IAAF World Championships
LONDON 2017

BIOMECHANICAL REPORT

FOR THE

IAAF World Championships
LONDON 2017

Marathon Women's

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INTRODUCTION

The women'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 close finishing times are evidence of group running until close to the 40 km marker. The race was won by Chelimo, who had finished 8th at the previous year's Olympic marathon. The results for the first 32 finishers are shown below.

IAAF World Championships — London 4-13 August 2017

RESULTS

Marathon Women - Final

RECORDS		RESULT	NAME	COUNTRY	AGE	VENUE	DATE
World Record Women Only	WRwo	2:17:01	Mary Jepkosgei KEITANY	KEN	35	London	23 Apr 2017
Championships Record	CR	2:20:57	Paula RADCLIFFE	GBR	32	Helsinki (Olympic Stadium)	14 Aug 2005
World Leading	WL	2:17:01	Mary Jepkosgei KEITANY	KEN	35	London	23 Apr 2017

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

6 August 2017 — 14:00 START TIME — 17:44 END TIME — 19° C TEMPERATURE — 56 % HUMIDITY

PLACE	NAME	COUNTRY	DATE of BIRTH	RESULT		
1	Rose CHELIMO	BRN	12 Jul 89	2:27:11	SB	
2	Edna Ngeringwony KIPLAGAT	KEN	15 Nov 79	2:27:18	SB	+ 7
3	Amy CRAGG	USA	21 Jan 84	2:27:18	SB	+ 7
4	Flomena Cheyech DANIEL	KEN	5 Jul 82	2:27:21		+ 10
5	Shure DEMISE	ETH	21 Jan 96	2:27:58		+ 47
6	Eunice Jepkirui KIRWA	BRN	20 May 84	2:28:17		+ 1:06
7	Helah Jelagat KIPROP	KEN	7 Apr 85	2:28:19		+ 1:08
8	Mare DIBABA	ETH	20 Oct 89	2:28:49	SB	+ 1:38
9	Jessica TRENGOVE	AUS	15 Aug 87	2:28:59		+ 1:48
10	Berhane DIBABA	ETH	11 Sep 93	2:29:01		+ 1:50
11	Serena BURLA	USA	27 Sep 82	2:29:32		+ 2:21
12	Aselefech MERGIA	ETH	23 Jan 85	2:29:43		+ 2:32
13	Charlotte PURDUE	GBR	10 Jun 91	2:29:48		+ 2:37
14	Eva VRABCOVÁ NÝVLTOVÁ	CZE	6 Feb 86	2:29:56	PB	+ 2:45
15	Hye-Gyong KIM	PRK	9 Mar 93	2:30:29	SB	+ 3:18
16	Mao KIYOTA	JPN	12 Sep 93	2:30:36		+ 3:25
17	Yuka ANDO	JPN	16 Mar 94	2:31:31		+ 4:20
18	Alyson DIXON	GBR	24 Sep 78	2:31:36		+ 4:25
19	Helalia JOHANNES	NAM	13 Aug 80	2:32:01		+ 4:50
20	Sinead DIVER	AUS	17 Feb 77	2:33:26		+ 6:15
21	Marta ESTEBAN	ESP	6 Nov 82	2:33:37	SB	+ 6:26
22	Fate TOLA	GER	22 Oct 87	2:33:39		+ 6:28
23	Izabela TRZASKALSKA	POL	9 Jan 88	2:35:03		+ 7:52
24	Milly CLARK	AUS	1 Mar 89	2:35:27	SB	+ 8:16
25	Anne-Mari HYRYLÄINEN	FIN	15 Aug 78	2:35:33		+ 8:22
26	Inés MELCHOR	PER	30 Aug 86	2:35:34		+ 8:23
27	Risa SHIGETOMO	JPN	29 Aug 87	2:36:03		+ 8:52
28	Filomena COSTA	POR	22 Feb 85	2:36:42	SB	+ 9:31
29	Un-Ok JO	PRK	29 Aug 92	2:36:46		+ 9:35
30	Beata NAIGAMBO	NAM	11 Mar 80	2:37:24	SB	+ 10:13
31	Ilona MARHELE	LAT	5 Apr 86	2:37:40	PB	+ 10:29
32	Rosa CHACHA	ECU	8 Dec 82	2:37:50		+ 10:39

Timing and Measurement by SEIKO — AT-MAR-W-f--1--.RS1..v1 — Issued at 17:44 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.

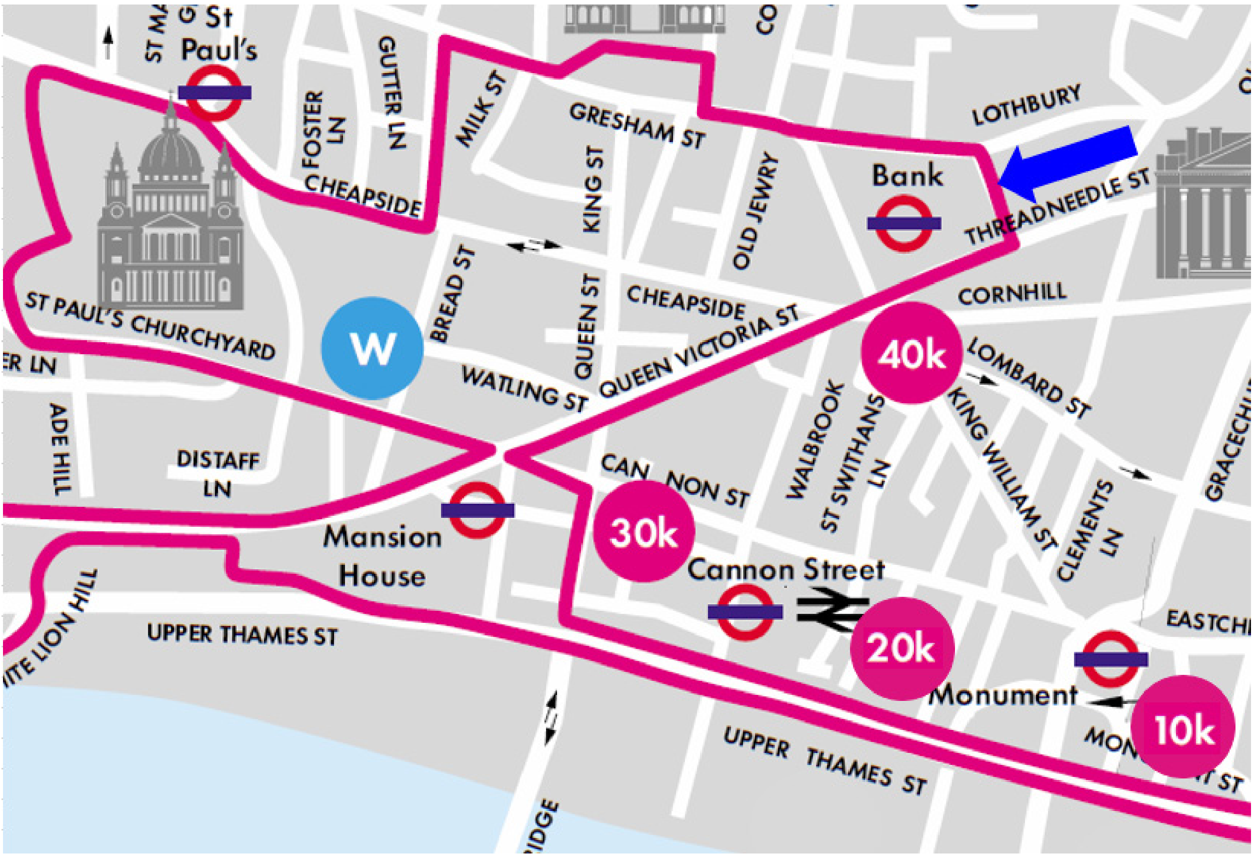

Figure 1. The cameras were placed near the end of each loop (location shown by the blue arrow).

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. 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
CHELIMO	2:24:14	12	-	-
KIPLAGAT	2:19:50	2	-	-
CRAGG	2:27:03	19	-	-
DANIEL	2:21:22	7	2:21:22	3
DEMISE	2:20:59	4	2:22:57	5
KIRWA	2:21:17	5	2:21:17	1
KIPROP	2:21:27	8	2:25:39	9
DIBABA	2:19:52	3	-	-

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)
CHELIMO	2:27:11	SB	2:57	-
KIPLAGAT	2:27:18	SB	7:28	-
CRAGG	2:27:18	SB	0:15	-
DANIEL	2:27:21		5:59	5:59
DEMISE	2:27:58		6:59	5:01
KIRWA	2:28:17		7:00	7:00
KIPROP	2:28:19		6:52	2:40
DIBABA	2:28:49	SB	8:57	-

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 35 km, it was only possible to analyse them on Lap 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.

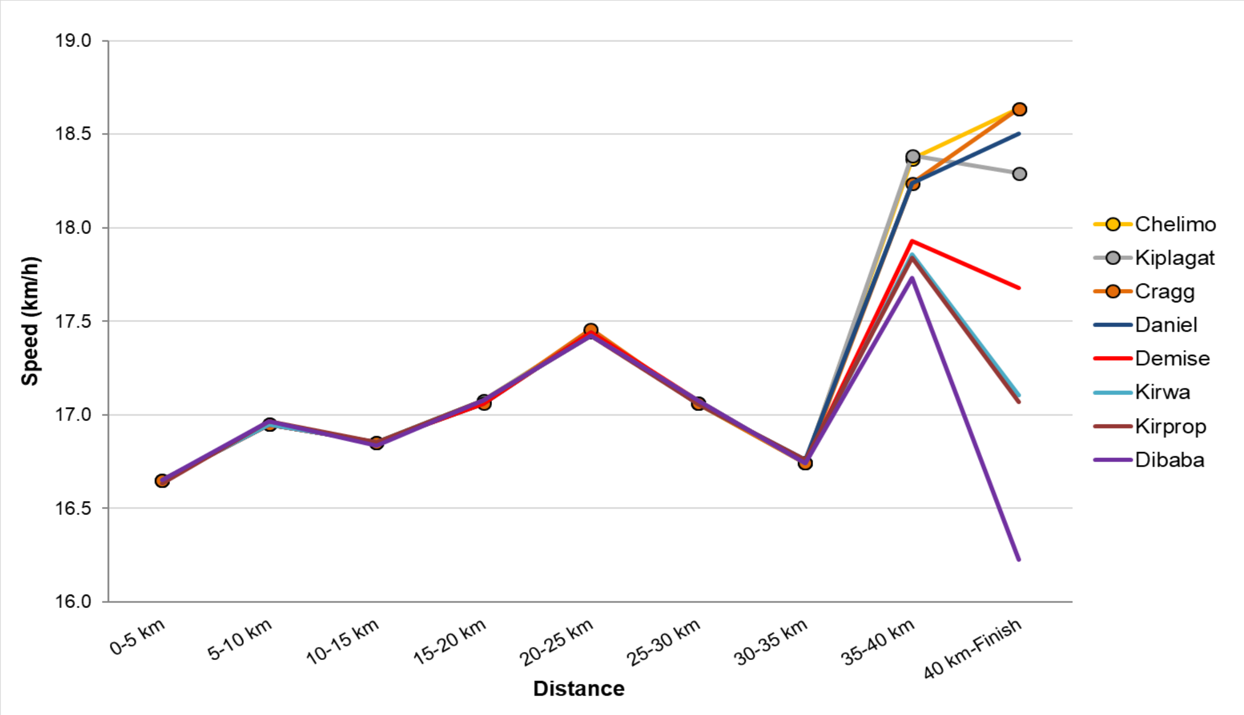

Figure 4. The mean speeds for each 5 km segment for the top eight finishers.

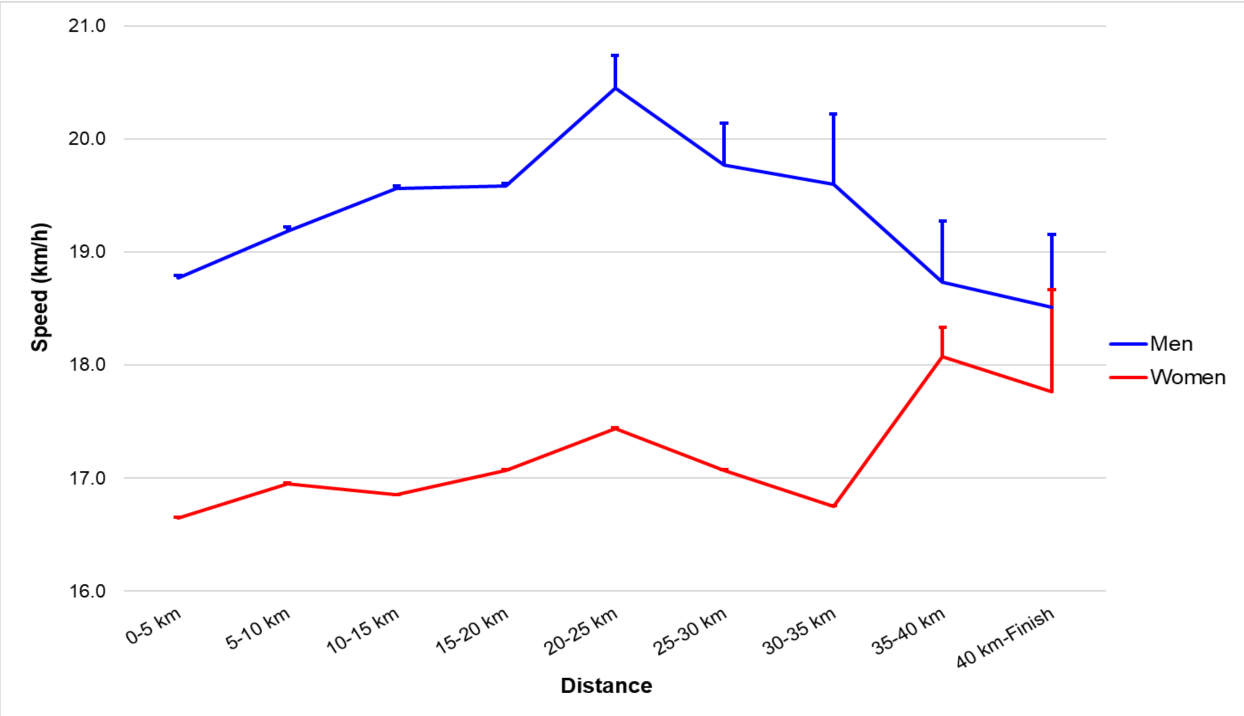

Figure 5. Mean speeds (+ SD) for each 5 km segment of the top eight finishers in the men's and women's marathons.

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.

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
CHELIMO	Rearfoot	Rearfoot	Midfoot	Midfoot
KIPLAGAT	Forefoot	Forefoot	Forefoot	Forefoot
CRAGG	Midfoot	Midfoot	Midfoot	Midfoot
DANIEL	Rearfoot	Rearfoot	Rearfoot	Rearfoot
DEMISE	Rear / Midfoot*	Midfoot	Midfoot	Midfoot
KIRWA	Rearfoot	Rearfoot	Rearfoot	Rearfoot
KIPROP	Midfoot	Midfoot	Midfoot	Midfoot
DIBABA	Rearfoot	Rearfoot	Rearfoot	Rearfoot

* The athlete had a rearfoot strike on one foot, and a midfoot strike on the other.

Of the 78 finishers, 57 (73%) were rearfoot strikers, 19 (24%) were midfoot strikers and two (3%) were forefoot strikers during Lap 4.

Figure 7 shows the shows the mean values for spatiotemporal variables of the top eight athletes during Lap 4, whereas Table 5 shows the values for each individual runner.

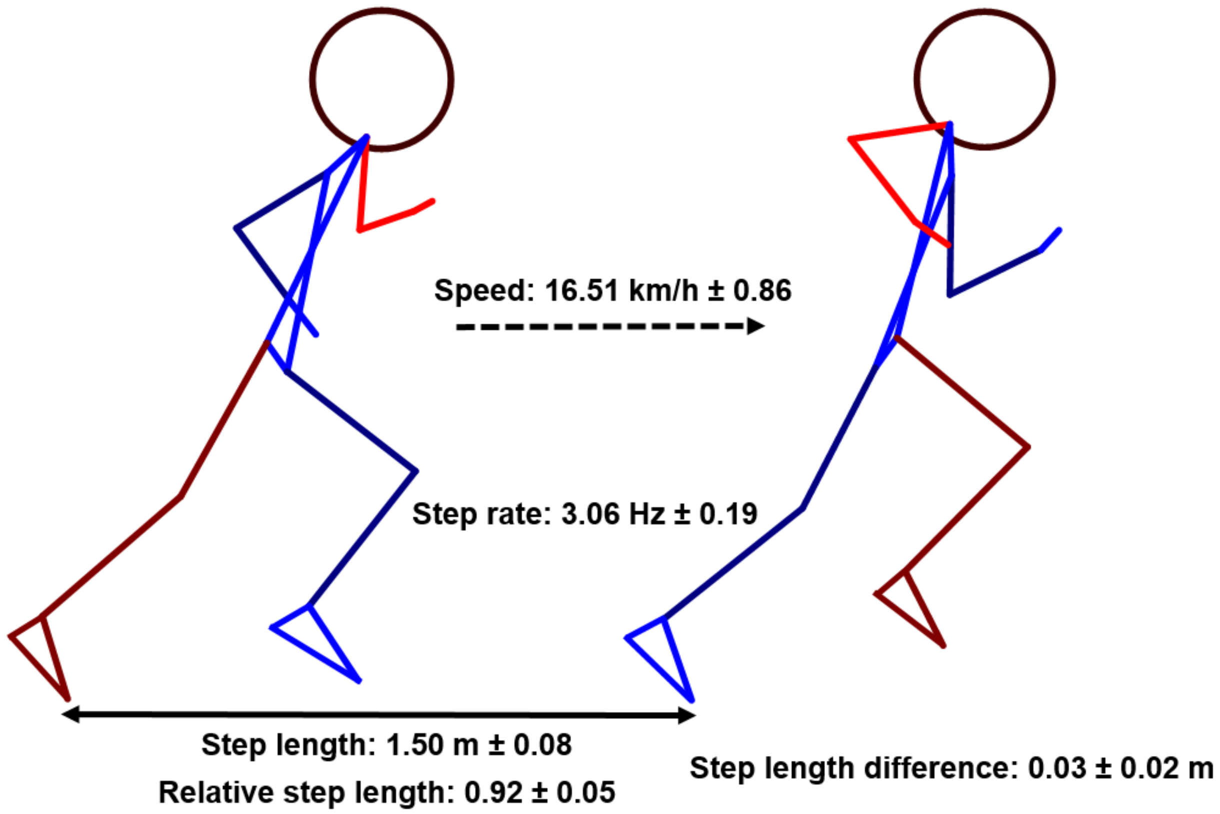

Figure 7. Mean running speed and spatiotemporal variables measured during Lap 4.

Table 5. Speed and spatiotemporal values (Lap 4).

	Speed (km/h)	Step length (m)	Relative step length	Step length difference (m)	Step rate (Hz)
CHELIMO	16.97	1.42	0.88	0.00	3.31
KIPLAGAT	16.98	1.54	0.90	–0.03	3.07
CRAGG	17.69	1.49	0.92	–0.07	3.29
DANIEL	17.22	1.55	0.92	0.00	3.09
DEMISE	16.29	1.53	0.91	0.01	2.95
KIRWA	15.35	1.37	0.83	–0.01	3.10
KIPROP	16.20	1.64	1.00	0.03	2.75
DIBABA	15.35	1.46	0.96	0.05	2.92

Figures 8 and 9 show the contributions of contact time and flight time (absolute values and percentages, respectively) for the top eight athletes during Lap 4.

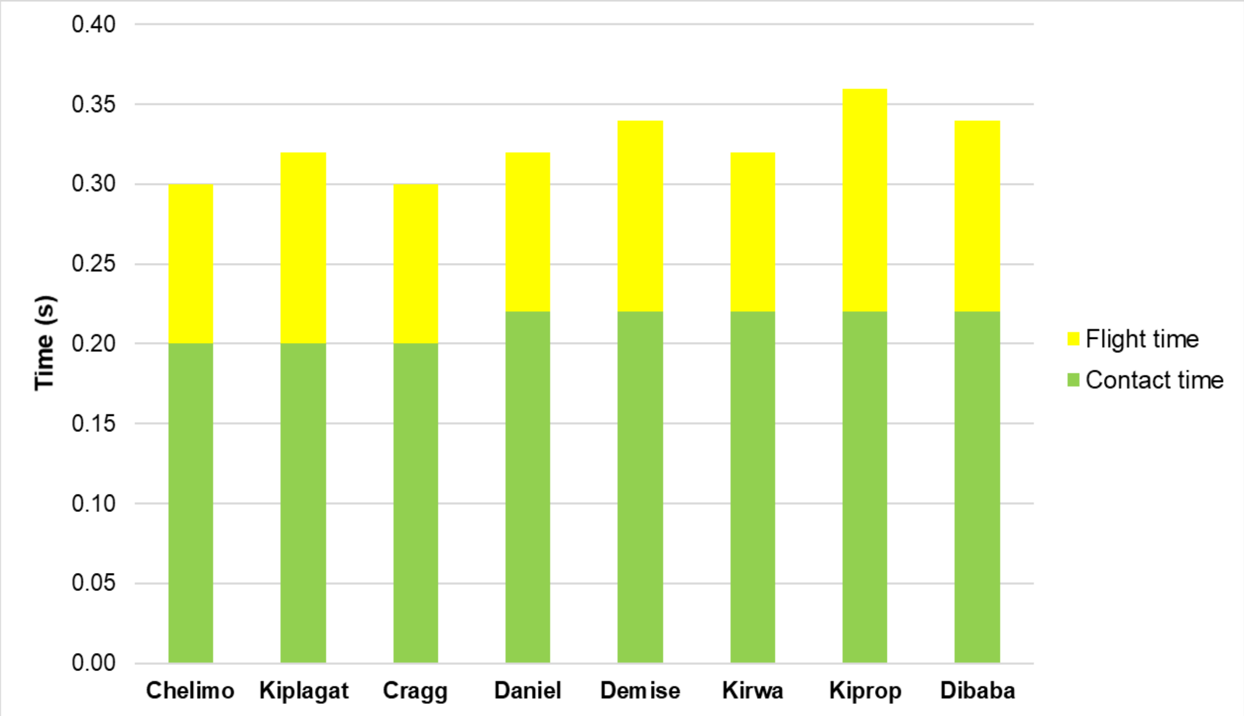

Figure 8. Contact and flight times for the top eight finishers.

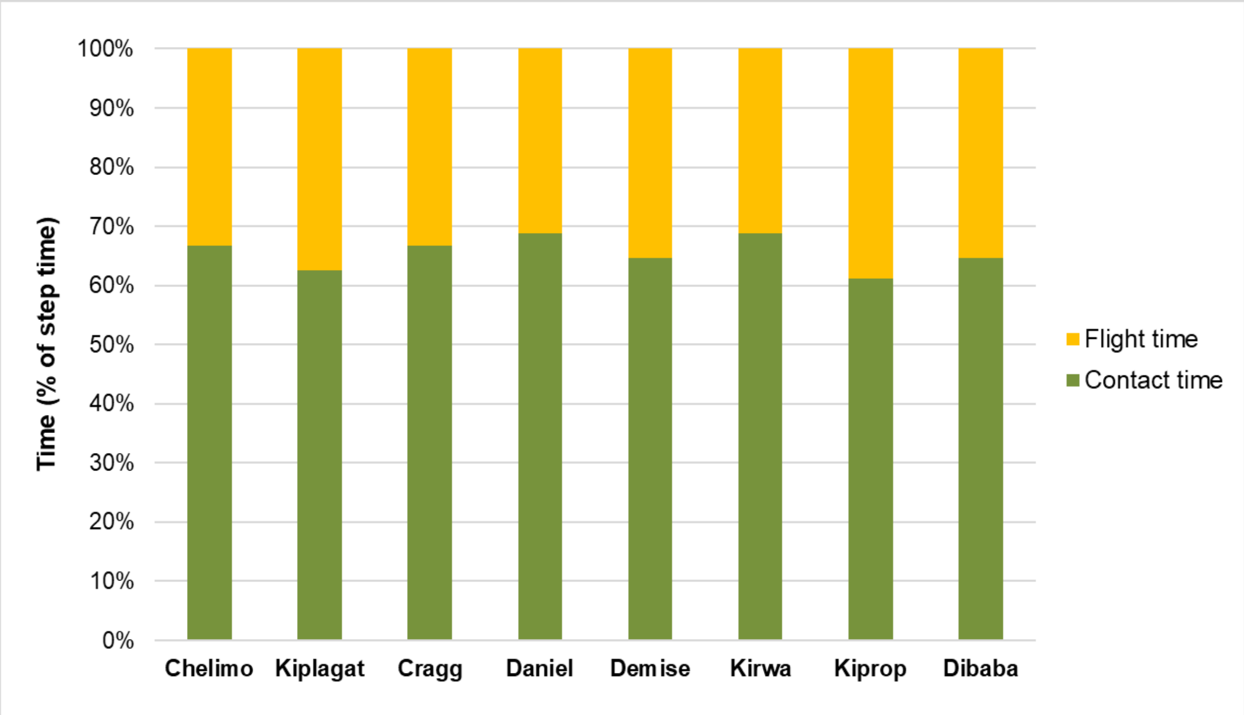

Figure 9. Contact and flight times (as % of step time) for the top eight finishers.

Figure 10 shows the mean values for joint angular data of the top eight athletes during Lap 4, whereas Tables 6 and 7 show each individual's values.

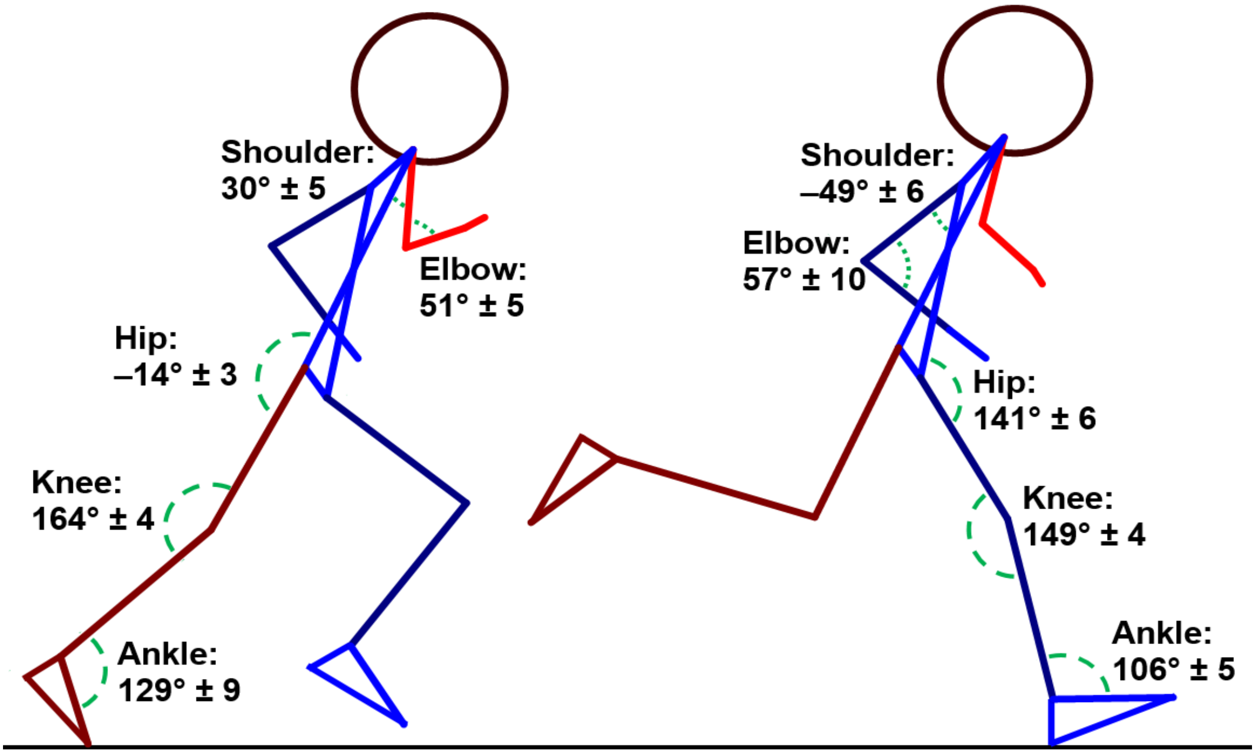

Figure 10. Mean joint angles at toe-off (left) and initial contact (right) (Lap 4).

Table 6. Joint angle values at toe-off (Lap 4).

	Hip (°)	Knee (°)	Ankle (°)	Shoulder (°)	Elbow (°)
CHELIMO	–14	162	137	29	54
KIPLAGAT	–11	171	137	32	56
CRAGG	–18	163	123	29	56
DANIEL	–8	161	126	29	46
DEMISE	–16	166	141	30	54
KIRWA	–15	163	116	30	44
KIPROP	–12	167	129	22	48
DIBABA	–16	161	124	39	54

Table 7. Joint angle values at initial contact (Lap 4).

	Hip (°)	Knee (°)	Ankle (°)	Shoulder (°)	Elbow (°)
CHELIMO	136	146	110	–44	72
KIPLAGAT	145	152	114	–50	66
CRAGG	151	152	105	–58	65
DANIEL	133	146	106	–45	63
DEMISE	143	155	109	–45	51
KIRWA	146	150	98	–57	51
KIPROP	135	145	107	–46	45
DIBABA	141	151	100	–51	48

COACH'S COMMENTARY

In the analysis of the women's marathon, what we see is a relatively modest pace through halfway, a slight slow-down over the next 15 km, and then a dramatic increase in speed over the final 7 km. The final 7 km provides a nice showcase of the tactics of the marathon.

From a training standpoint, these data show that medalling at a major championship in the marathon often relies on a different skill set from racing a major marathon, where the focus is often on time. The top eight athletes stay together until well into the race. The dramatic increase in speed over the last 7 km requires athletes to have the ability to shift gears under heavy fatigue. Additionally, Kiplagat almost lost her silver medal from slightly misjudging how much energy she had left in the tank. Her slow down over the last 2 km almost allowed Cragg to snag a silver medal. What this shows is that running a marathon is often about accurately assessing how much one has left and whether they can handle the surge all the way to the finish or not.

Once the athletes were dropped, their speed essentially fell off a cliff. In particular, Dibaba, Demise, Kirwa, and Kiprop found themselves outside of medal contention and dramatically slowed once this was the case. We know from the latest research on fatigue and performance that motivation plays a large role in determining how much effort one can withstand. Once the incentive drops off (i.e., personal best, medal, etc.), there's nothing holding fatigue back. It comes at you with full force. For coaches, this is a clear demonstration of why secondary goals are important. They provide athletes with a reason to continue on when their primary goal is lost.

As we dig into the biomechanics of the athletes, we are left with the idea of movement signatures. Although running similar speeds, we have athletes who have step lengths ranging from 1.37 to 1.64 m and step rates ranging from 2.75 to 3.31 Hz. Similarly, their flight times and contact times demonstrate subtle but significant variations. Even among elite athletes of similar calibre, the way in which they get there mechanically can be very different.

When analysing the footstrike patterns of the women, a similar picture emerges. Recently in the mass media and even some coaching literature, there has been a shift to identifying and changing footstrike to a more midfoot style, the elite women show a wide range of footstrikes, from rearfoot to forefoot. The most interesting takeaway from the foot strike data may be that Chelimo runs the first two laps with a rearfoot strike while shifting to a midfoot strike on the final two laps. This could be due to a changing of speed, or a compensation from fatigue. Given that Chelimo was the winner, my inclination is to guess that as Chelimo picked up the pace, a midfoot strike was more economical at these faster speeds. Although we don't have data on the early laps, Chelimo also had the highest step rate and a comparably low step length late in the race, which makes sense with a midfoot landing versus a pronounced rearfoot one.

From a coach's standpoint, there is much to be learned from these data. The pacing data further demonstrate the difference between a big city marathon focused on time and a championship-style marathon. When the focus is on time, the race becomes essentially a time trial until exhaustion for all but the winner. They hang on for as long as possible. During the 2017 World Championship marathon, the athletes had to manage major changes in pace and accurately judge how fast they could run to the finish from several kilometres out. This requires self-awareness of the athlete, but also an ability to change pace without large changes in energetic cost.

Although we don't have the full data on how these athletes accomplished that, you can see a wide range of movement signatures of how they attempted to. For a coach, the goal should be to understand why the athlete moves in that particular manner and then see if it is constraining them from accomplishing their goals. The elite athletes in this marathon provide some clues to how to get it done.

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*.