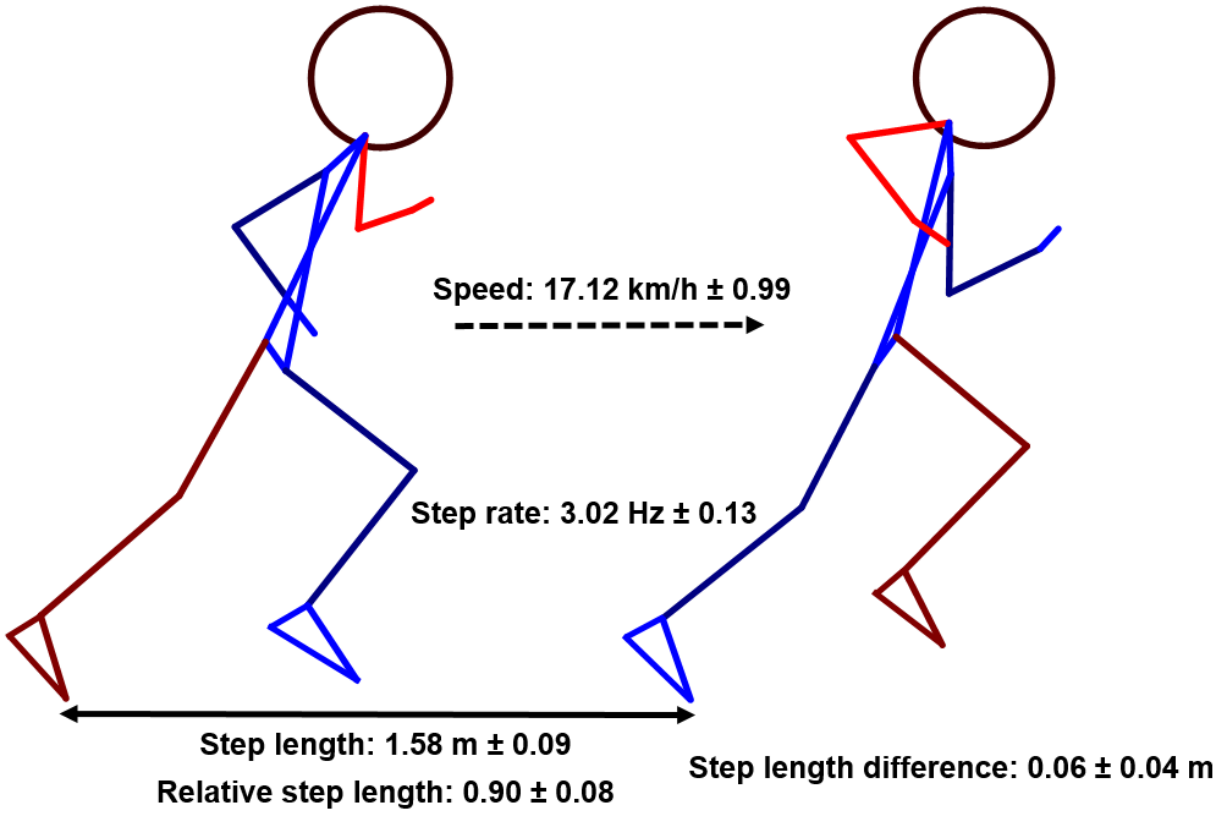

Figure 8. Mean running speed and spatiotemporal variables measured during Lap 4. Step length was measured as a percentage of standing height for five of the athletes.

Table 6. Speed and spatiotemporal values (Lap 4).

	Speed (km/h)	Step length (m)	Relative step length	Step length difference (m)	Step rate (Hz)
KIRUI	17.83	1.60	1.01	–0.01	3.10
TOLA	16.50	1.53	0.84	–0.03	3.00
SIMBU	17.66	1.69	-	0.03	2.89
HAWKINS	18.64	1.60	0.90	–0.01	3.23
KIPKETER	16.96	1.65	0.93	–0.09	2.86
MEUCCI	-	-	-	-	-
GHEBREGERGIS	16.62	1.54	-	0.11	2.99
WANJIRU	15.66	1.41	0.81	0.11	3.08

Figures 9 and 10 show the relative contributions of contact time and flight time (absolute values and percentages, respectively) for the top eight athletes during Lap 3.

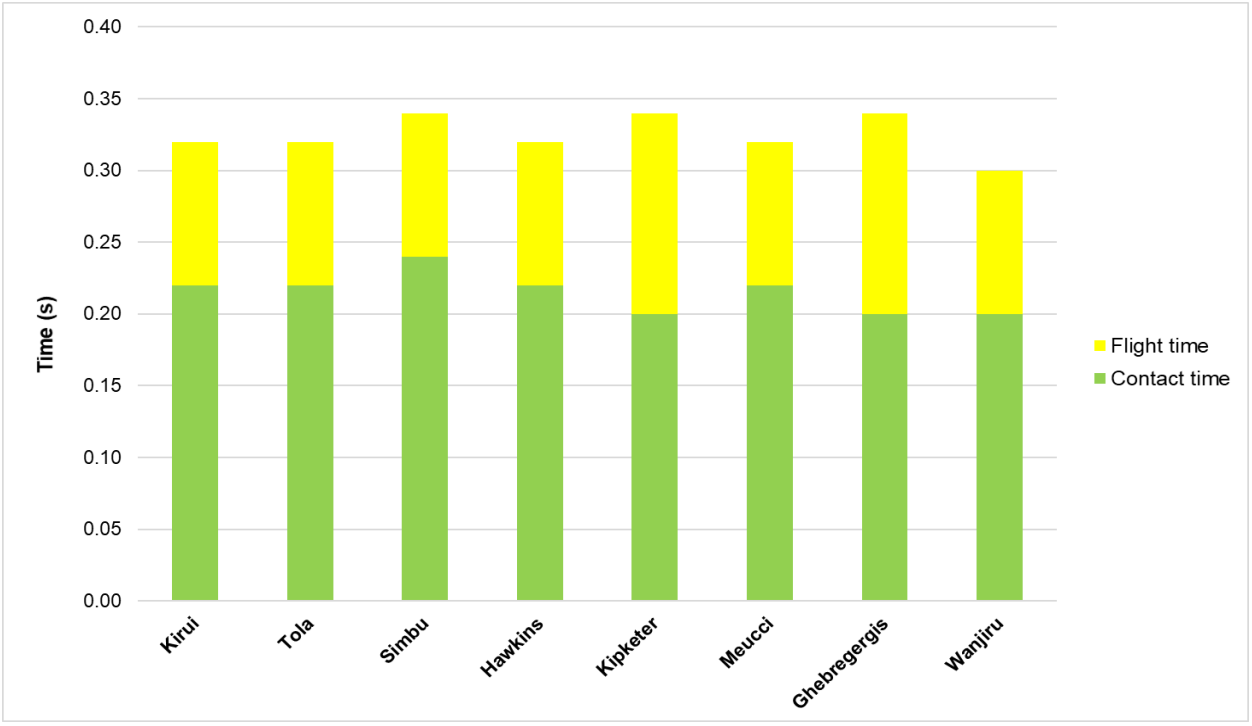

Figure 9. Contact and flight times for each of the top eight finishers (Lap 3).

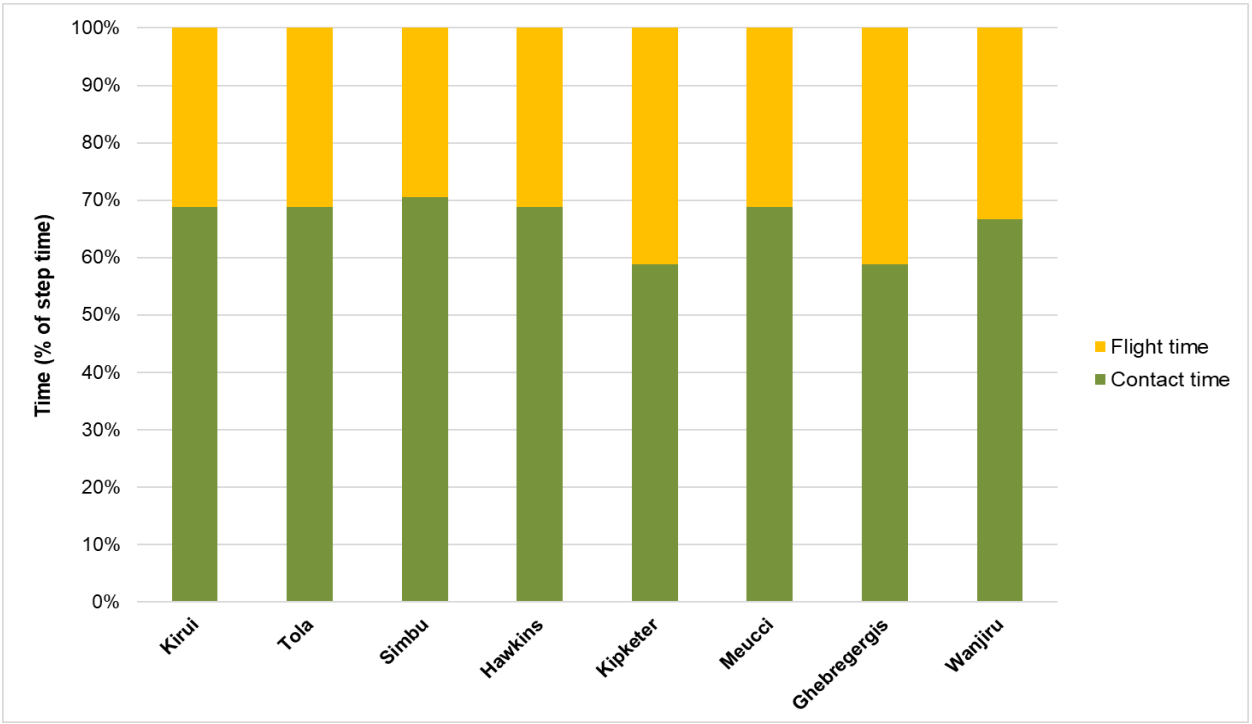

Figure 10. Contact and flight times (as % of step time) for the top eight finishers (Lap 3).

Figures 11 and 12 show the contributions of contact time and flight time (absolute values and percentages, respectively) for the top eight athletes during Lap 4 (except for Meucci, who could not be analysed). Figure 12 also shows the percentage decrease in contact time from Lap 3 to Lap 4.

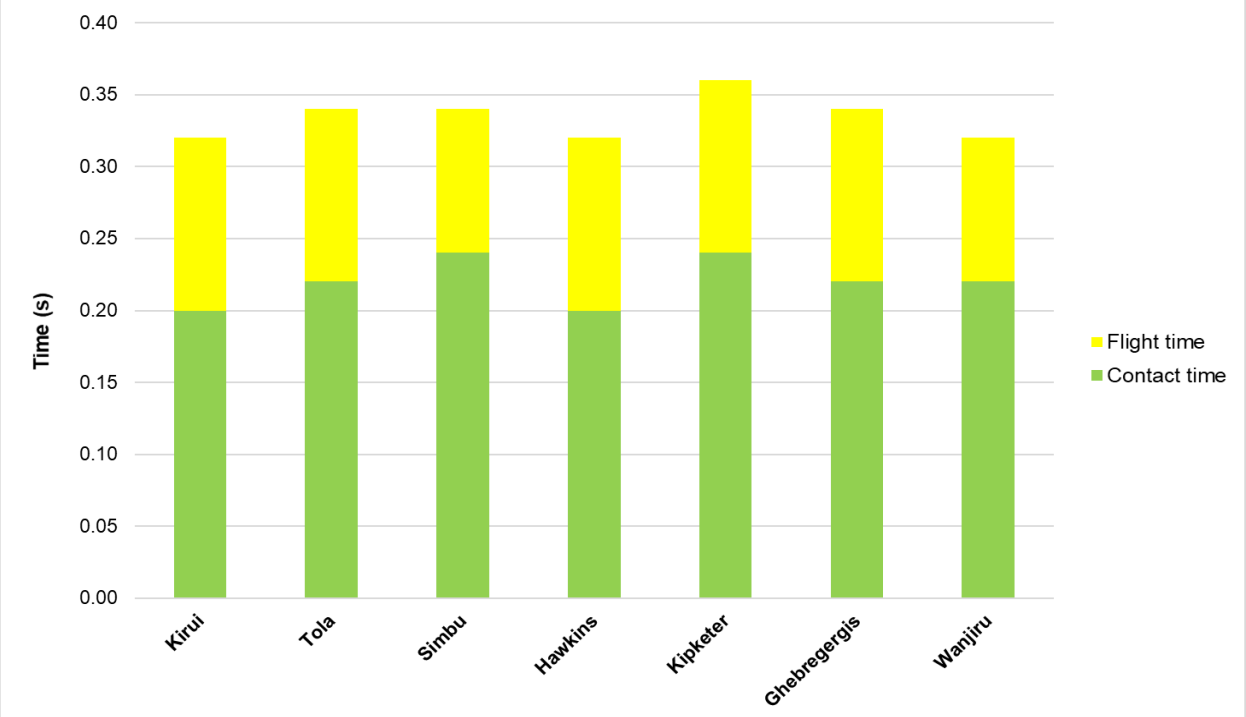

Figure 11. Contact and flight times for each of the top eight finishers (Lap 4).

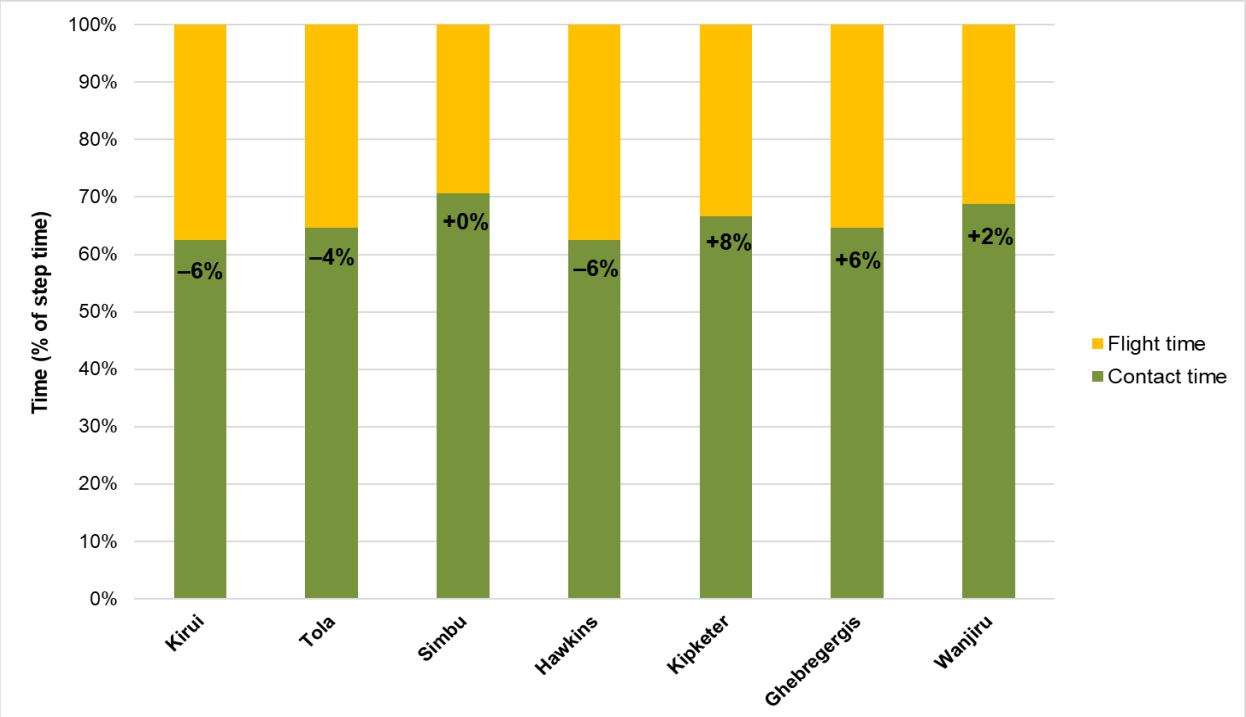

Figure 12. Contact and flight times (as % of step time) for the top eight finishers (Lap 4). The percentage change in contact time (%) from Lap 3 is also shown.

Figure 13 shows the mean values for joint angular data of the top eight athletes during Lap 3, whereas Tables 7 and 8 show each individual's values.

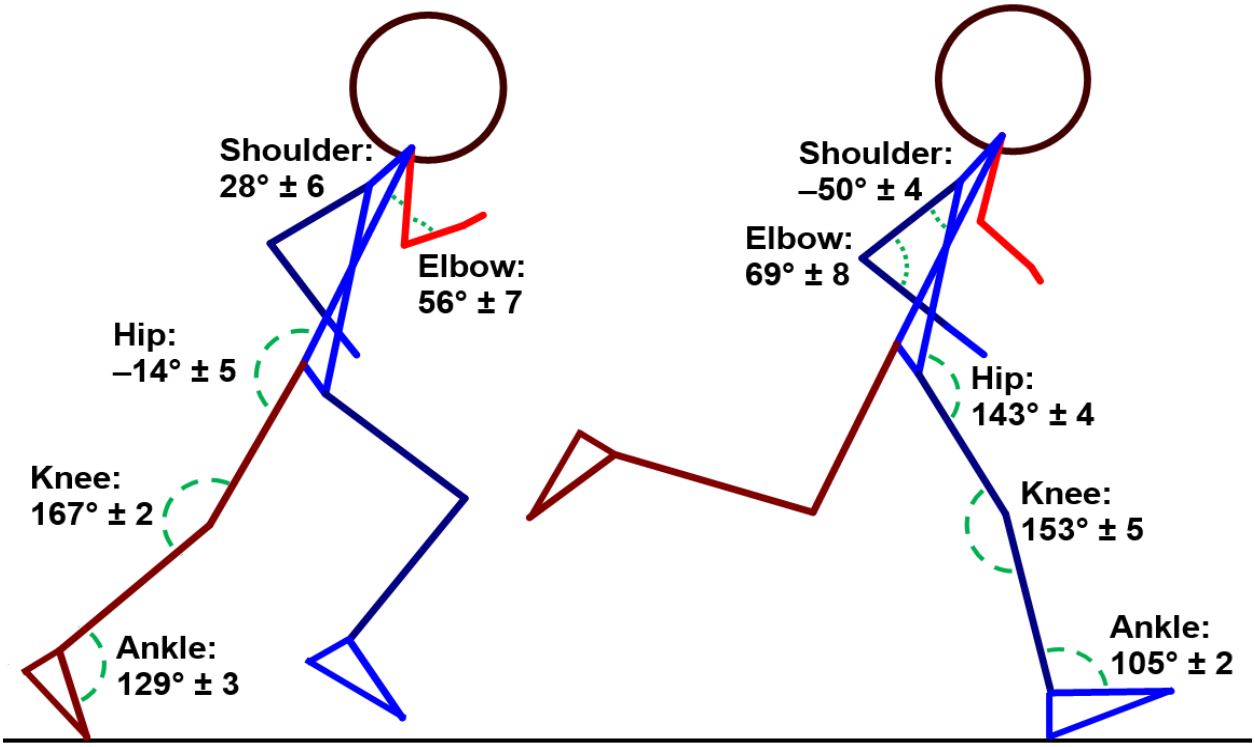

Figure 13. Mean joint angles at toe-off (left) and initial contact (right) (Lap 3).

Table 7. Joint angle values at toe-off (Lap 3).

	Hip (°)	Knee (°)	Ankle (°)	Shoulder (°)	Elbow (°)
KIRUI	–9	164	124	35	57
TOLA	–14	165	133	34	58
SIMBU	–11	167	131	30	59
HAWKINS	–19	169	131	31	53
KIPKETER	–10	169	131	21	43
MEUCCI	–14	167	126	34	53
GHEBREGERGIS	–17	168	132	22	66
WANJIRU	–21	169	130	21	60

Table 8. Joint angle values at initial contact (Lap 3).

	Hip (°)	Knee (°)	Ankle (°)	Shoulder (°)	Elbow (°)
KIRUI	137	161	103	–56	69
TOLA	142	156	105	–48	73
SIMBU	143	154	105	–50	73
HAWKINS	148	154	108	–47	81
KIPKETER	140	146	105	–52	55
MEUCCI	143	155	105	–54	60
GHEBREGERGIS	142	152	107	–49	70
WANJIRU	147	149	104	–45	72

Figure 14 shows the mean values for joint angular data of the top eight athletes during Lap 4 (except Meucci), whereas Tables 9 and 10 show each individual's values.

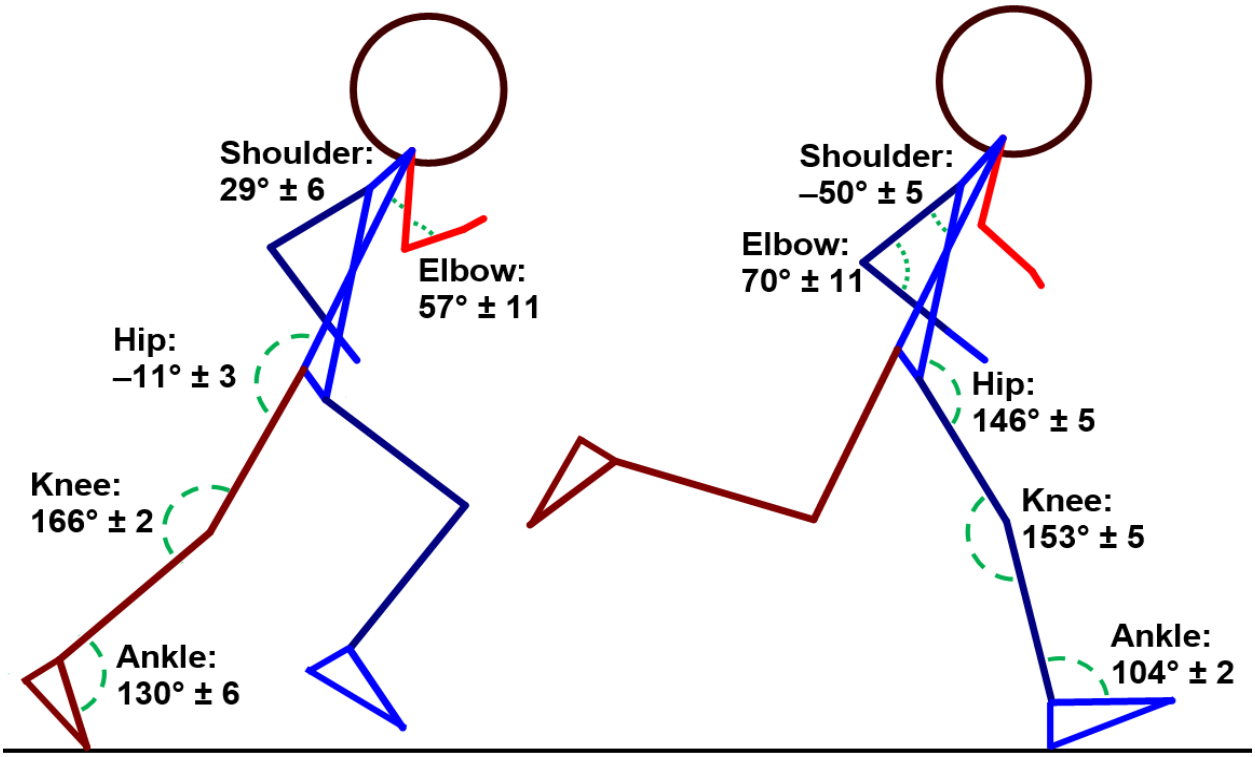

Figure 14. Mean joint angles at toe-off (left) and initial contact (right) (Lap 4).

Table 9. Joint angle values at toe-off (Lap 4).

	Hip (°)	Knee (°)	Ankle (°)	Shoulder (°)	Elbow (°)
KIRUI	–9	165	123	34	57
TOLA	–5	164	129	36	57
SIMBU	–9	166	133	27	52
HAWKINS	–13	168	130	32	54
KIPKETER	–15	170	141	27	44
MEUCCI	-	-	-	-	-
GHEBREGERGIS	–13	167	129	29	79
WANJIRU	–9	166	125	17	58

Table 10. Joint angle values at initial contact (Lap 4).

	Hip (°)	Knee (°)	Ankle (°)	Shoulder (°)	Elbow (°)
KIRUI	143	162	105	–51	73
TOLA	146	152	102	–49	65
SIMBU	149	152	103	–47	73
HAWKINS	149	155	106	–53	76
KIPKETER	154	153	108	–58	49
MEUCCI	-	-	-	-	-
GHEBREGERGIS	139	149	102	–42	101
WANJIRU	143	146	105	–48	72

COACH'S COMMENTARY

For a coach, the real beauty in the marathon data is that we get to see a glimpse of how athletes fatigue. Thanks to the pacing of the marathon, with a large surge around halfway and a gradual slowing of every athlete, by comparing the latter laps, we can see how fatigue manifests itself.

When comparing laps 3 and 4 of the runners, what is remarkable is how symmetrical most of the athletes are. On lap 3, before full fatigue has hit, the majority of the athletes show very little step length difference between their left and right side. This means they cover the same amount of ground when pushing off their left foot or right. The one major exception is Wanjiru who covers 0.11 m more difference on one side. If I were Wanjiru or his coach, this would be an area of investigation for potential improvement.

If we then look at lap 4, we can see that some of our athletes start to see greater left-right differences. This is likely a result of fatigue. In particular, Ghebregergis and Kipketer see their step length differences jump to 0.11 and 0.09 m, respectively. As athletes fatigue, they start to compensate and their 'weak links' in the chain start to show. Fatigue doesn't happen symmetrically and the data demonstrate this clearly. On the other hand, our top athletes hold things together remarkably well, with only very slight shifts in step length differences (i.e., Kirui from 0.00 to –0.01 m).

Digging into the step length and step rate data from laps 3 to 4 provides another interesting look at the impact of fatigue. For instance, Kirui slows down from 19.69 to 17.83 km/h. His step length drops from 1.71 to 1.60 m, while his step rate drops slightly less from 3.19 to 3.10 Hz. Kirui is seeing a gradual slow down coming from both length and step rate. Tola, on the other hand, saw a dramatic drop off in step length 1.77 to 1.53 m, while maintaining step rate (3.05 vs. 3.00 Hz) to a large degree. The way in which he slowed was almost entirely due to how much ground he covered from step to step. Hawkins was the only athlete to increase their speed from lap 3 to 4 and he did so entirely by increasing his step rate (from 3.12 to 3.23 Hz). His step length remained the same.

For coaches, the lesson is clearly that every athlete doesn't have the same running form and does not respond to fatigue in the same way. Each athlete has their own signature of how they increase speed, and how they deal with fatigue and the slow decreasing of speed. Do we see right to left differences, does their step rate change or is it in their step length? Answering how an athlete speeds up or breaks down will provide clues to what each athlete needs to work on. Often, as coaches we teach how to increase speed at the end of a race, but how often do we teach how to slowly fade, like was the case in this men's marathon.

Where an athlete shows fatigue provides an indicator for where their weak link in the chain is. For instance, if we see a maintenance in step rate but a significant drop in step length, it's likely that the athlete is losing his ability to put force into the ground so that he can cover the same distance. Find how your athletes tend to show breakdown, and then develop a plan to combat that, whether that is from biomechanics work and cueing, or strength and power development in the gym.

CONTRIBUTORS

Dr Brian Hanley is a Senior Lecturer in Sport and Exercise Biomechanics. Brian's particular research interests are in the area of elite athletics, especially race walking and distance running, as well as the pacing profiles adopted by endurance athletes. He is also interested in musculotendon profiling of athletes to appreciate internal limiting and contributing factors affecting performance, in addition to longitudinal studies measuring the technical development of junior athletes as they progress to become senior athletes.

Dr Athanassios Bissas is the Head of the Biomechanics Department in the Carnegie School of Sport at Leeds Beckett University. His research includes a range of topics but his main expertise is in the areas of biomechanics of sprint running, neuromuscular adaptations to resistance training, and measurement and evaluation of strength and power. Dr Bissas has supervised a vast range of research projects whilst having a number of successful completions at PhD level. Together with his team he has produced over 100 research outputs and he is actively involved in research projects with institutions across Europe.

Steve Magness is a performance coach, author and lecturer. He currently serves as a coach to almost 20 professional runners, is the Head Cross Country coach at the University of Houston and a Lecturer of Strength and Conditioning at St. Mary's University, UK. In addition, he has served a consultant or executive coach to high performers in a variety of business fields. Steve is also the author of the books *Peak Performance* and *The Science of Running*.