IAAF World Championships
LONDON 2017

BIOMECHANICAL REPORT

FOR THE

IAAF World Championships
LONDON 2017

Shot Put Women's

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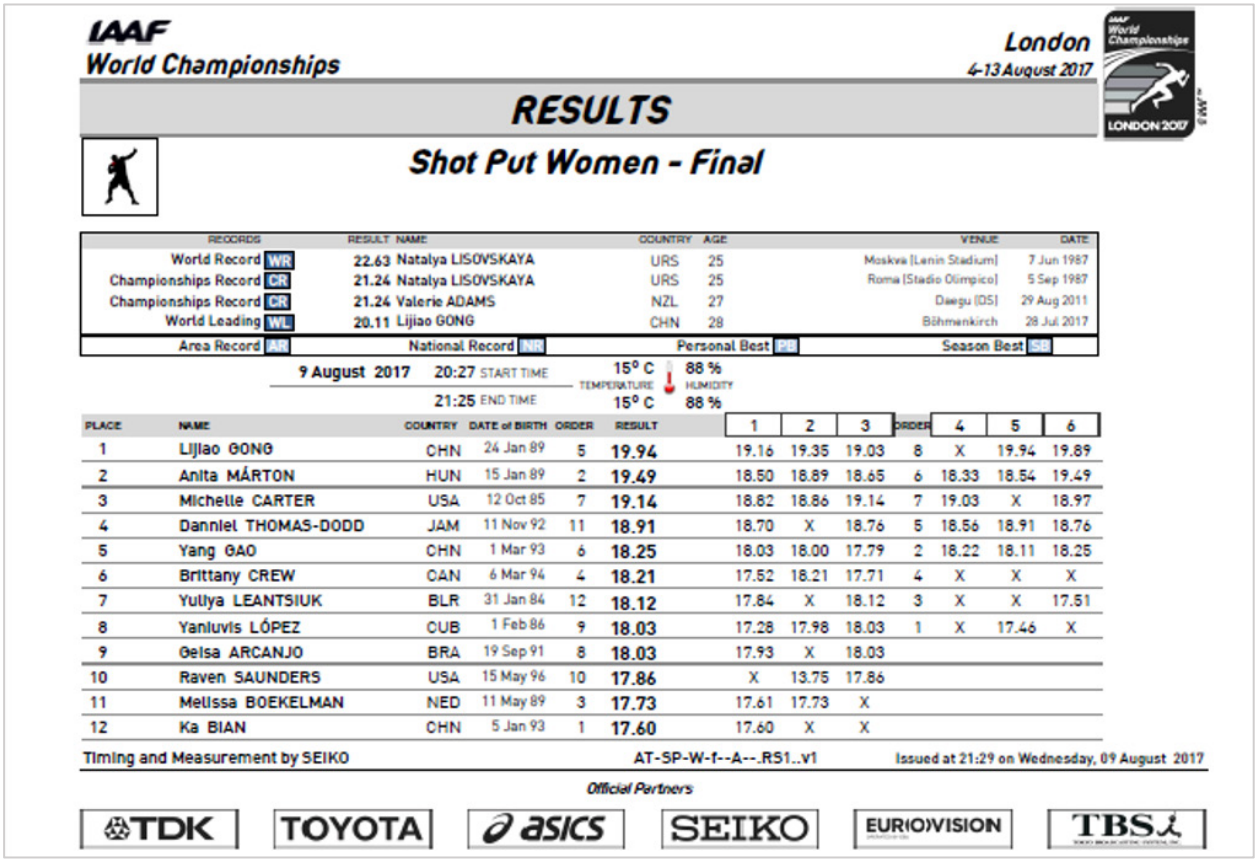
INTRODUCTION

The women's shot put final took place on the night of August 9th in very wet weather conditions. Coming into the final, Lijiao Gong from China was the favourite as the world leader in 2017. Gong dominated the competition from the first round, whereby she provided a magnificent sequence of throws culminating with the gold medal throw in the fifth round measured at 19.94 m. The competition for the silver and bronze medal was hotly contested between Anita Márton from Hungary and Michelle Carter from the USA. The silver medal position swapped backwards and forwards between these two athletes over the first five rounds. However, in a dramatic finale Márton threw 19.49 m in the final round to snatch the silver medal. Michelle could not respond with her final throw of the competition and as such she obtained the bronze medal from her third round throw measured at 19.14 m.



IAAF World Championships — London 4-13 August 2017

RESULTS

Shot Put Women - Final

RECORDS	RESULT	NAME	COUNTRY	AGE	VENUE	DATE
World Record WR	22.63	Natalya LISOVSKAYA	URS	25	Moskva (Lenin Stadium)	7 Jun 1987
Championships Record CR	21.24	Natalya LISOVSKAYA	URS	25	Roma (Stadio Olimpico)	5 Sep 1987
Championships Record CR	21.24	Valerie ADAMS	NZL	27	Daegu (DS)	29 Aug 2011
World Leading WL	20.11	Lijiao GONG	CHN	28	Böhmenkirch	28 Jul 2017

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

9 August 2017 — 20:27 START TIME — 15° C TEMPERATURE — 88 % HUMIDITY
21:25 END TIME — 15° C — 88 %

PLACE	NAME	COUNTRY	DATE of BIRTH	ORDER	RESULT	1	2	3	ORDER	4	5	6
1	Lijiao GONG	CHN	24 Jan 89	5	19.94	19.16	19.35	19.03	8	X	19.94	19.89
2	Anita MÁRTON	HUN	15 Jan 89	2	19.49	18.50	18.89	18.65	6	18.33	18.54	19.49
3	Michelle CARTER	USA	12 Oct 85	7	19.14	18.82	18.86	19.14	7	19.03	X	18.97
4	Danniel THOMAS-DODD	JAM	11 Nov 92	11	18.91	18.70	X	18.76	5	18.56	18.91	18.76
5	Yang GAO	CHN	1 Mar 93	6	18.25	18.03	18.00	17.79	2	18.22	18.11	18.25
6	Brittany CREW	CAN	6 Mar 94	4	18.21	17.52	18.21	17.71	4	X	X	X
7	Yuliya LEANTSIUK	BLR	31 Jan 84	12	18.12	17.84	X	18.12	3	X	X	17.51
8	Yaniuvis LÓPEZ	CUB	1 Feb 86	9	18.03	17.28	17.98	18.03	1	X	17.46	X
9	Geisa ARCANJO	BRA	19 Sep 91	8	18.03	17.93	X	18.03				
10	Raven SAUNDERS	USA	15 May 96	10	17.86	X	13.75	17.86				
11	Melissa BOEKELMAN	NED	11 May 89	3	17.73	17.61	17.73	X				
12	Ka BIAN	CHN	5 Jan 93	1	17.60	17.60	X	X				

Timing and Measurement by SEIKO — AT-SP-W-f--A--.RS1..v1 — Issued at 21:29 on Wednesday, 09 August 2017

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METHODS

Three vantage locations for camera placements were identified and secured at strategic locations around the stadium. A total of three high-speed cameras were used to record the action during the shot put final. Three Sony PXW-FS7 cameras operating at 150 Hz (shutter speed: 1/1250; ISO: 2000-4000 depending on the light; FHD: 1920x1080 px) were positioned at the three locations to provide three-dimensional (3D) footage for the analysis of all key phases of the shot put throw.

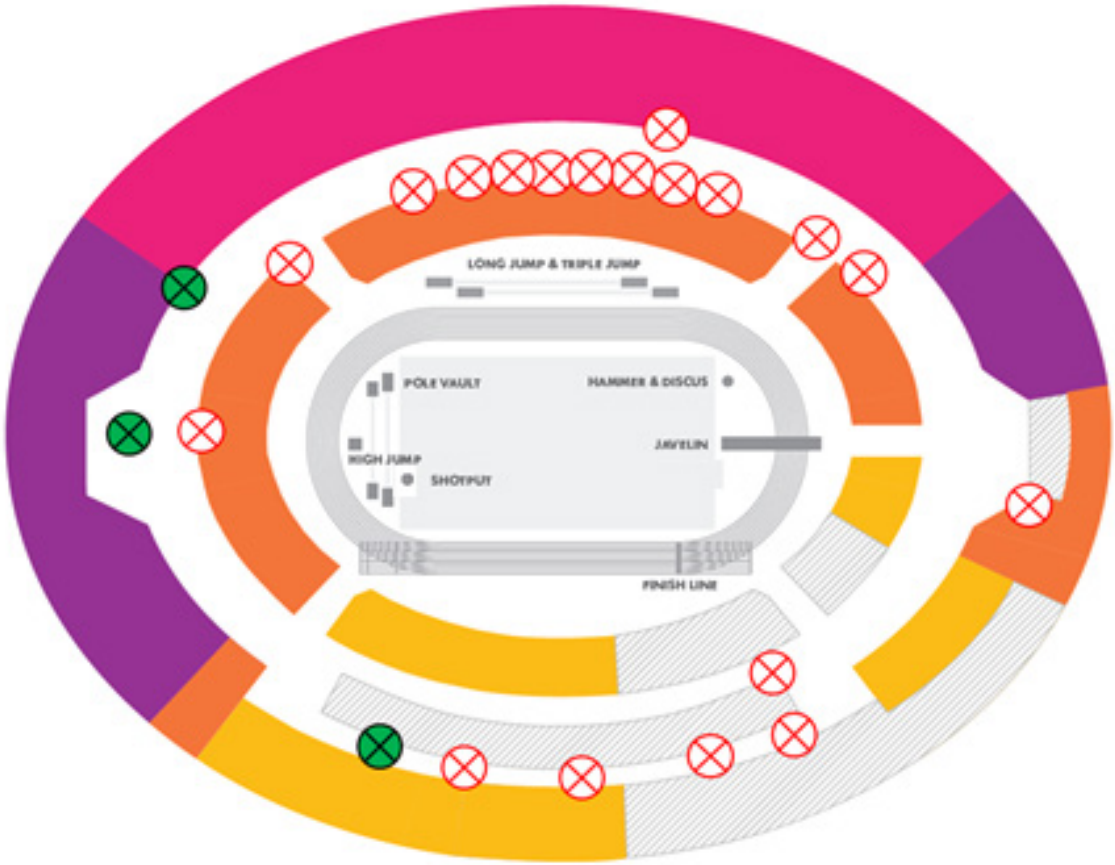

Figure 1. Stadium layout with camera locations for the women's shot put (shown in green).

Before and after the final competition, a calibration procedure was conducted to capture the performance volume. A rigid cuboid calibration frame was positioned around the throwing circle providing an accurate volume within which athletes performed the throwing movement. This approach produced a large number of non-coplanar control points within the calibrated volume to facilitate the construction of a global coordinate system.

Figure 2. The calibration frame was constructed and recorded before and after the competition.

All 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. Each video file was synchronised at critical instants to synchronise the two-dimensional coordinates from each camera involved in the recording. The shot was digitised 15 frames before the movement was initiated within the start position and 10 frames after release to provide padding during filtering. Discrete and temporal kinematic characteristics were also digitised at key events. All video files were digitised frame by frame and upon completion points over frame method was used to make any necessary adjustments, where the shot was tracked at each point through the full motion. The Direct Linear Transformation (DLT) algorithm was used to reconstruct the real-world 3D coordinates from individual camera's x and y image coordinates. The reliability of the manual digitising was estimated by repeated digitising of a whole throw with an intervening period of 48 hours. Results showed minimal systematic and random errors and therefore confirmed the high reliability of the digitising process.

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. Release parameters were used to mathematically calculate the projectile's range, which was subsequently compared to the officially published distance. The minor but expected differences between the calculated range and the measured distance confirmed the high level of accuracy of the data analysis process. Where available, athletes' heights and weights were obtained from 'Athletics 2017' (edited by Peter Matthews and published by the Association of Track and Field Statisticians), and online sources.

Table 1. Definitions of variables examined in the shot put.

Variable	Definition
Release velocity	The resultant velocity of the shot at release.
Angle of release	The angle between the shot direction of travel and the horizontal at release.
Height of release	The vertical distance from the shot centre to the ground at release.
Reach over stop board	The horizontal distance of shot to the stop board at release.
Path length of the shot	The shot's cumulative distance travelled across the circle.
Height of shot	The vertical position of the shot at key phases of the movement.
Velocity of shot	The resultant velocity of the shot at key phases of the movement.
Length of glide or flight phase	The anteroposterior distance travelled across the circle in the glide phase or flight phase.
Foot distance in power position	The anteroposterior distance between the two feet in the power position.
Duration of key phases	The total time taken to perform each key phase.
Forward-backward trunk lean at release (α)	The forward-backward trunk lean signifies the angle to the vertical (see Figure 4). Therefore, 0° identifies the trunk to be positioned vertically, whereas a positive angle identifies that the trunk is leaning towards the front of the circle (e.g. forward trunk lean). In contrast, a negative angle represents the trunk is leaning towards the back of the circle (e.g. backwards trunk lean).
Left-right trunk lean at release (β)	The left-right trunk lean signifies the angle to the vertical (see Figure 4). Therefore, 0° identifies the trunk to be positioned vertically, whereas a positive angle identifies that the trunk is leaning towards the right of the circle (e.g. right trunk lean) as viewed from behind. In contrast, a negative angle represents the trunk is leaning towards the left of the circle (e.g. left trunk lean) as viewed from behind.

Shoulder-hip separation angle (γ)	The angle between the line of the shoulders and the line of the hips (see Figure 4), where a negative separation angle indicates that the shoulder axis is ahead of the hip axis in the angular motion path.

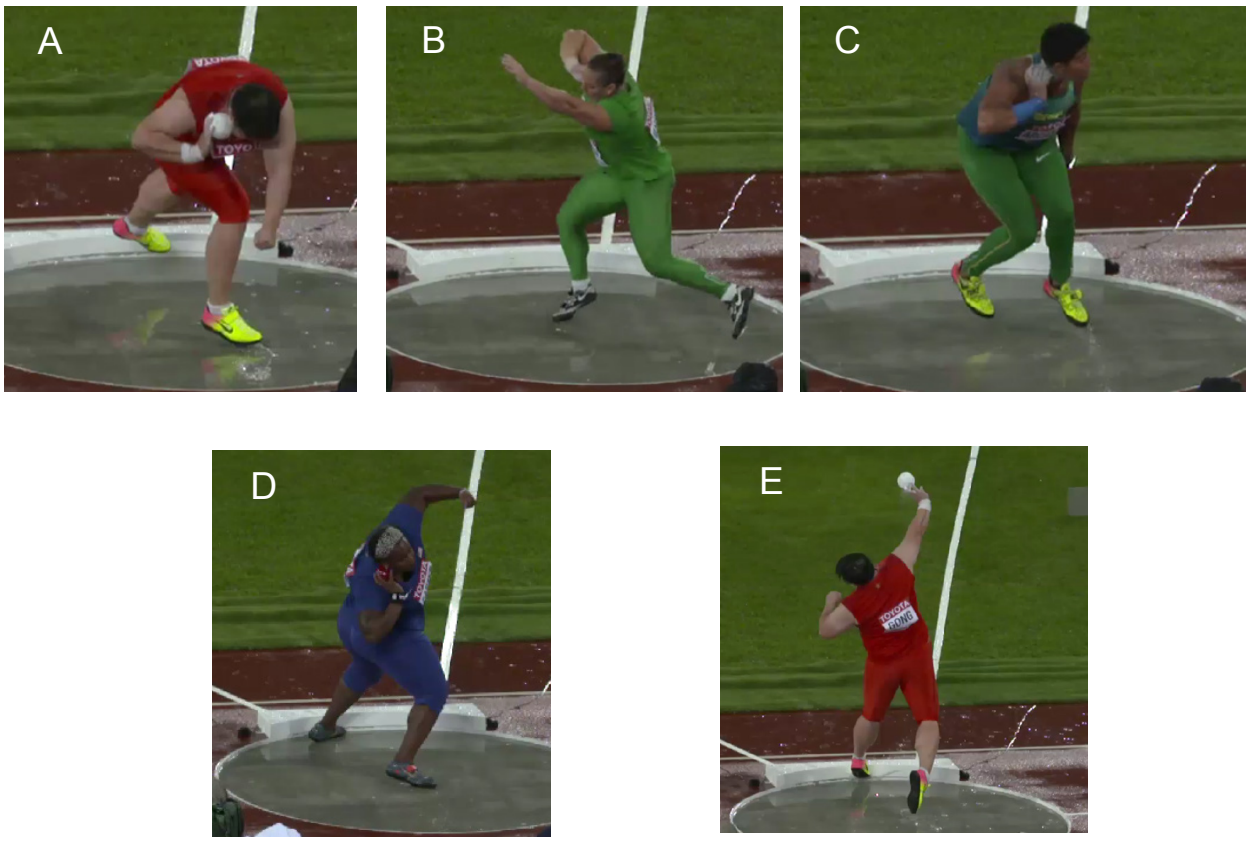

Figure 3. Visual representation of the phases for the three different techniques implemented, the power position and release. A) glide, B) rotational, C) switch glide, D) the power position and E) release.

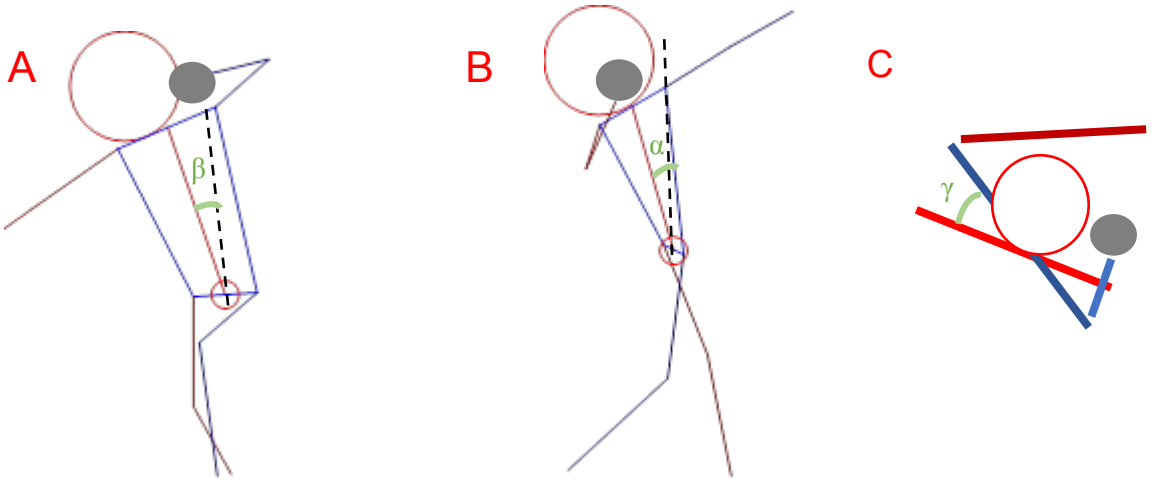

Figure 4. Visual representation of A) left trunk lean (β), B) forward-backward trunk lean (α) and C) shoulder-hip separation angle (γ).

RESULTS

Performance

Table 2 details the twelve finalists' season's (SB) and personal best (PB) throw before the World Championships, as well as a comparison with their performance in both qualifying and the final. Notably, only one of the finalists threw a season's best over the course of the championship and none of the finalists threw personal bests.

Table 2. The measured distances for the season's best (SB), personal best (PB), performance during qualifying (QP), performance during final (FP) and change scores between these variables for the twelve finalists.

Athlete	SB (m)	PB (m)	QP (m)	SB vs. QP (m)	FP (m)	SB vs. FP (m)	PB vs. FP (m)
GONG	20.11	20.43	18.97	−1.14	19.94	−0.17	−0.49
MÁRTON	19.63	19.87	18.76	−0.87	19.49	−0.14	−0.38
CARTER	19.34	20.63	18.92	−0.42	19.14	−0.20	−1.49
THOMAS-DODD	19.15	19.15	18.42	−0.73	18.91	−0.24	−0.24
GAO	18.34	19.20	17.87	−0.47	18.25	−0.09	−0.95
CREW	18.58	18.58	18.01	−0.57	18.21	−0.37	−0.37
LEANTSIUK	18.39	19.79	18.01	−0.38	18.12	−0.27	−1.67
LÓPEZ	18.92	18.92	17.84	−1.08	18.03	−0.89	−0.89
ARCANJO	18.08	19.02	17.79	−0.29	18.03	−0.05	−0.99
SAUNDERS	19.76	19.76	18.63	−1.13	17.86	−1.90	−1.90
BOEKELMAN	18.66	18.66	17.88	−0.78	17.73	−0.93	−0.93
BIAN	18.18	18.71	18.18	0.53	17.60	−0.58	−1.11

Anthropometric data and implemented technique

Table 3 details that seven of the twelve finalists utilised the glide technique, whereas only four of the finalists utilised the rotational technique. Interestingly, Arcanjo utilised a switch glide technique, whereby she switched her legs during the airborne phase of the glide (see Figure 3).

Table 3. The anthropometric data and implemented technique for the twelve finalists.

Athlete	Height (m)	Body mass (kg)	Technique
GONG	1.74	110	Glide
MÁRTON	1.71	84	Rotational
CARTER	1.75	110	Glide
THOMAS-DODD	1.66	89	Rotational
GAO	1.78	110	Glide
CREW	1.78	111	Rotational
LEANTSIUK	1.85	80	Glide
LÓPEZ	1.80	71	Glide
ARCANJO	1.80	92	Switch Glide
SAUNDERS	1.66	108	Rotational
BOEKELMAN	1.77	66	Glide
BIAN	1.82	115	Glide

Release parameters

Table 4 and Figures 5 and 6 detail the release parameters of the best throws for the twelve finalists. Thomas-Dodd (13.34 m/s) and Márton (13.31 m/s) produced the highest release velocities out of all of the finalists using their rotational technique. However, Gong achieved the third highest release velocity (13.24 m/s) using the glide technique, although she compensated her lower release velocity by optimising her angle of release (37.0°), height of release (2.08 m) and reach over stop board (0.09 m). Similarly, Carter achieved the fourth highest release velocity (12.95 m/s) using the glide technique, whereas she reached the furthest over the stop board (0.18 m) and the highest height of release expressed as a percentage of her body height (121%). In general, the athletes who utilised the rotational technique leant slightly backwards (rotational mean: −4 ± 2°) and towards the right (rotational mean: 1 ± 8°) at release. In contrast, the athletes who utilised the glide technique on the whole leant slightly forward (glide mean: 6 ± 6°) and towards the left (glide mean: −15 ± 8°).

Table 4. The release parameters of the best throws for the twelve finalists.

Athlete	Analysed throw	Result (m)	Release velocity (m/s)	Angle of release (°)	Release height (m)	Release height relative to body height (%)	Reach over stop board (m)	FB trunk lean at release (°)	LR trunk lean at release (°)
GONG	5	19.94	13.24	37.0	2.08	119	0.09	8	−21
MÁRTON	6	19.49	13.31	35.0	1.91	112	−0.02	−2	4
CARTER	3	19.14	12.95	35.4	2.11	121	0.18	6	−20
THOMAS-DODD	5	18.91	13.34	33.0	1.89	114	0.00	−2	−10
GAO	6	18.25	12.64	38.1	2.00	112	−0.14	−6	−4
CREW	2	18.21	12.63	39.3	1.98	111	0.13	−7	9
LEANTSIUK	3	18.12	12.44	37.7	2.11	114	0.08	3	−8
LÓPEZ	3	18.03	12.59	35.8	2.09	116	0.01	13	−24
ARCANJO	3	18.03	12.37	35.3	2.08	115	0.17	6	−13
SAUNDERS	3	17.86	12.50	41.0	1.97	119	−0.03	−5	1
BOEKELMAN	2	17.73	12.48	34.4	2.05	116	0.10	5	−17
BIAN	1	17.60	12.35	36.6	2.05	113	−0.06	11	−17

***Key**: FB = forward-backward and LR = left-right lean.*

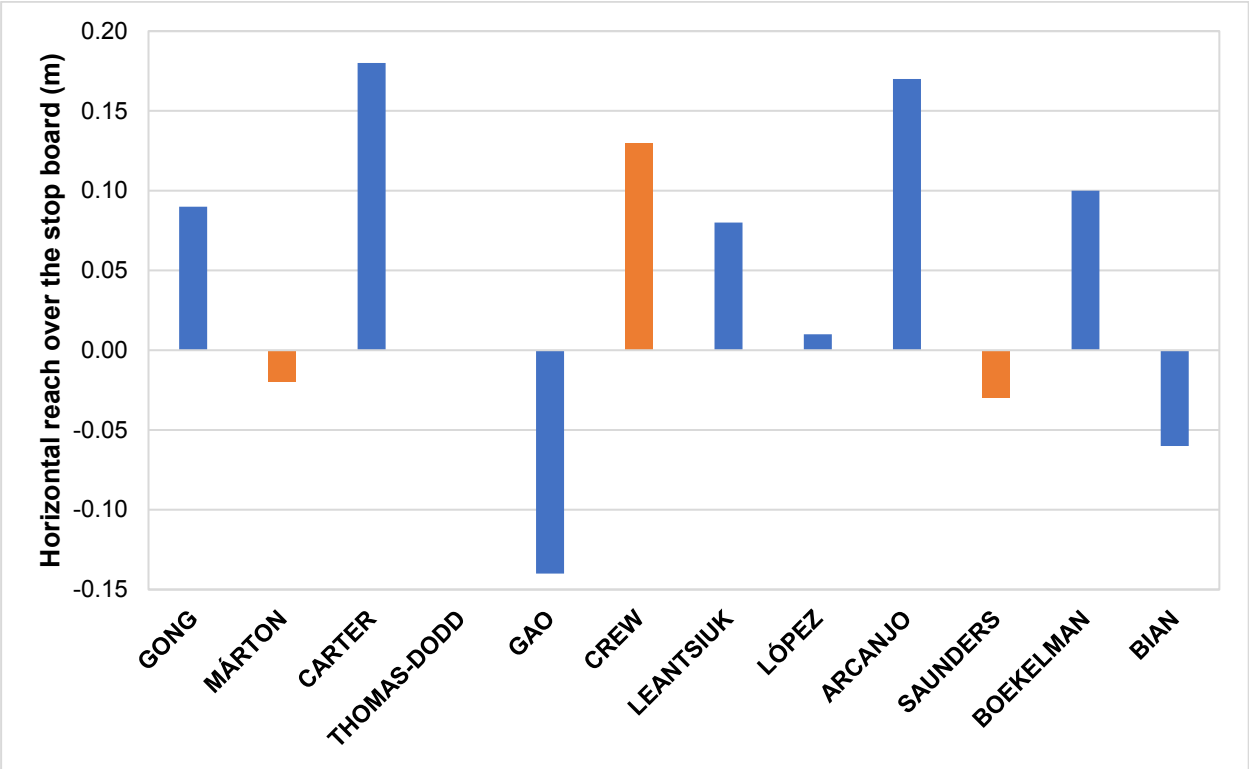

Figure 5. The reach over stop board for the twelve finalists. The orange bars signify the athletes who utilised the rotational technique and the blue bars signify the athletes who utilised the glide technique.

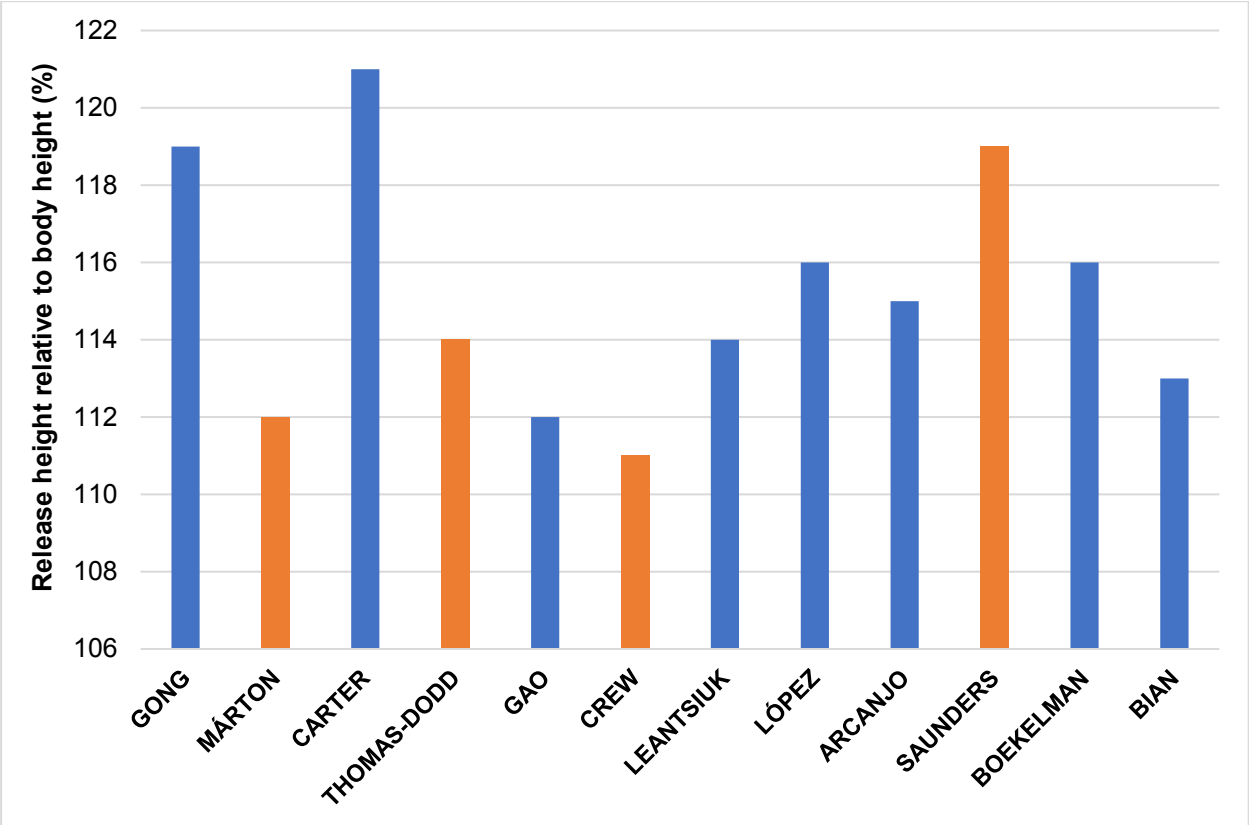

Figure 6. The height of release expressed as a percentage of body height for the twelve finalists. The reach over stop board for the twelve finalists. The orange bars signify the athletes who utilised the rotational technique and the blue bars signify the athletes who utilised the glide technique.

Velocity of the shot

Figure 7 provides a visual description of each key phase in the glide technique. Table 5 details the resultant velocity of the shot at key phases for the athletes who utilised the glide technique.

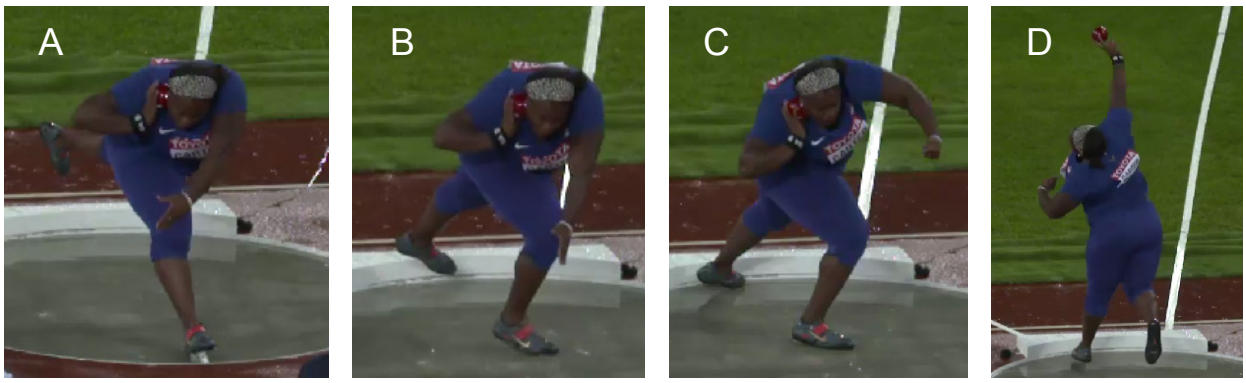

Figure 7. Visual description for each of the key phases in the glide technique: A) right leg push-off, B) right leg touchdown, C) brace leg touchdown and D) release.

Table 5. The velocity of the shot at the key phases for the switch glide and seven glide athletes.

Athlete	Right leg push-off (m/s)	Right leg touch down (m/s)	Brace leg touch down (m/s)	Right leg take-off (m/s)	Brace leg take-off (m/s)	Release (m/s)
GONG	2.48	2.26	2.58	6.78	12.17	13.24
CARTER	2.17	2.77	2.59	6.59	13.04	12.95
GAO	2.60	2.72	2.48	8.19	9.32	12.64
LEANTSIUK	2.50	2.02	3.05	6.22	8.65	12.44
LÓPEZ	3.09	2.65	2.64	7.62	9.68	12.59
ARCANJO	2.78	2.53	2.28	7.28	11.84	12.37
BOEKELMAN	2.46	2.32	2.72	6.09	12.09	12.48
BIAN	2.51	2.59	2.69	3.58	8.88	12.35

Table 5 and Figure 8 detail the resultant velocity of the shot at key phases for the athletes that utilised the glide technique. Gong gained the most velocity (10.66 m/s) within the power position in comparison with the other finalists who utilised the glide technique. Interestingly, all of the athletes that utilised the glide technique delivered the shot without being in contact with the ground. Furthermore, all of these athletes delivered the shot utilising the same sequence, whereby the right leg took off before the brace leg. Notably, Carter gained the most velocity (6.45 m/s) between the right leg take-off and the brace leg take-off, although unlike the other glide athletes Carter actually lost velocity (−0.09 m/s) between the brace leg take-off and release.

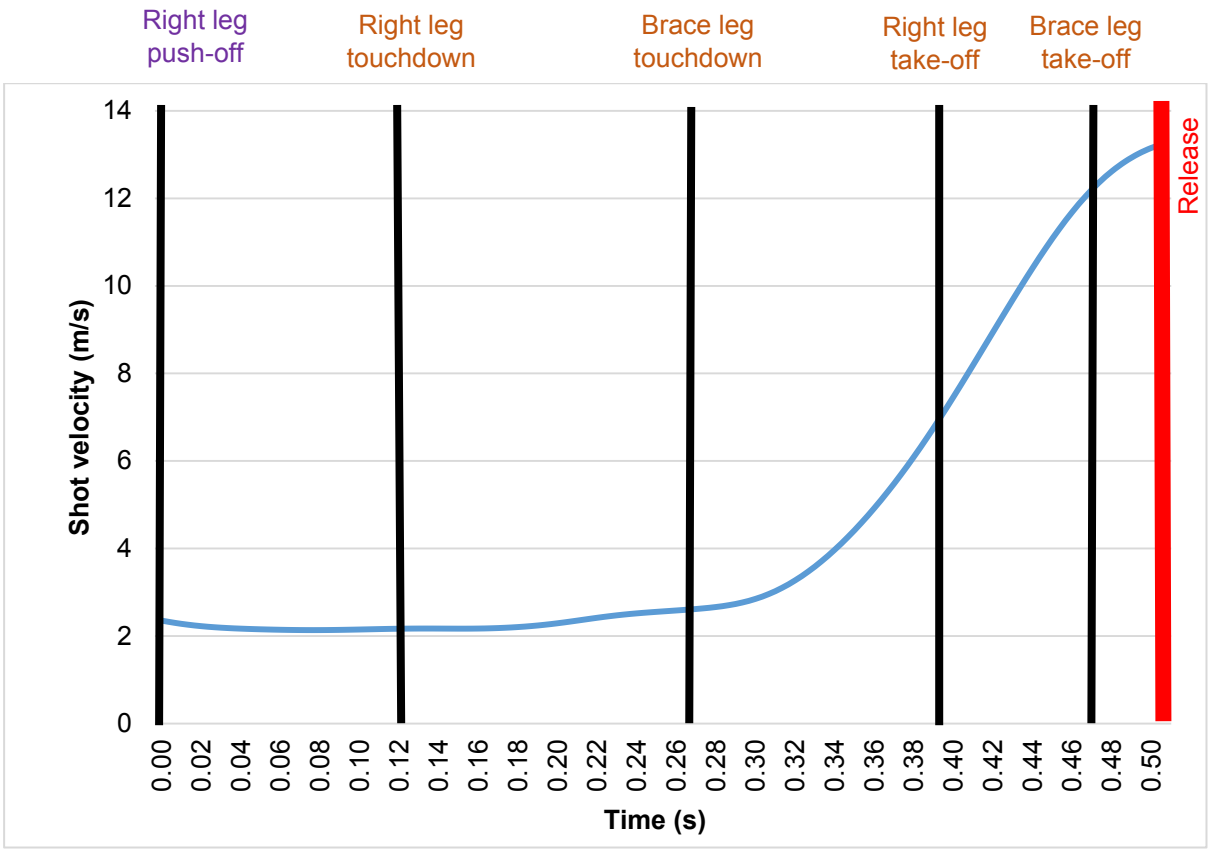

Figure 8. Gong's velocity profile of the shot from right leg push-off to release.

Figure 9 provides a visual description of each key phase in the rotational technique. Table 6 and Figure 10 detail the resultant velocity of the shot at key phases for the athletes that utilised the rotational technique.

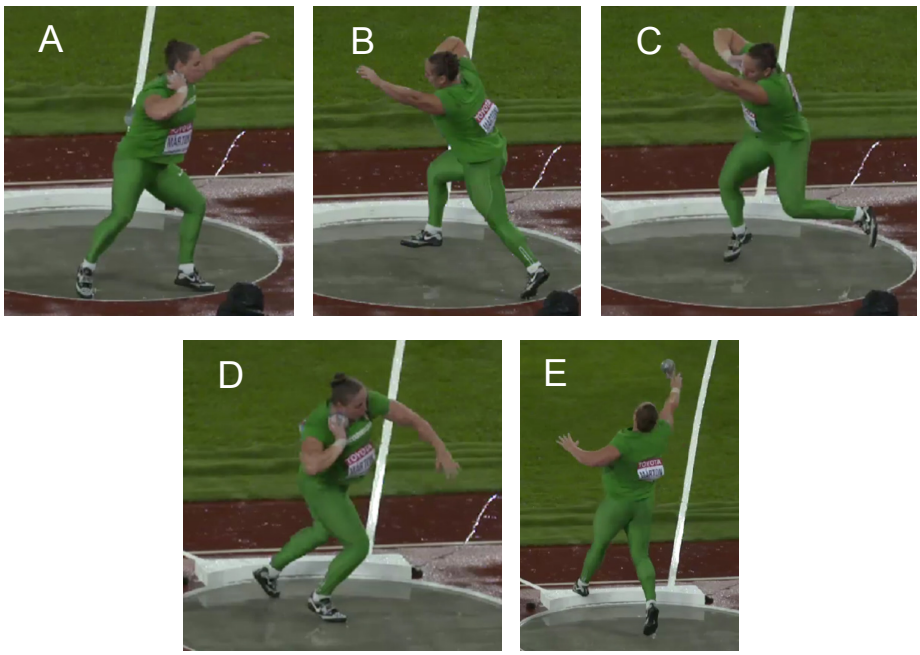

Figure 9. Visual description for each of the key phases in the rotational technique: A) right leg push off, B) left leg push-off, C) right leg touchdown, D) brace leg touchdown and E) release.

Table 6. The velocity of the shot at the key phases for the four rotational athletes.

Athlete	Right leg push-off (m/s)	Left leg push-off (m/s)	Right leg touchdown (m/s)	Brace leg touchdown (m/s)	Rear leg take-off (m/s)	Brace leg take-off (m/s)	Release (m/s)
MÁRTON	1.62	1.60	1.39	1.41	11.43	10.39	13.31
THOMAS-DODD	1.22	1.45	1.54	2.68	7.62	11.49	13.34
CREW	1.26	2.20	1.71	2.13	5.83	11.00	12.63
SAUNDERS	1.88	1.22	1.93	0.78	10.94	7.98	12.50

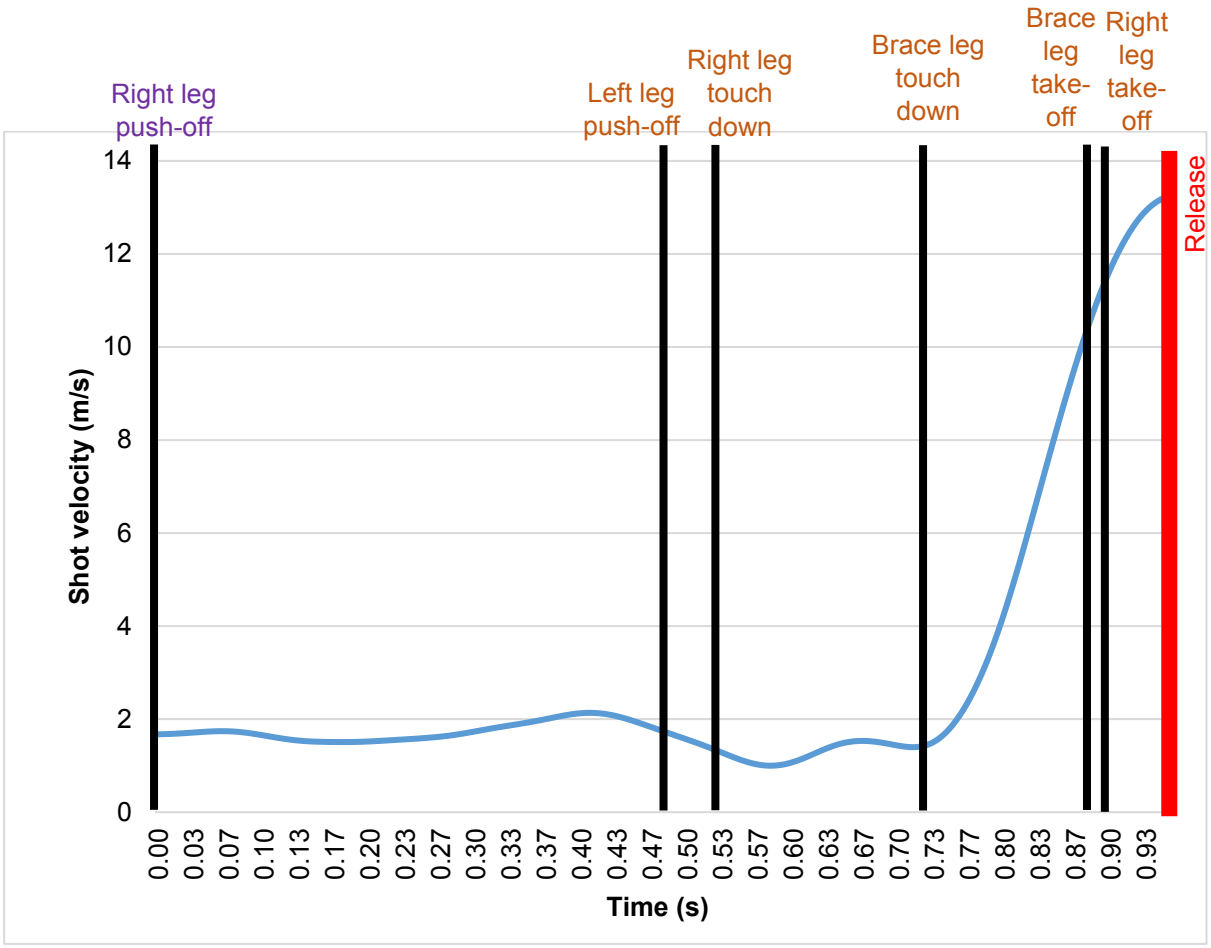

Figure 10. Márton's velocity profile of the shot from right leg push-off to release.

Márton gained the most velocity (12.31 m/s) within the power position in comparison with the four finalists who utilised the rotational technique. Interestingly, all of the four athletes that utilised the rotational technique delivered the shot without being in contact with the ground. Thomas-Dodd and Crew delivered the shot utilising a sequence whereby the right leg took off before the brace leg, whereas Márton and Saunders delivered the shot utilising a different sequence (brace leg

take-off and then right leg take-off). Notably, Márton gained the least velocity (1.04 m/s) between the brace leg take-off and the right leg take-off, whereas she gained the most velocity (1.88 m/s) between the right leg take-off and release.

Path of the shot during the key phases

The following page contains Figure 11, which shows the individual motion path (from a superior view) for the athletes who utilised the glide technique. Following Figure 10, Table 7 shows the path length of the shot through each key phase of the glide technique. The path length represents the shot's cumulative distance travelled across the circle.

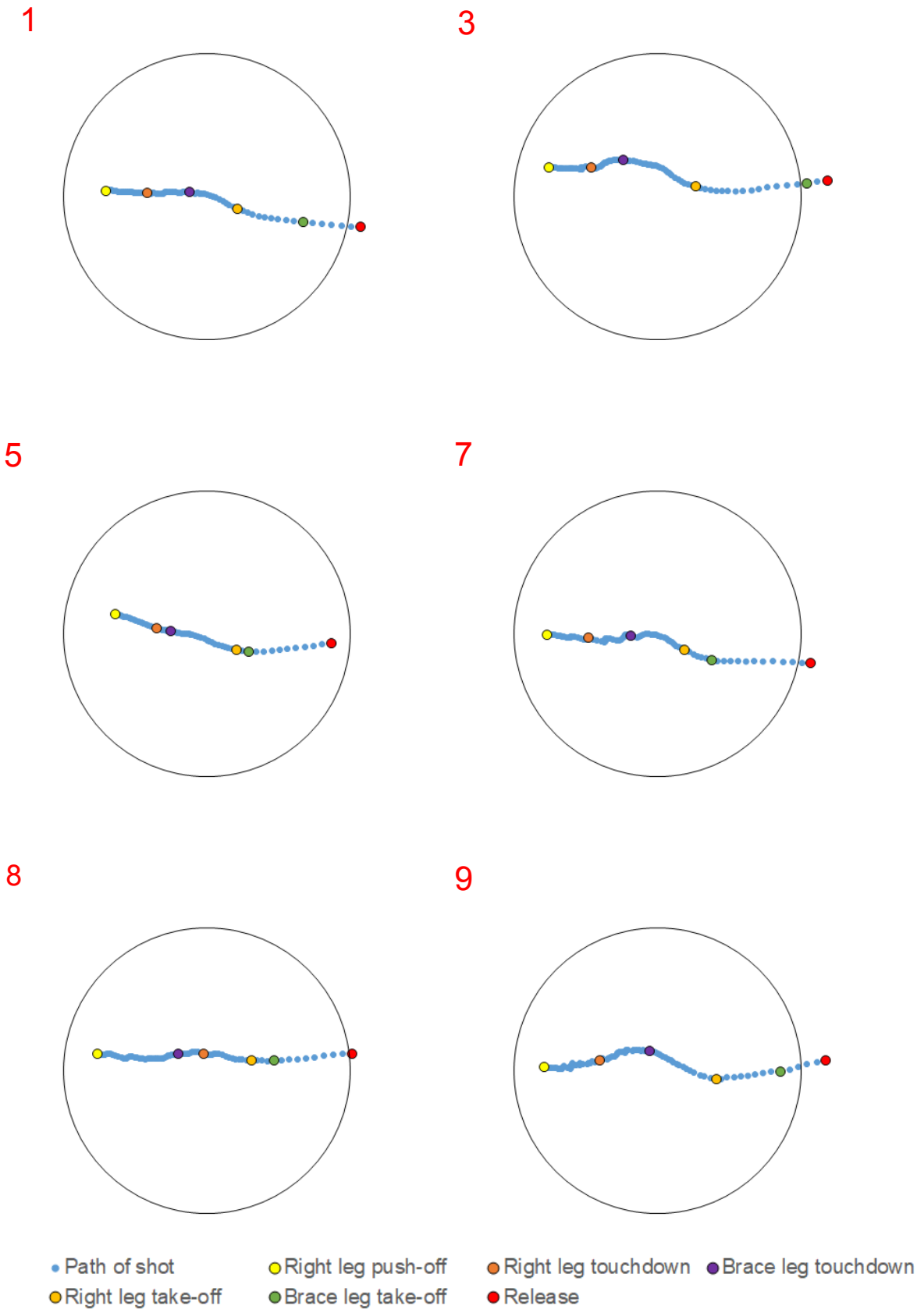

Figure 11. A visual representation from a superior view of the path of the shot from right leg push-off to release. Key: 1) Gong, 3) Carter, 5) Gao, 7) Leantsiuk, 8) Lopez, 9) Arcanjo, 11) Boekelman and 12) Bian.

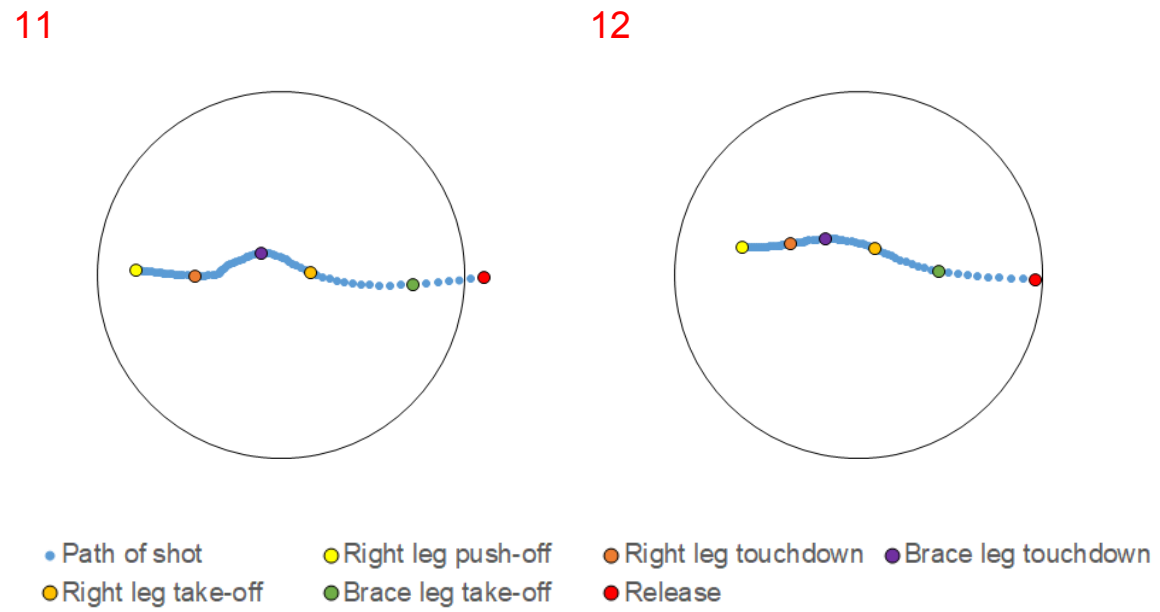

Figure 11 continued. A visual representation from a superior view of the path of the shot from right leg push-off to release. Key: 1) Gong, 3) Carter, 5) Gao, 7) Leantsiuk, 8) López, 9) Arcanjo, 11) Boekelman and 12) Bian.

Table 7. The path length of the shot depicting the key phases for the switch glide and seven glide athletes.

Athlete	Right leg push-off to right leg touchdown (m)	Right leg touchdown to brace leg touchdown (m)	Brace leg touchdown to release (m)	Total path (m)
GONG	0.26	0.57	1.43	2.26
CARTER	0.33	0.24	1.85	2.42
GAO	0.32	0.11	1.56	1.99
LEANTSIUK	0.32	0.35	1.76	2.43
LÓPEZ	0.39	0.22	1.65	2.26
ARCANJO	0.41	0.38	1.59	2.38
BOEKELMAN	0.34	0.41	1.57	2.32
BIAN	0.31	0.19	1.47	1.97

The following page contains Figure 12, which shows the individual motion path (from a superior view) for the athletes who utilised the rotational technique. Following Figure 12, Table 8 shows the path length of the shot through each key phase of the rotational technique. The path length represents the shot's cumulative distance travelled across the circle.

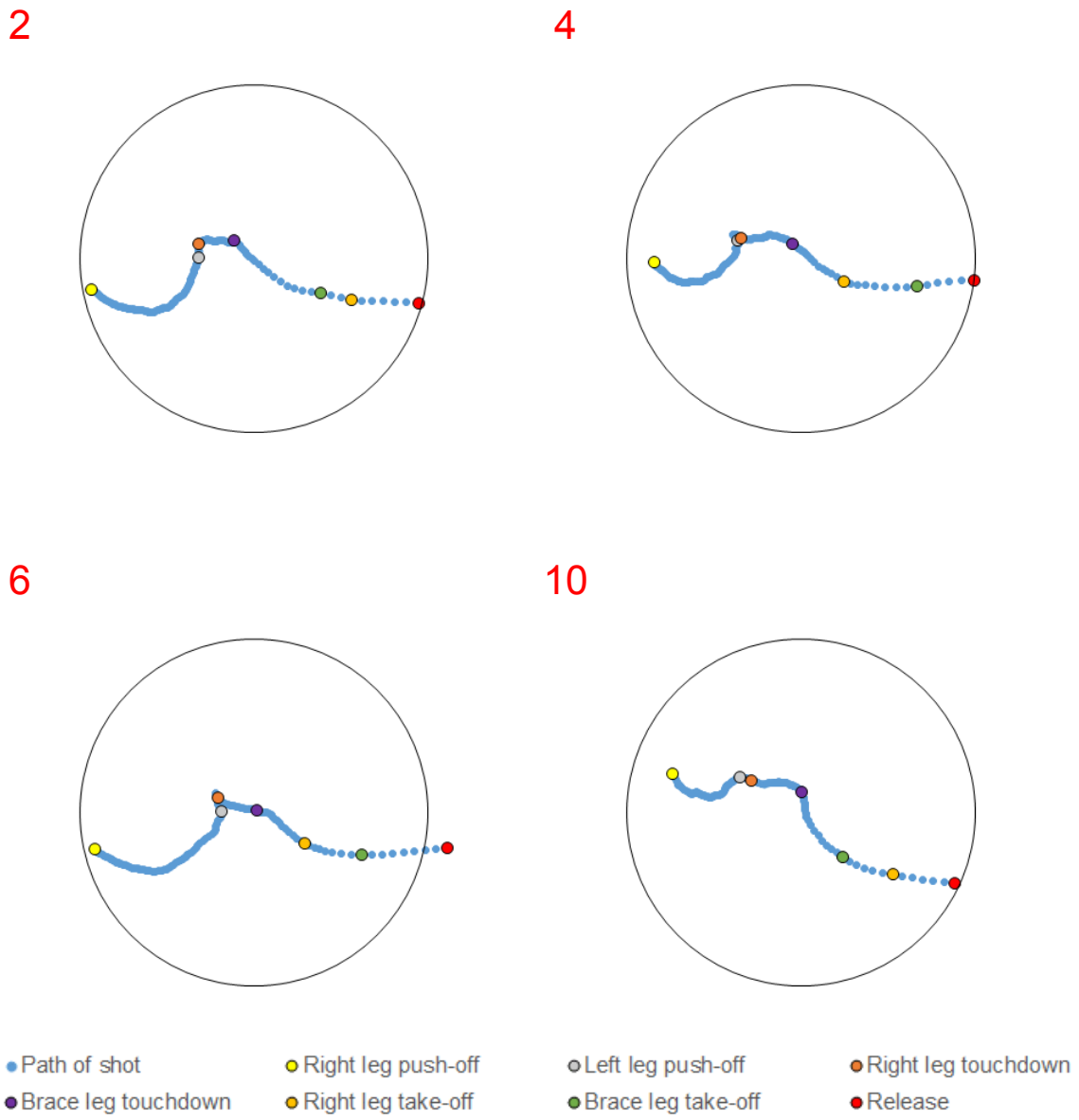

Figure 12. A visual representation from a superior view of the path of the shot from right leg push-off to release. Key: 2) Márton, 4) Thomas-Dodd, 6) Crew, 10) Saunders.

Table 8. The total path length of the shot depicting the key phases for the four rotational athletes.

Athlete	Right leg push off to left leg push-off (m)	Left leg push-off to right leg touchdown (m)	Right leg touchdown to left leg touchdown (m)	Left leg touchdown to release (m)	Total path (m)
MÁRTON	0.86	0.08	0.26	1.42	2.62
THOMAS-DODD	0.70	0.10	0.34	1.39	2.53
CREW	0.98	0.10	0.34	1.47	2.89
SAUNDERS	0.53	0.07	0.33	1.39	2.32

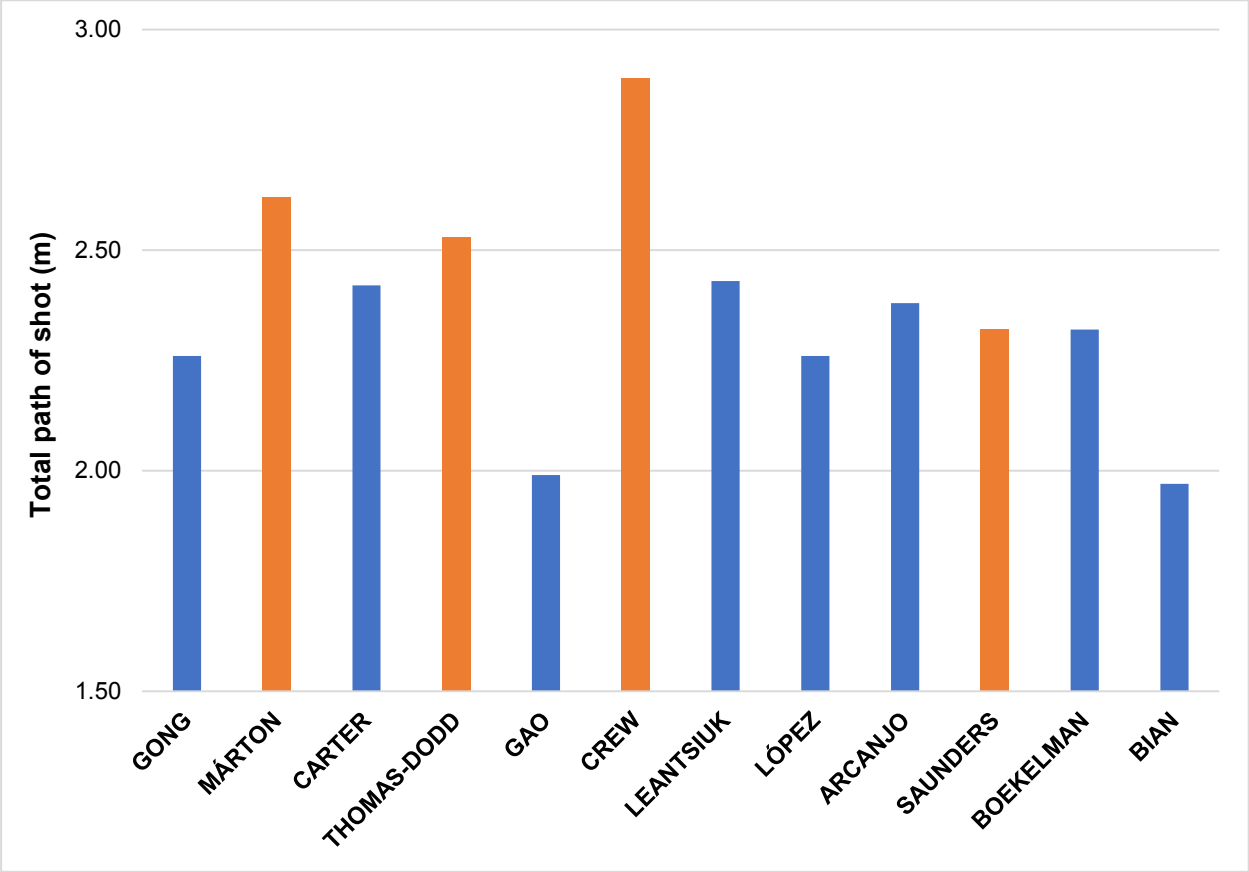

Figure 13. The total path length of shot for the twelve finalists. The reach over stop board for the twelve finalists. The orange bars signify the athletes who utilised the rotational technique and the blue bars signify the athletes who utilised the glide technique.

Figure 14 and Table 9 detail the height of the shot for the athletes that utilised the glide technique. Notably, Gong gained the most height (1.17 m) across the circle, which was identified from the right foot push-off to release. Figure 14 and Table 10 detail the height of the shot for the athletes that utilised the rotational technique. Interestingly, Márton gained the least height (0.61 m) across the circle, which was identified from the left foot push-off to release.

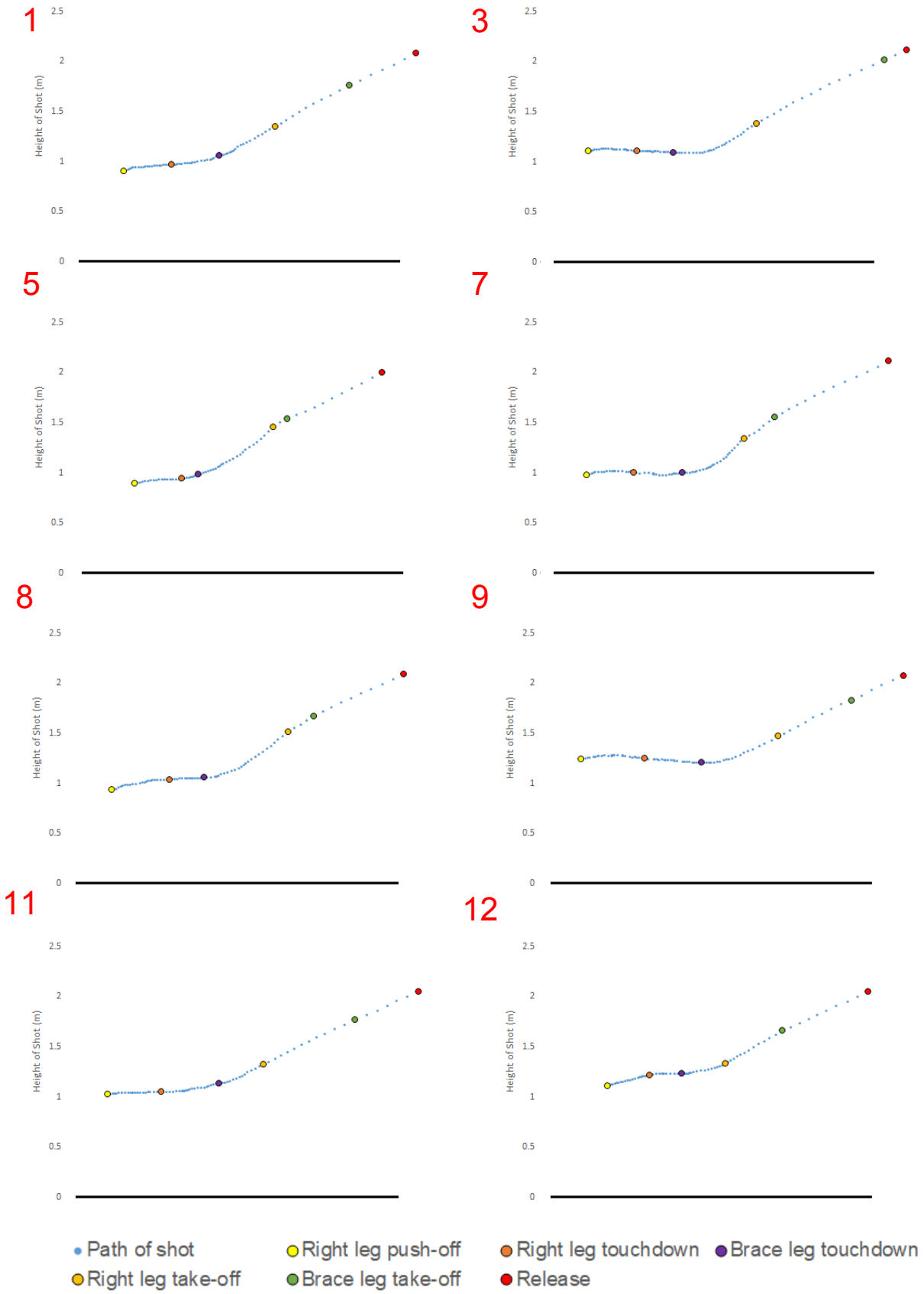

Figure 14. A visual representation from a side on view of the path of the shot from right leg push-off to release. Key: 1) Gong, 3) Carter, 5) Gao, 7) Leantsiuk, 8) López, 9) Arcanjo, 11) Boekelman and 12) Bian.

Table 9. The height of the shot at key phases for the switch glide and seven glide athletes.

Athlete	Right leg push-off (m)	Right leg touchdown (m)	Brace leg touchdown (m)	Release (m)
GONG	0.91	0.97	1.06	2.08
CARTER	1.11	1.11	1.10	2.11
GAO	0.89	0.94	0.98	2.00
LEANTSIUK	0.98	1.00	1.00	2.11
LÓPEZ	0.94	1.04	1.06	2.09
ARCANJO	1.24	1.25	1.21	2.08
BOEKELMAN	1.03	1.05	1.13	2.05
BIAN	1.11	1.22	1.24	2.05

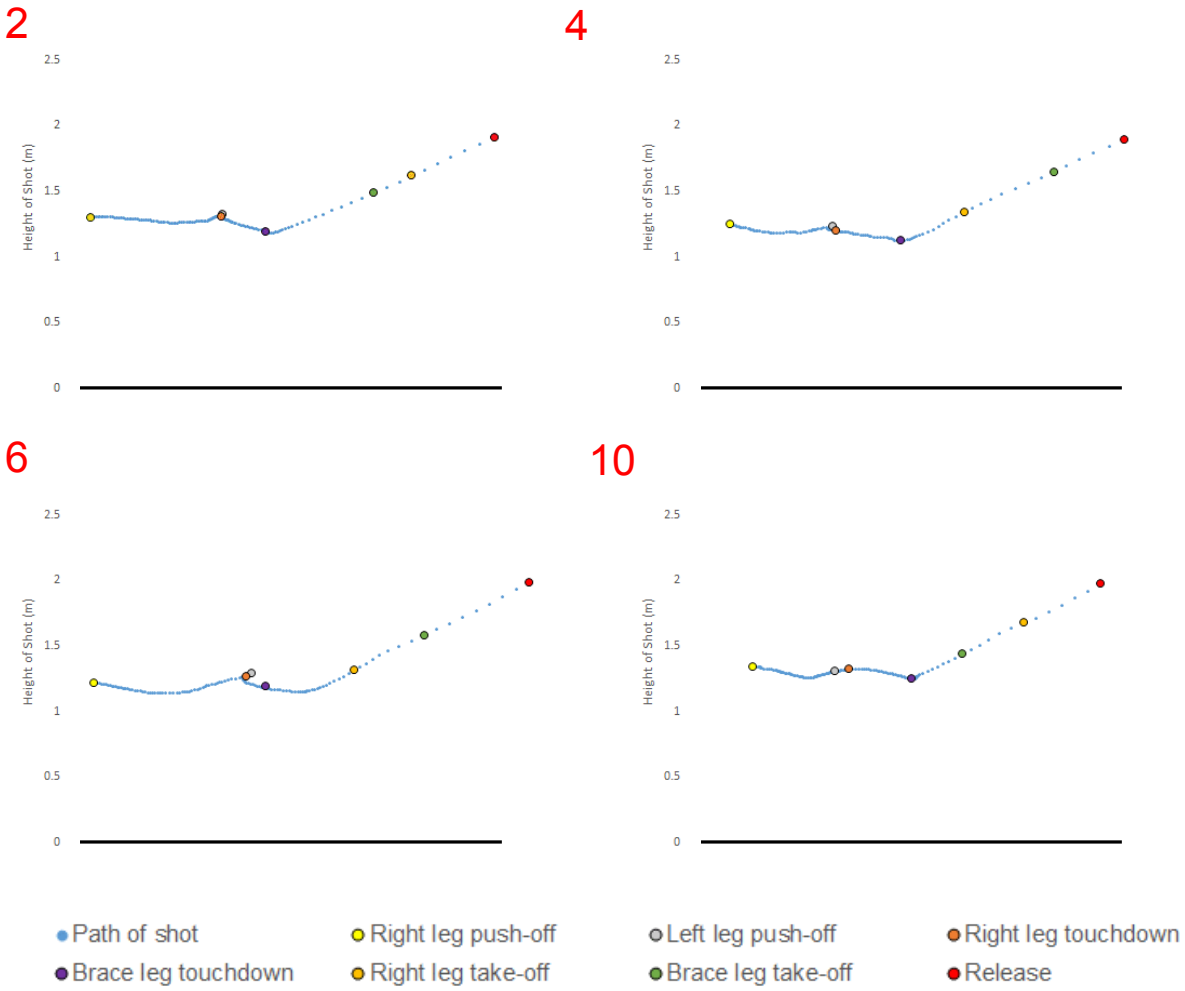

Figure 14. A visual representation from a side on view of the path of the shot from right leg push-off to release. Key: 2) Márton, 4) Thomas-Dodd, 6) Crew and 10) Saunders.

Table 10. The height of the shot at key phases for the four rotational athletes.

Athlete	Right leg push-off (m)	Left leg push-off (m)	Right leg touchdown (m)	Brace leg touchdown (m)	Release (m)
MÁRTON	1.30	1.33	1.30	1.19	1.91
THOMAS-DODD	1.25	1.23	1.20	1.12	1.89
CREW	1.22	1.29	1.26	1.15	1.98
SAUNDERS	1.34	1.31	1.32	1.25	1.97

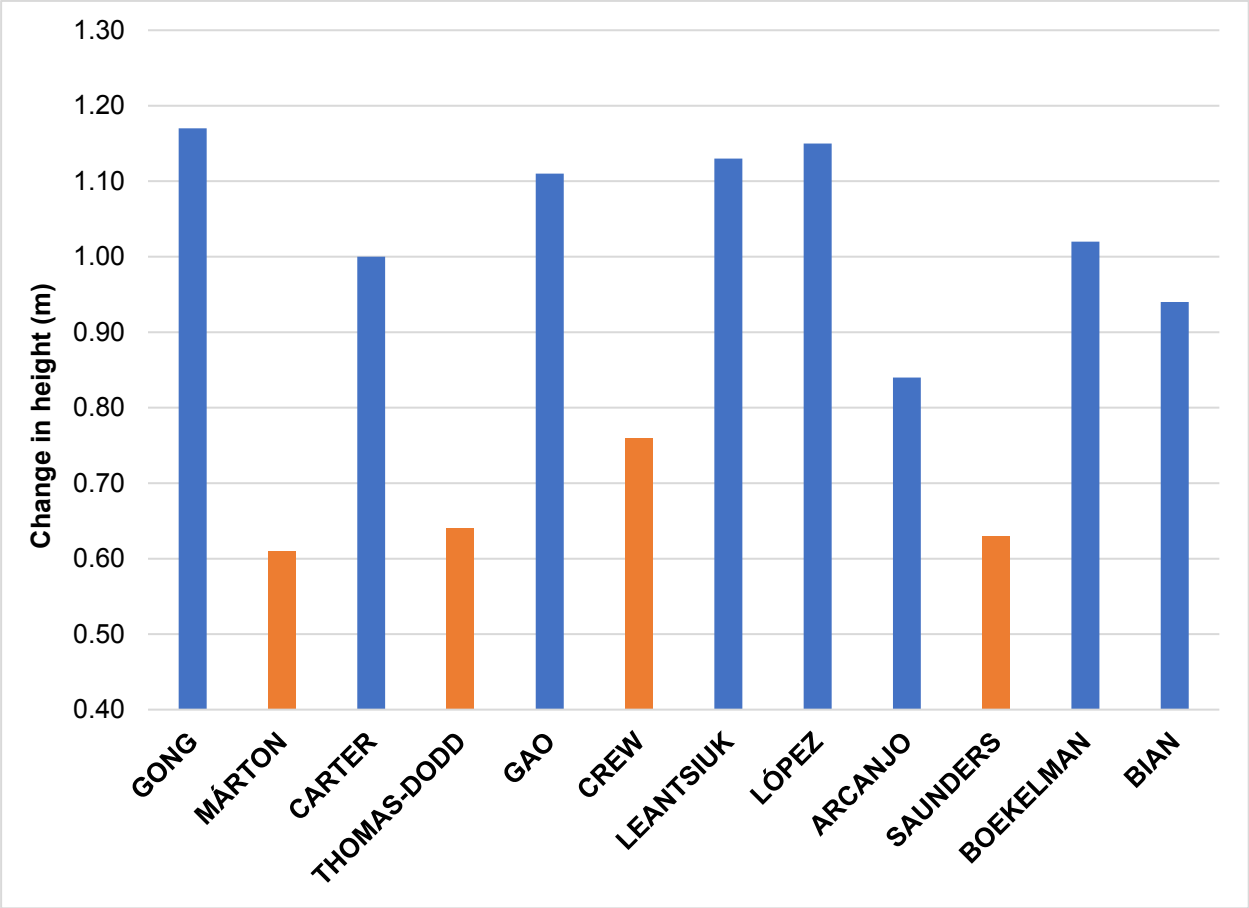

Figure 15. The height gained from toe-off to release for the twelve finalists. The orange bars signify the athletes who utilised the rotational technique and the blue bars signify the athletes who utilised the glide technique.

Duration of key phases

Table 11 and Figure 16 detail the duration between the key phases for the athletes that utilised the glide technique.

Table 11. The duration of the key phases for the switch glide and seven glide athletes.

Athlete	Right leg push-off to right leg touchdown (s)	Right leg touchdown to brace leg touchdown (s)	Brace leg touchdown to release (s)
GONG	0.120	0.153	0.227
CARTER	0.154	0.120	0.293
GAO	0.113	0.054	0.246
LEANTSIUK	0.140	0.127	0.280
LÓPEZ	0.146	0.100	0.254
ARCANJO	0.180	0.154	0.226
BOEKELMAN	0.140	0.160	0.214
BIAN	0.140	0.073	0.253

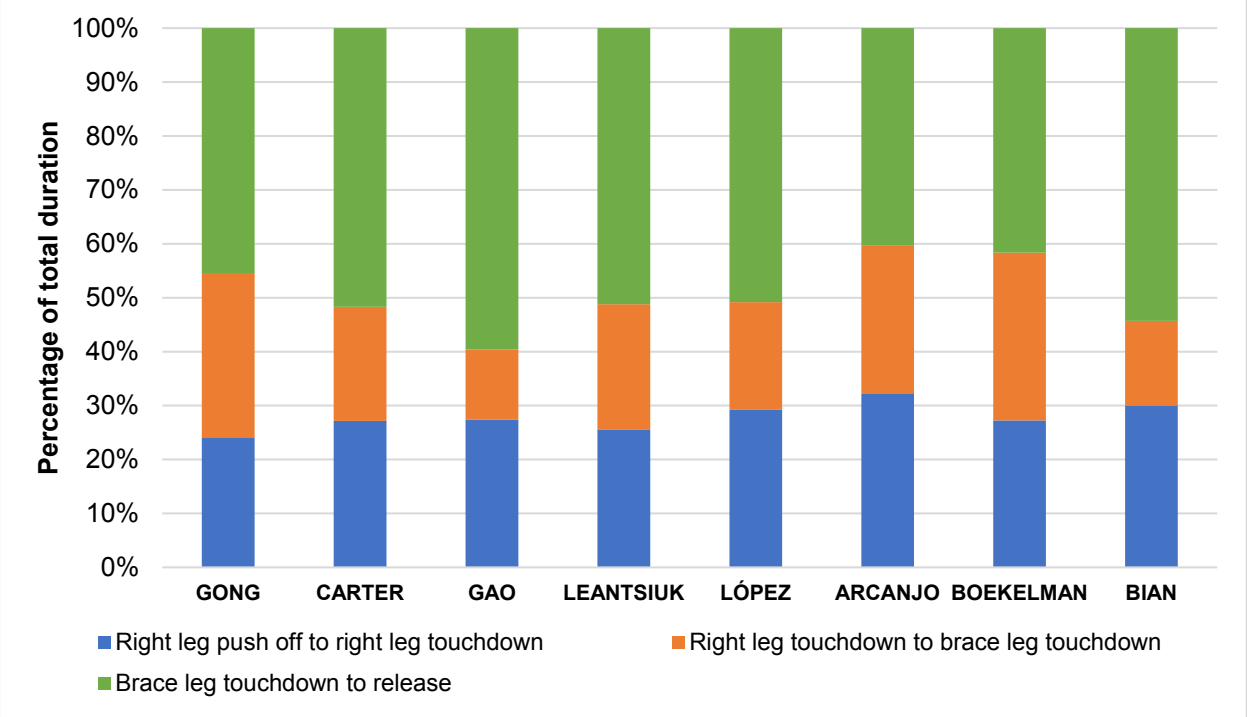

Figure 16. The time taken to perform each of the key phases, which is expressed as a percentage of the total duration for the switch glide and seven glide athletes.

Table 12 and Figure 17 detail the duration between the key phases for the athletes that utilised the rotational techniques.

Table 12. The duration of the key phases for the four rotational athletes.

Athlete	Right leg push-off to left leg push-off (s)	Left leg push-off to right leg touchdown (s)	Right leg touchdown to brace leg touchdown (s)	Brace leg touchdown to release (s)
MÁRTON	0.487	0.053	0.194	0.200
THOMAS-DODD	0.386	0.080	0.194	0.186
CREW	0.460	0.047	0.180	0.240
SAUNDERS	0.413	0.053	0.220	0.220

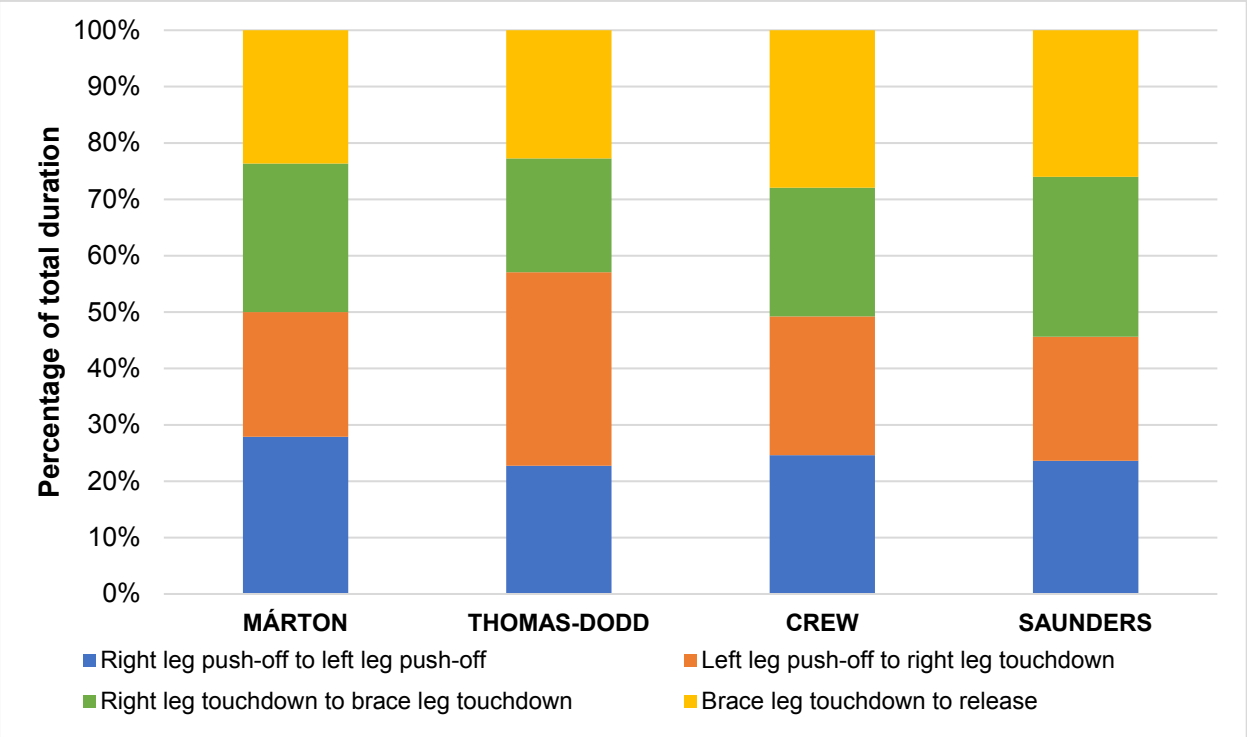

Figure 17. The time taken to perform each of the key phases, which is expressed as a percentage of the total duration for the four rotational athletes.

Distance travelled across the circle

Table 13. The distance travelled in the glide / flight phase and power position for the twelve finalists.

Athlete	Distance of glide / flight phase (m)	Distance in power position (m)	Total distance in glide / flight phase (%)	Total distance in power position (%)
GONG	0.66	1.27	34	66
MÁRTON	0.96	0.61	61	39
CARTER	0.78	1.15	40	60
THOMAS-DODD	0.87	0.80	52	48
GAO	0.76	0.98	44	56
CREW	0.97	0.78	55	45
LEANTSIUK	0.78	1.24	39	61
LÓPEZ	1.04	0.98	51	49
ARCANJO	1.06	0.94	53	47
SAUNDERS	1.14	0.59	66	34
BOEKELMAN	0.84	1.09	44	56
BIAN	0.77	0.86	47	53

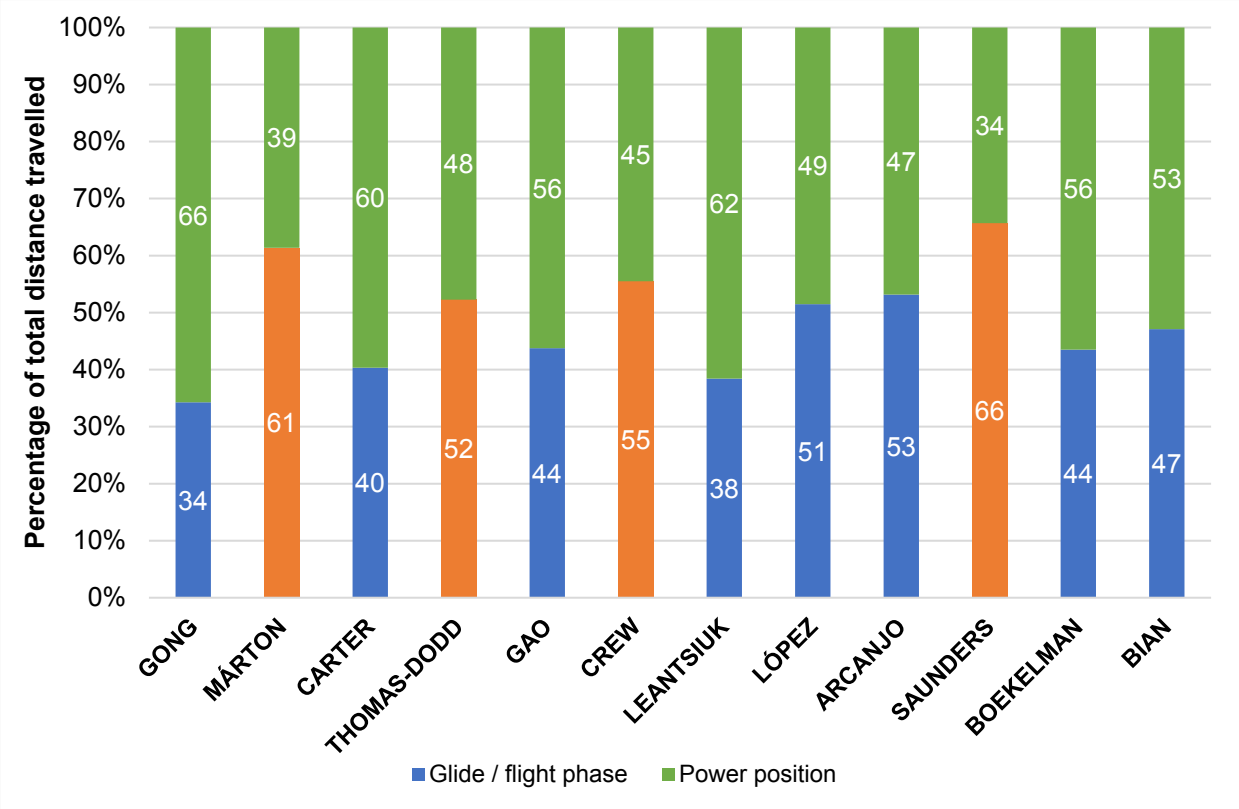

Figure 18. The percentage of total distance travelled in the glide / flight phase and power position for the twelve finalists. The orange bars signify the athletes who utilised the rotational technique and the blue bars signify the athletes who utilised the glide technique.

Shoulder-hip separation angle

Tables 14 and 15, as well as Figures 19 and 20 detail the shoulder-hip separation angle, which represents the angle between the line of the shoulders and the line of the hips. Hence, a negative separation angle indicates that the shoulder axis is ahead of the hip axis in the angular motion path and likewise, a positive separation angle indicates that the hip axis is ahead of the shoulder axis in the angular motion path. All of the finalists released the shot with a negative value and as such the line of their shoulders crossed in front of the line of their hips. Interestingly, Márton and Thomas-Dodd produced some of the smallest changes in shoulder-hip separation within the power position with 64° and 46°, respectively. Interestingly, Gong and Carter produced similar changes in shoulder-hip separation within the power position with 78° and 79°, respectively.

Table 14. The shoulder-hip separation angle at the key phases for the switch glide and seven glide athletes.

Athlete	Right leg push-off (°)	Right leg touchdown (°)	Brace leg touchdown (°)	Release (°)
GONG	25	40	36	−42
CARTER	20	50	59	−20
GAO	31	42	50	−22
LEANTSIUK	28	46	42	−29
LÓPEZ	28	56	46	−18
ARCANJO	−25	0	57	−21
BOEKELMAN	20	54	63	−34
BIAN	9	21	33	−47

Table 15. The shoulder-hip separation angle at the key phases for the four rotational athletes.

Athlete	Right leg push-off (°)	Left leg push-off(°)	Right leg touchdown (°)	Brace leg touchdown (°)	Release (°)
MÁRTON	−4	15	31	39	−25
THOMAS-DODD	14	16	17	35	−11
CREW	15	27	40	46	−38
SAUNDERS	−5	35	51	46	−24

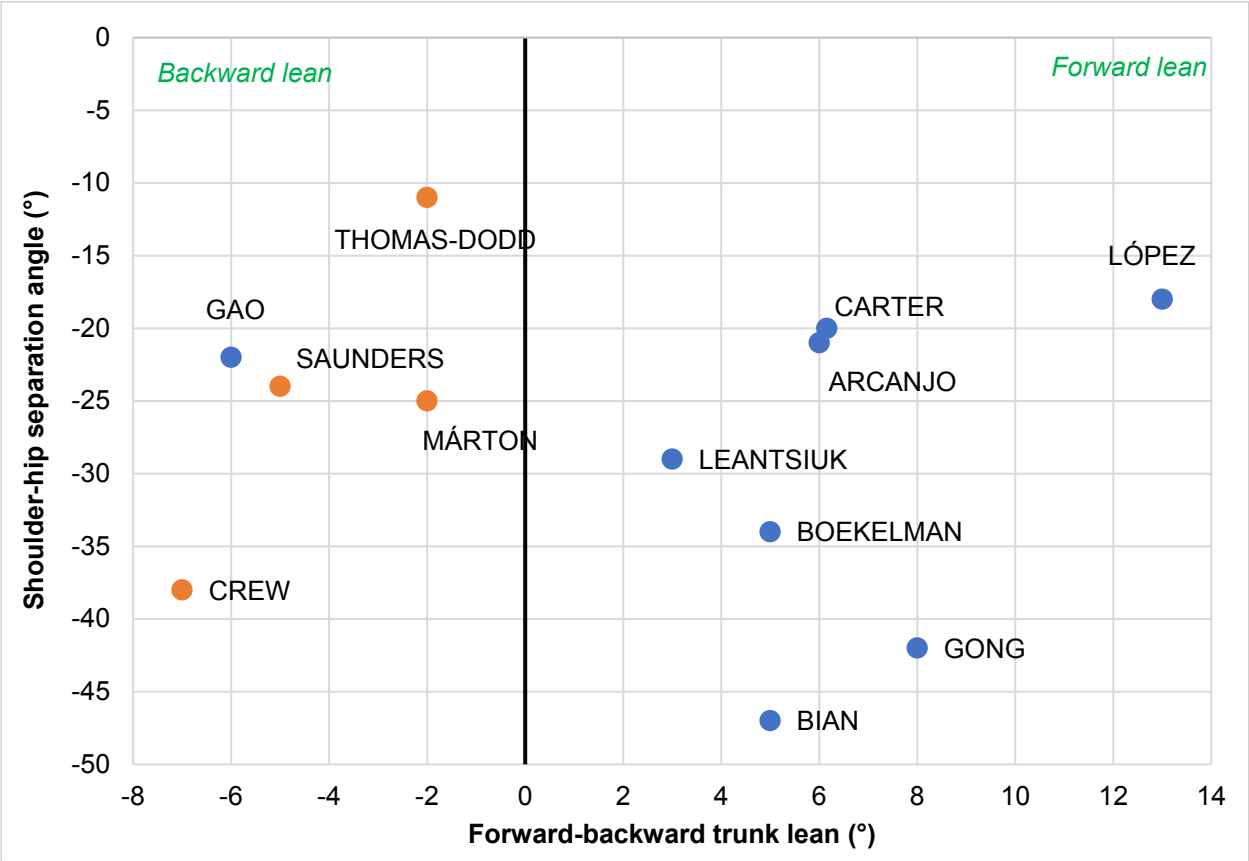

Figure 19. The relationship between forward-backward trunk lean and shoulder-hip separation at release for the twelve finalists. The orange circles signify the athletes who utilised the rotational technique and the blue circles signify the athletes who utilised the glide technique.

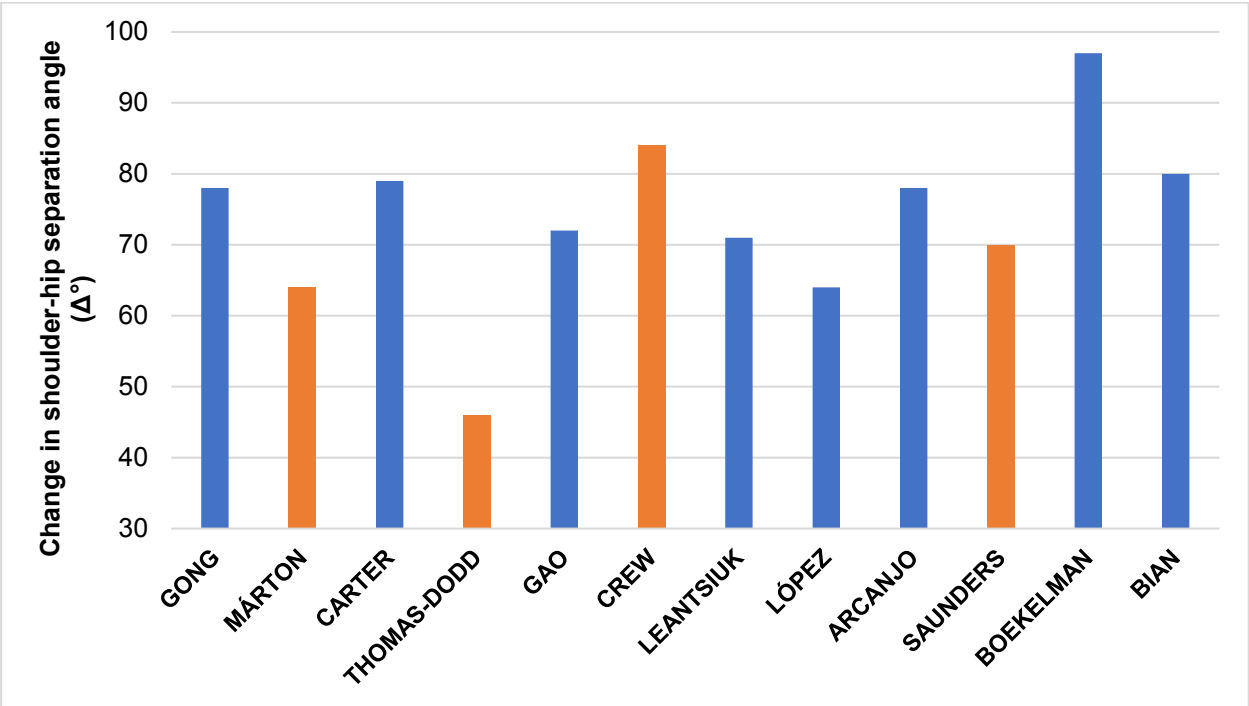

Figure 20. The change in shoulder-hip separation angle between brace leg touchdown and release for the twelve finalists. The orange bars signify the athletes who utilised the rotational technique and the blue bars signify the athletes who utilised the glide technique.

COACH'S COMMENTARY

By comparison to the men's shot put final, where 11 of the 12 athletes employed the rotational technique, the women's event has continued over recent years to remain the domain of the more traditional glide technique. This year saw more female athletes beginning to adopt the rotational technique, largely coming out of the North American influenced (and perhaps the NCAA Collegiate system) countries of USA, Canada and the Caribbean countries such as Jamaica, with 4 of the 12 athletes utilising rotation, and one athlete (Arcanjo of Brazil) using a somewhat hybrid "switch glide" technique popular among some multi-eventers.

It should also be noted that the weather conditions for this event were the worst for the whole of the 8 days of the championships, with constant heavy rain that would have made the circle very difficult for all athletes to contend with, but certainly the rotational athletes would have found it particularly difficult.

The top four finishers in the women's shot put, who were more than half a meter clear of the field, had by far the largest implement velocities at release (ranging from 13.34 m/s and 12.95 m/s). The gold medallist, Gong, actually had the third highest speed of release, at 13.24 m/s but was able to couple that with a superior angle of release of 37.0°, which was more than one degree higher that the other medallists. The angles of release for the women's finalists as a group ranged from 33.0-41.0°, and averaged 36.6°, which was similar to what was found with the men's shot finalists (30.4-41.9°, mean 36.7°).

There were a couple of release parameters (see Table 4) for the women's shot putters that were noticeably different from the men's finalists. The first, was the disparity in the reach over the stop board at delivery by the women's finalists (who ranged between 17 cm and −14 cm) compared to the men (who ranged between 33 cm and −4 cm). In addition, the women's shot finalists seemed to exhibit a much more upright trunk position at delivery with ranges between −7° to +11° for the forward-backward trunk lean at release. The men's throwers exhibited a much larger degree of backward lean as a group with ranges between −14° and 1° for forward-backward trunk lean at release.

In terms of technical style, the women's finalists utilised three different types of techniques. These were the glide, switch-glide, and rotational technique. With the appearance of four rotational shot putters in the final, it was the highest number on record so far in a major championship. Inspection of Tables 5 and 6 show that the women's shot finalists were able to produce between 75.5% and 94% of their final release velocity in the delivery phase. What should be noted is that when broken down into groups based on using the linear technique (glide or switch-glide) and rotational technique, there was a clear distinction and the percentage of final release velocity that was

developed in the power position. The linear practitioners ranged between 75.5% to 82%, while the rotational throwers ranged between 80% and 94%. These findings were similar to what was found with the men's shot put finalists as well.

Among the rotational shot putters, three of the four finalists showed an increase of shot velocity while in the transition phase. Only Raven Saunders, of the USA had a marked decrease in the implement velocity in this phase, which was similar to what many of her American teammates in the men's shot were executing. This technical approach saw her generate 94% of her final release velocity at delivery, which again was within the range exhibited by her male counterparts (89-96%). When looking at the data presented in Figure 20 there were some interesting differences between the male and female rotators as well with the women (other than Márton) having lower percentages of velocity developed in Doubled support (DS) and more velocity in Single Support (SS) than the men. This may be due to the relatively high strength levels compared to the weight of the implement. Márton displays a pattern much more related to the male rotational throwers, relying more on speed throughout the full movement than pure strength to develop delivery velocity. Thomas-Dodd and Crew were much more like the gliders in their implement velocity development through the delivery phase.

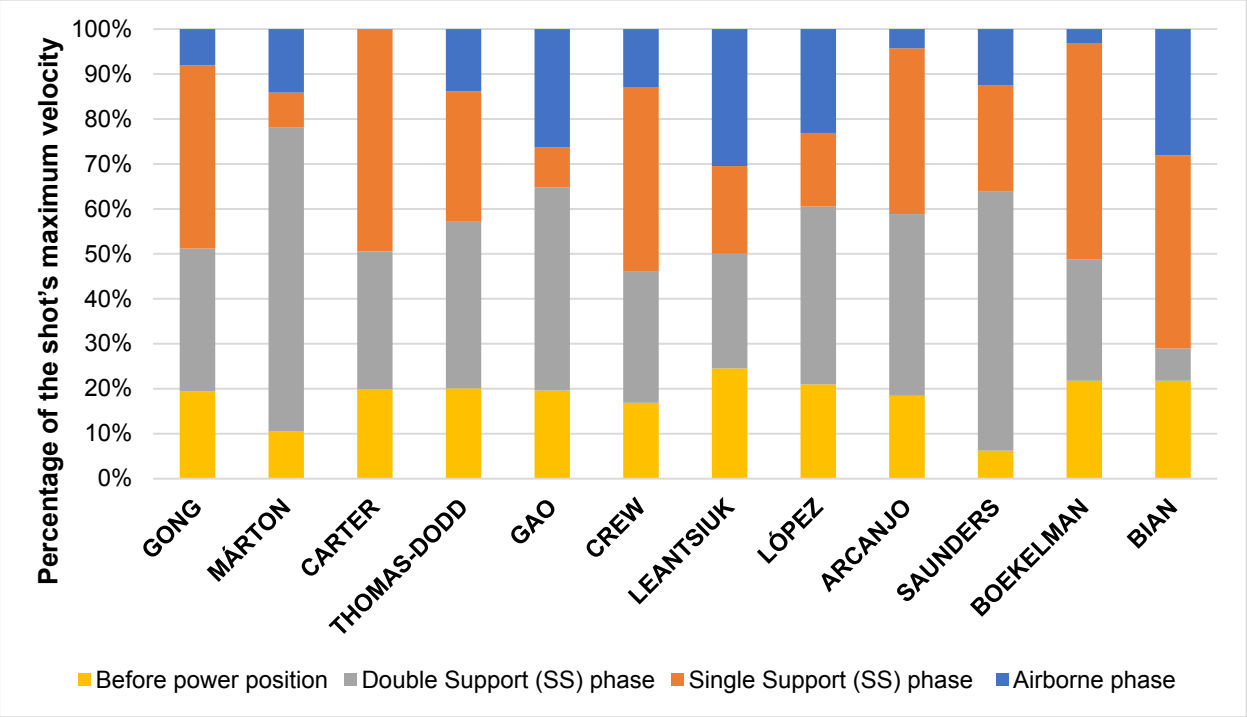

Figure 21. The percentage change in the velocity of the shot within the key phases of the movement for the twelve finalists.

***Note:** Cater lost velocity during her airborne phase and as such her maximum velocity was during the single support phase.*

A few individual observations were also of note for the women's shot put competition. The gold medallist, Gong, utilised a unique variation of the short-long glide technique that has always been her hallmark. Table 13 shows that her power position ratio was 66% which was by far the largest in the field (6% more than the next closest, which was Michelle Carter, the bronze medallist). Along with this wide base is the fact that Gong's shot travels nearly twice as far (57 cm) while getting her brace leg down after landing on her right leg than rest of the gliding finalists (see Figure 14). Finally, what is also indicative of Gong's short-long delivery is the ability to generate 5.92 m/s of shot velocity from right leg take-off to brace leg take-off (see Figure 11). By comparison, Anita Márton, the silver medallist, was only able to produce just over 1 m/s of shot velocity in this part of the throw, and men's shot gold medallist, Tom Walsh only added 1.6 m/s in this same phase.

When looking for more general trends between the two main techniques utilised, the glide and the rotation, there were a few interesting details that come out of the study. As expected, the relative size of the base of support at the power position, was much shorter for the rotational athletes (mean 69.5 cm) compared to the gliders (mean 108 cm) with Gong having the widest base of all, as mentioned above, with 127 cm, through her use of the short-long glide technique.

The rotational throwers also demonstrated a relatively lower height the shot at release of 1.94 m on average, compared to the gliders' mean of 2.07 m. This clear differentiation was inversely displayed between the techniques when looking at the height of the shot at landing in the power position with brace leg touchdown where the rotational throwers were markedly higher with a mean of 118 cm across the group, compared to a mean of 108 cm for the gliders, resulting in a much smaller change in the pathway of the shot between power position and delivery, of 76 cm for rotation and 99 cm for gliders on average, reflecting the rotational athletes keeping a flatter trajectory throughout the transition across the circle, and to overcome this the rotational throwers as a group all demonstrated a marked backward lean of the trunk at release as shown in Figure 23 necessary to give a better angle of release at delivery. The one glider that also showed significant backward lean at release was Gao of China, who landed lowest in the power position and perhaps needed a more pronounced backward lean to come out of this low position.

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Shaun Pickering is the former Head of Heavy Throws for UK Athletics through the London 2012 Olympic Games and is an IAAF Coaching Academy Member. As an athlete, Shaun was a GB International in the Shot Put, Discus and Hammer throw, and competed at the 1996 Atlanta Olympics and was a Commonwealth Games medallist in 1998. Shaun is coach to various international athletes, and has previously coached Rob Womack (Great Britain) to Paralympic bronze medal in the F55 Shot Put at London 2012.