BIOMECHANICAL REPORT

FOR THE

IAAF World Championships
LONDON 2017

Shot Put Men's

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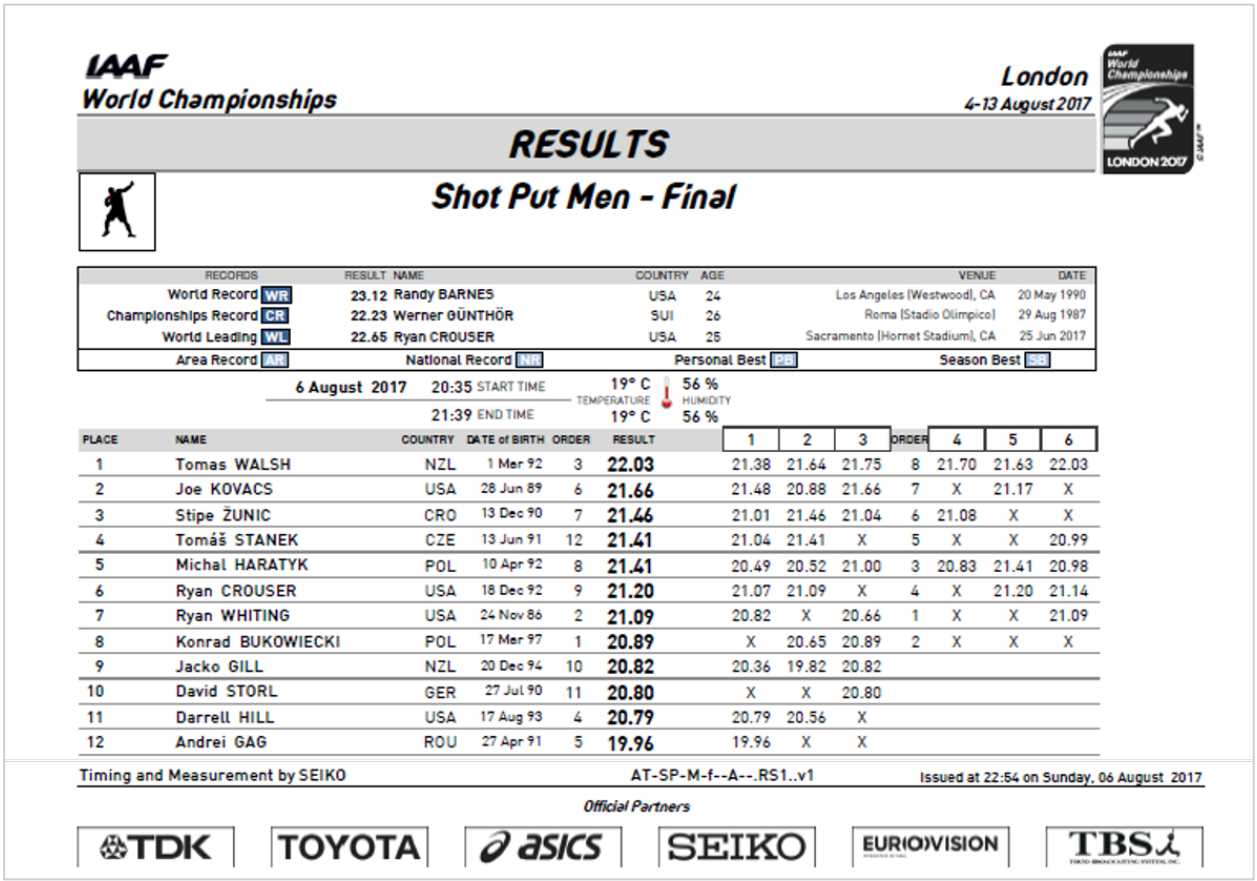
INTRODUCTION

The men's shot put final took place on August 6th in good weather conditions. Coming into the final, Ryan Crouser of the USA was the favourite as he held the world leading throw in 2017. Despite this, Tomas Walsh from New Zealand took a commanding lead in the second round with a throw of 21.64 m. Walsh then produced a tremendous sequence of throws to win the gold medal – his best throw came in the sixth round and was measured at 22.03 m. Joe Kovacs from the USA secured the silver medal in the third round with a throw of 21.66 m but he could not better Walsh. Stipe Žunić from Croatia earned the bronze medal with a second round throw of 21.46 m.



IAAF World Championships — London 4-13 August 2017

RESULTS

Shot Put Men - Final

RECORDS	RESULT	NAME	COUNTRY	AGE	VENUE	DATE
World Record WR	23.12	Randy BARNES	USA	24	Los Angeles (Westwood), CA	20 May 1990
Championships Record CR	22.23	Werner GÜNTHÖR	SUI	26	Roma (Stadio Olimpico)	29 Aug 1987
World Leading WL	22.65	Ryan CROUSER	USA	25	Sacramento (Hornet Stadium), CA	25 Jun 2017

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

6 August 2017 — 20:35 START TIME — 19° C TEMPERATURE — 56 % HUMIDITY

21:39 END TIME — 19° C — 56 %

PLACE	NAME	COUNTRY	DATE of BIRTH	ORDER	RESULT	1	2	3	ORDER	4	5	6
1	Tomas WALSH	NZL	1 Mar 92	3	22.03	21.38	21.64	21.75	8	21.70	21.63	22.03
2	Joe KOVACS	USA	28 Jun 89	6	21.66	21.48	20.88	21.66	7	X	21.17	X
3	Stipe ŽUNIC	CRO	13 Dec 90	7	21.46	21.01	21.46	21.04	6	21.08	X	X
4	Tomáš STANEK	CZE	13 Jun 91	12	21.41	21.04	21.41	X	5	X	X	20.99
5	Michal HARATYK	POL	10 Apr 92	8	21.41	20.49	20.52	21.00	3	20.83	21.41	20.98
6	Ryan CROUSER	USA	18 Dec 92	9	21.20	21.07	21.09	X	4	X	21.20	21.14
7	Ryan WHITING	USA	24 Nov 86	2	21.09	20.82	X	20.66	1	X	X	21.09
8	Konrad BUKOWIECKI	POL	17 Mar 97	1	20.89	X	20.65	20.89	2	X	X	X
9	Jacko GILL	NZL	20 Dec 94	10	20.82	20.36	19.82	20.82				
10	David STORL	GER	27 Jul 90	11	20.80	X	X	20.80				
11	Darrell HILL	USA	17 Aug 93	4	20.79	20.79	20.56	X				
12	Andrei GAG	ROU	27 Apr 91	5	19.96	19.96	X	X				

Timing and Measurement by SEIKO — AT-SP-M-f--A--.RS1..v1 — Issued at 22:54 on Sunday, 06 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. However, due to unforeseen circumstances related to the location depicted in orange the analysis was mainly based on footage provided by the cameras located in the other two positions.

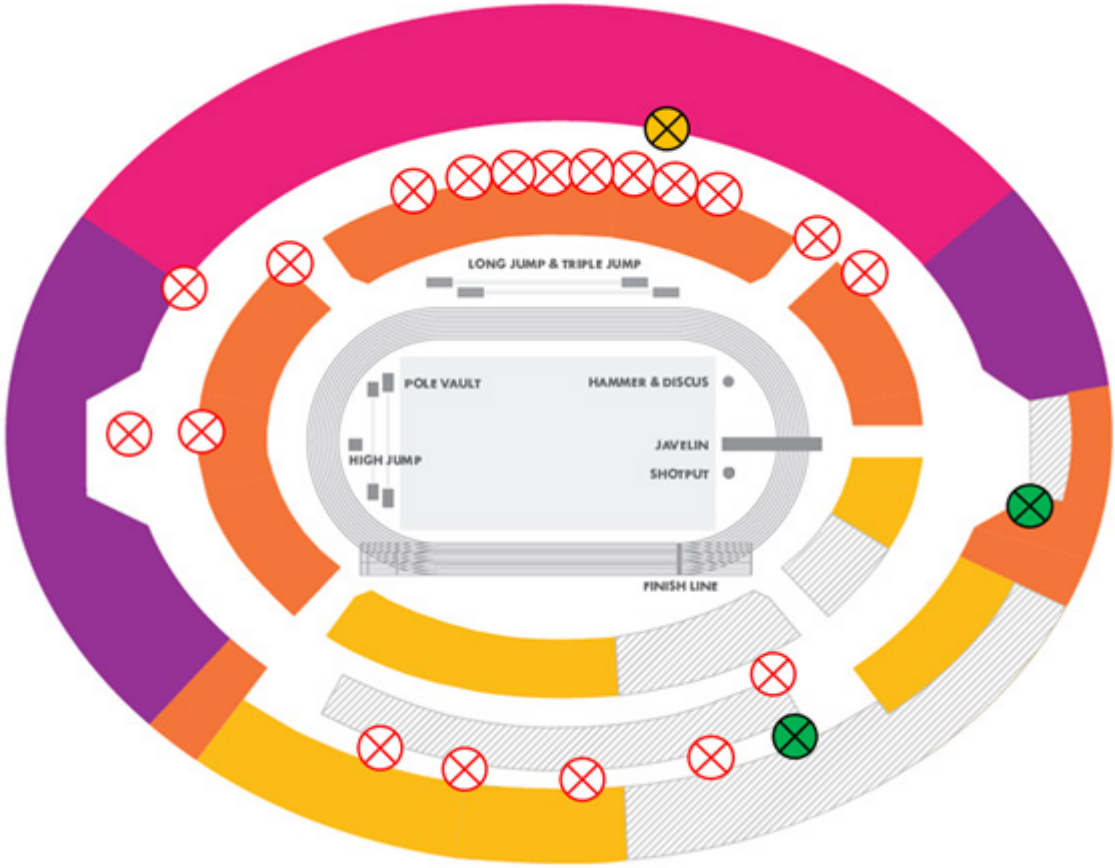

Figure 1. Stadium layout with camera locations for the men's shot put (shown in green).

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 two different techniques implemented and the power position and release. A) rotational flight, B) glide, C) the power position and D) release.

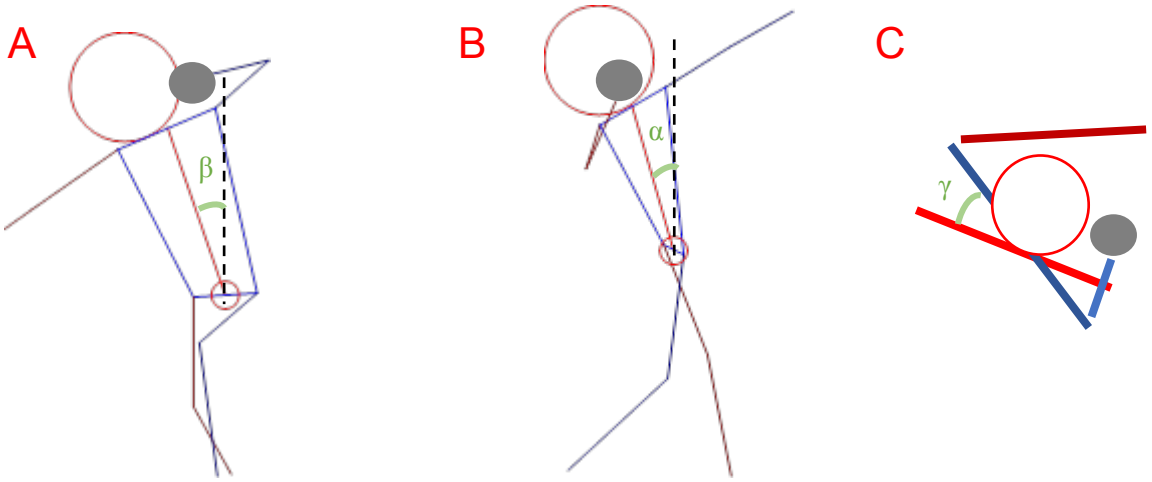

Figure 4. Visual representation of A) left-right trunk lean (β), B) forward-backward trunk lean (α) and C) shoulder-hip separation angle (γ).

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 two 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)
WALSH	22.04	22.21	22.14	0.10	22.03	−0.01	−0.18
KOVACS	22.57	22.57	20.67	−1.90	21.66	−0.91	−0.91
ŽUNIC	21.48	21.48	20.86	−0.62	21.46	−0.02	−0.02
STANEK	22.01	22.01	20.76	−1.25	21.41	−0.60	−0.60
HARATYK	21.88	21.88	21.27	−0.61	21.41	−0.47	−0.47
CROUSER	22.65	22.65	20.90	−1.75	21.20	−1.45	−1.45
WHITING	21.65	22.28	20.84	−0.81	21.09	−0.56	−1.19
BUKOWIECKI	21.97	21.97	20.55	−1.42	20.89	−1.08	−1.08
GILL	21.01	21.01	20.96	−0.05	20.82	−0.19	−0.19
STORL	21.87	22.20	21.41	−0.46	20.80	−1.07	−1.40
HILL	21.91	21.91	21.11	−0.80	20.79	−1.12	−1.12
GAG	20.52	21.06	20.61	−0.09	19.96	−0.56	−1.10

Anthropometric data and implemented technique

Table 3 identifies that eleven of the twelve finalists utilised the rotational technique, whereas only Storl utilised the glide technique.

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

Athlete	Height (m)	Body mass (kg)	Technique
WALSH	1.86	123	Rotational
KOVACS	1.81	132	Rotational
ŽUNIC	1.88	115	Rotational
STANEK	1.90	127	Rotational
HARATYK	1.94	136	Rotational
CROUSER	2.01	127	Rotational
WHITING	1.91	134	Rotational
BUKOWIECKI	1.91	129	Rotational
GILL	1.90	118	Rotational
STORL	1.99	122	Glide
HILL	1.93	135	Rotational
GAG	1.95	118	Rotational

Release parameters

Table 4, Figures 5 and 6 detail the release parameters of the best throws for the twelve finalists, although because of technical challenges when recording Whiting's best throw, the data presented within this report are based on his second-best throw of the finals (round 3). Walsh produced the highest release velocity (14.15 m/s), whereas Kovacs produced the fourth highest release velocity (13.84 m/s) and Žunić produced the seventh highest release velocity (13.68 m/s). However, both Kovacs and Žunić optimised their angle of release (Kovacs: 39.9° and Žunić: 37.8°), height of release expressed as a percentage of their body height (Kovacs: 122% and Žunić: 117%) and reach over stop board (Kovacs: 0.19 m and Žunić: 0.22 m). Interestingly, Walsh leaned his trunk slightly backwards (−11°) and to the left (−8°) at release. Similarly, most of the finalists leaned slightly backwards (finalist mean: −6° ± 5), although most of the men leant slightly to the right (finalist mean: −3° ± 7).

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 (°)
WALSH	6	22.03	14.15	35.1	2.12	114	0.23	−11	−8
KOVACS	3	21.66	13.84	39.9	2.22	122	0.19	−3	6
ŽUNIC	2	21.46	13.68	37.8	2.20	117	0.22	−13	6
STANEK	2	21.41	13.88	36.1	2.11	111	0.13	−11	12
HARATYK	5	21.41	13.65	39.6	2.15	111	0.04	−7	3
CROUSER	5	21.20	13.72	36.4	2.10	105	0.14	−8	5
WHITING	3*	20.66	13.49	41.9	2.24	117	−0.04	−14	−12
BUKOWIECKI	3	20.89	14.02	30.4	2.11	110	0.28	−4	2
GILL	3	20.82	13.72	32.9	1.97	104	0.33	1	14
STORL	3	20.80	13.43	38.2	2.22	112	0.10	−1	1
HILL	1	20.79	13.46	36.7	2.29	118	0.07	−1	6
GAG	1	19.96	13.24	35.0	2.08	106	0.29	−4	0

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

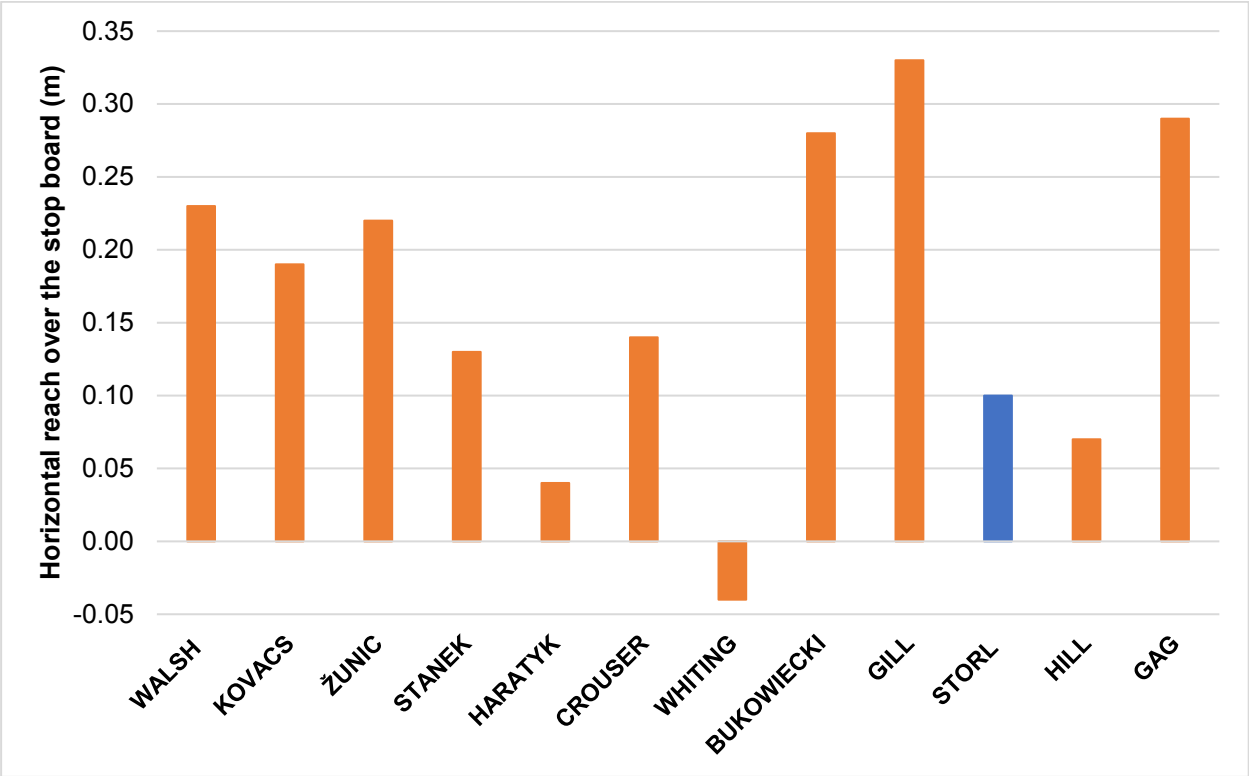

Figure 5. The reach over stop board for the twelve finalists. The orange bars signify the athletes who utilised the rotational technique and the blue bar signifies the athlete who utilised the glide technique.

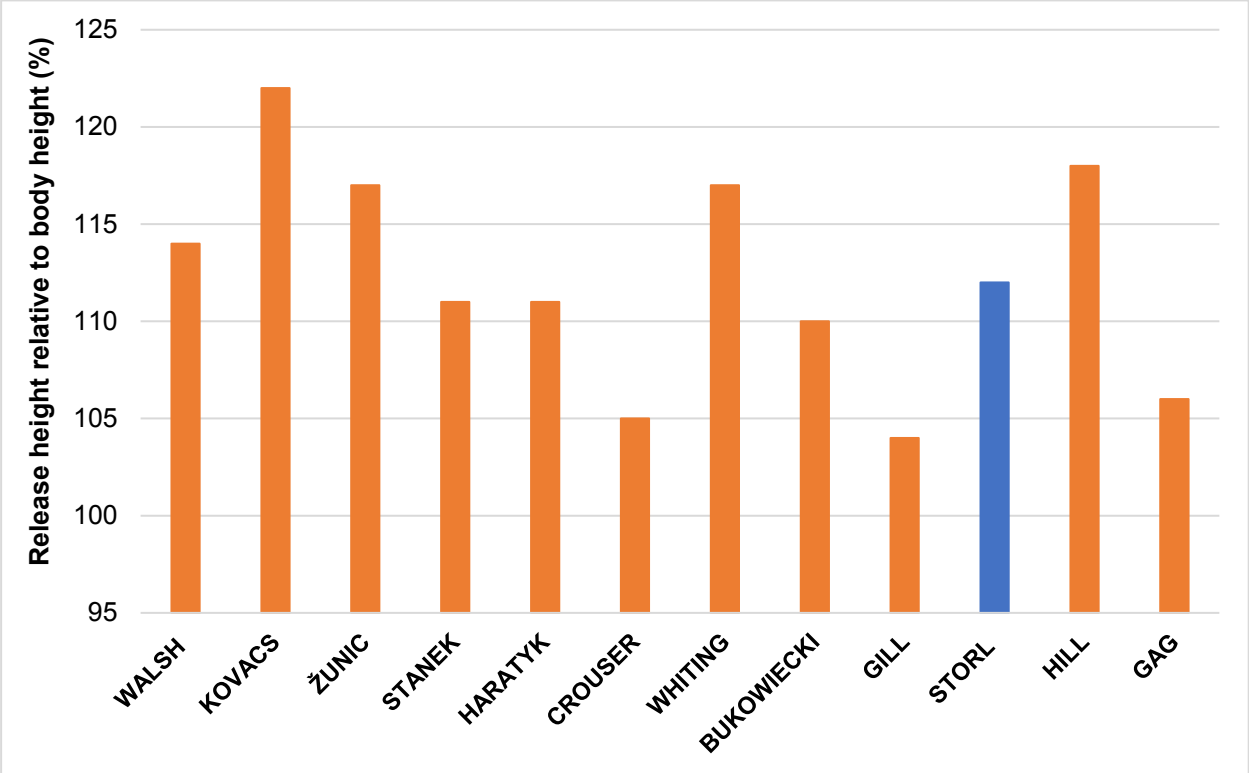

Figure 6. The height of release expressed as a percentage of body height for the twelve finalists. The orange bars signify the athletes who utilised the rotational technique and the blue bar signifies the athlete who utilised the glide technique.

Velocity of the shot

Figure 7 provides a visual description of each key phase in the rotational technique. Table 5 and Figure 8 detail the resultant velocity of the shot at key phases for the athletes that utilised the rotational technique.

Figure 7. 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 5. The velocity of the shot at the key phases for the athletes who utilised the rotational technique.

Athlete	Right leg push-off (m/s)	Left leg push - off (m/s)	Right leg touchdown (m/s)	Brace leg touchdown (m/s)	Right leg take-off (m/s)	Brace leg take-off (m/s)	Release (m/s)
WALSH	2.38	1.36	1.61	2.91	11.39	12.99	14.15
KOVACS	1.71	2.25	2.43	1.61	9.99	11.07	13.84
ŽUNIC	2.10	2.06	1.01	1.77	10.85	12.40	13.68
STANEK	2.08	2.93	1.86	2.34	11.32	12.98	13.88
HARATYK	2.09	1.48	1.57	2.10	10.77	13.50	13.65
CROUSER	1.65	1.63	2.20	1.35	13.43	12.82	13.72
WHITING	2.15	1.99	1.47	2.10	13.42	12.49	13.49
BUKOWIECKI	2.52	1.79	0.93	1.11	8.70	11.59	14.02
GILL	1.34	1.24	1.23	2.76	9.79	11.29	13.72
HILL	1.84	1.58	2.05	0.51	10.16	10.58	13.46
GAG	1.83	1.71	1.01	1.93	10.35	12.15	13.24

Notably, Hill gained the most velocity (12.95 m/s) within the power position in comparison to the ten other finalists who utilised the rotational technique. Interestingly, Walsh gained almost the least velocity (11.24 m/s) ranked tenth out of the eleven other finalists who utilised the rotational technique, having entered the power position with the highest velocity. Interestingly, all of the finalists delivered the shot without being in contact with the ground. Ten out of the twelve finalists delivered the shot with this sequence: right leg take-off, brace leg take off and the release.

However, both Crouser and Whiting delivered the shot with a different sequence, whereby the brace leg took off before the right leg.

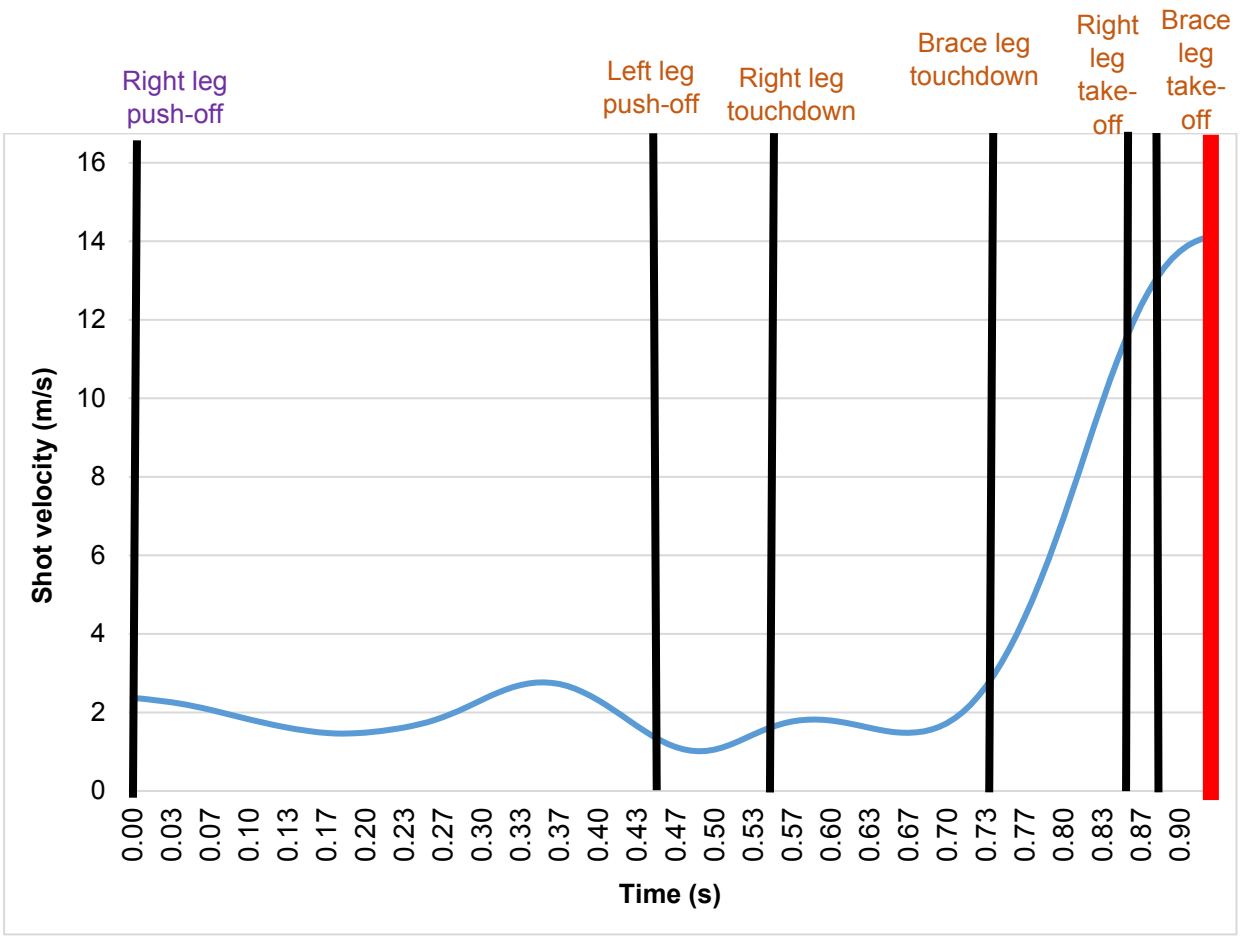

Figure 8. Walsh's velocity profile of the shot from right leg push-off to release.

Figure 9 provides a visual description of each key phase in the glide technique. Table 6 details the resultant velocity of the shot at key phases for the athlete that utilised the glide technique.

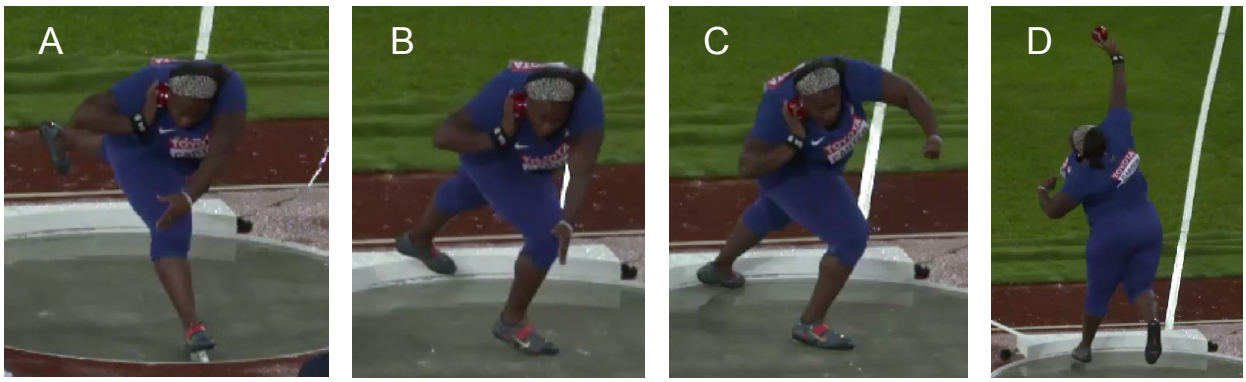

Figure 9. Visual description for each of the key phases in the glide technique: A) right leg push-off, B) right leg touchdown, C) brace leg touchdown and D) release.

Table 6. The velocity of the shot at the key phases of Storl's throw.

	Right 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)
STORL	2.89	2.54	2.97	5.78	11.56	13.43

Path of the shot during the key phases

The following pages contain Figure 10, which shows the individual motion path (from a superior view) for the athletes who utilised the rotational technique. Following Figure 10, Table 7 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.

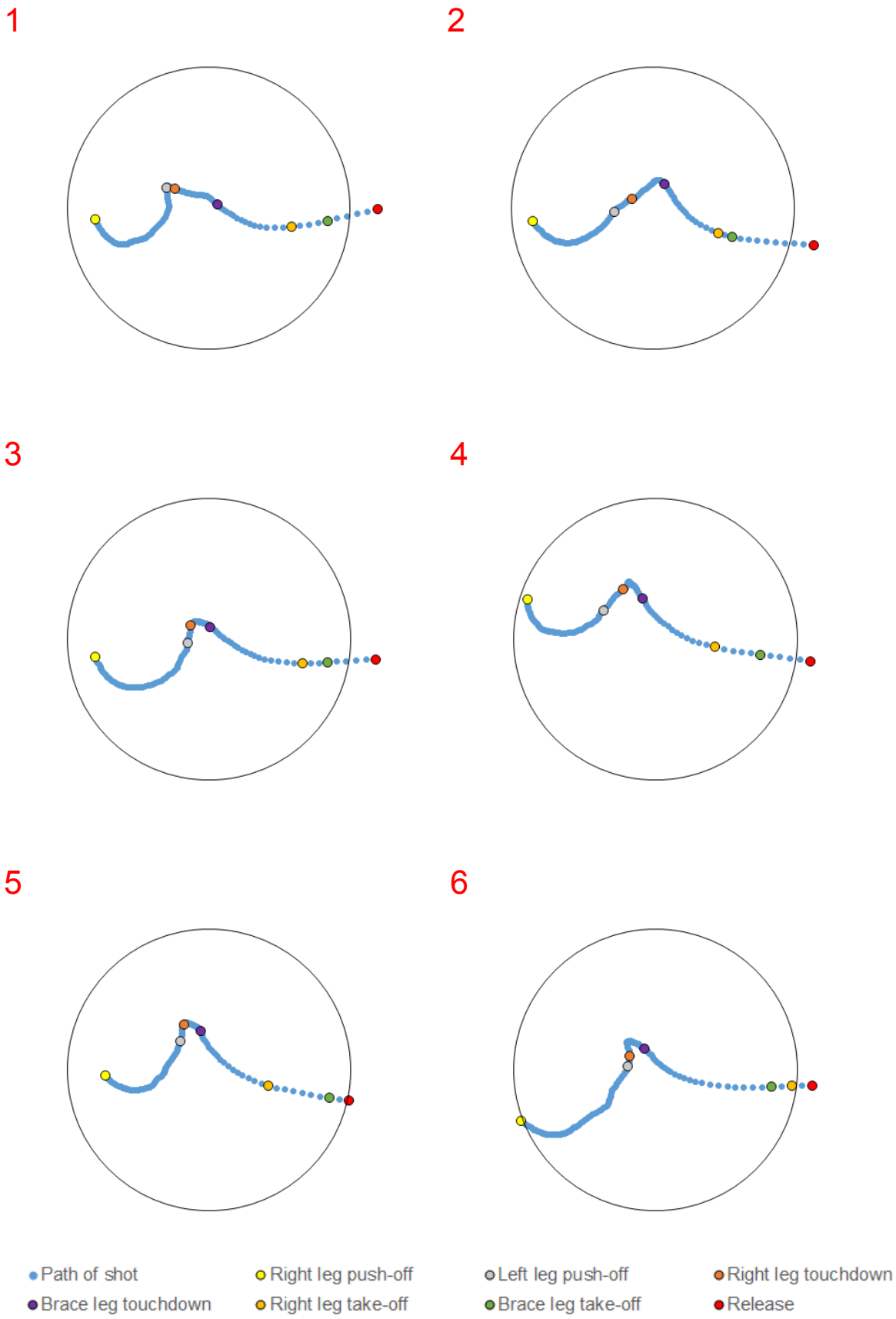

Figure 10. A visual representation from a superior view of the path of the shot from the right leg push-off to release. Key: 1) Walsh, 2) Kovacs, 3) Žunić, 4) Stanek, 5) Haratyk, 6) Crouser, 7) Whiting, 8) Bukowiecki, 9) Gill, 11) Hill and 12) Gag.

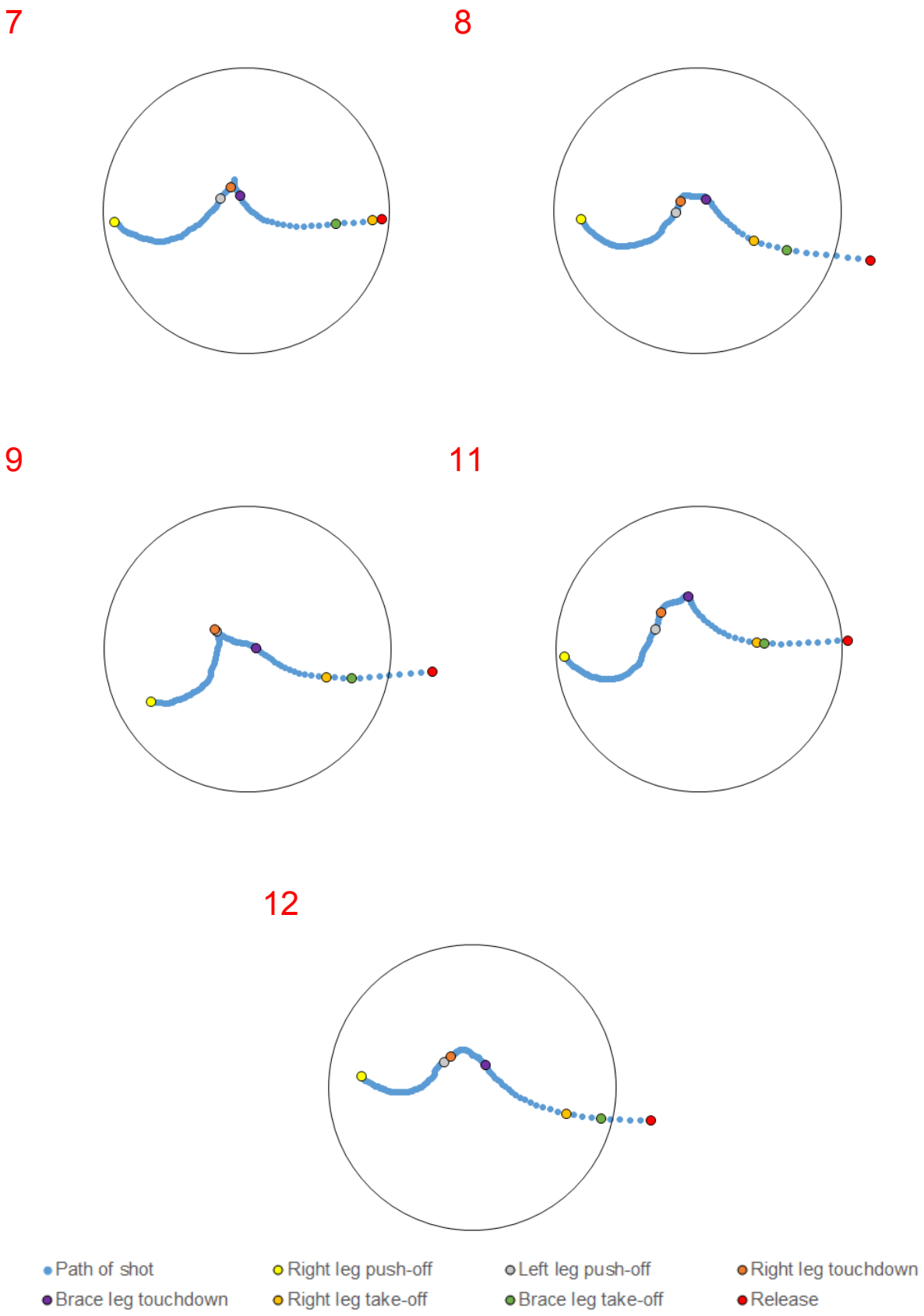

Figure 10 continued. A visual representation from a superior view of the path of the shot from right leg push-off to release. Key: 1) Walsh, 2) Kovacs, 3) Žunić, 4) Stanek, 5) Haratyk, 6) Crouser, 7) Whiting, 8) Bukowiecki, 9) Gill, 11) Hill and 12) Gag.

Table 7. The path length of the shot depicting the key phases for the athletes that utilised the rotational technique.

Athlete	Right leg push off to left leg push off (m)	Left leg push off to right leg touchdown (m)	Right leg touch down to left leg touchdown (m)	Left leg touchdown to release (m)	Total path (m)
WALSH	0.92	0.11	0.35	1.39	2.77
KOVACS	0.78	0.16	0.33	1.58	2.85
ŽUNIC	0.98	0.14	0.20	1.52	2.84
STANEK	0.79	0.23	0.32	1.62	2.96
HARATYK	0.79	0.14	0.23	1.51	2.67
CROUSER	1.08	0.08	0.32	1.56	3.04
WHITING	0.95	0.12	0.31	1.52	2.90
BUKOWIECKI	0.89	0.10	0.24	1.47	2.70
GILL	0.86	0.05	0.37	1.45	2.73
HILL	0.92	0.14	0.28	1.55	2.89
GAG	0.75	0.06	0.36	1.52	2.69

Figure 11 shows the motion path (from a superior view) for the athlete who utilised the glide technique. Following Figure 11, Table 8 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.

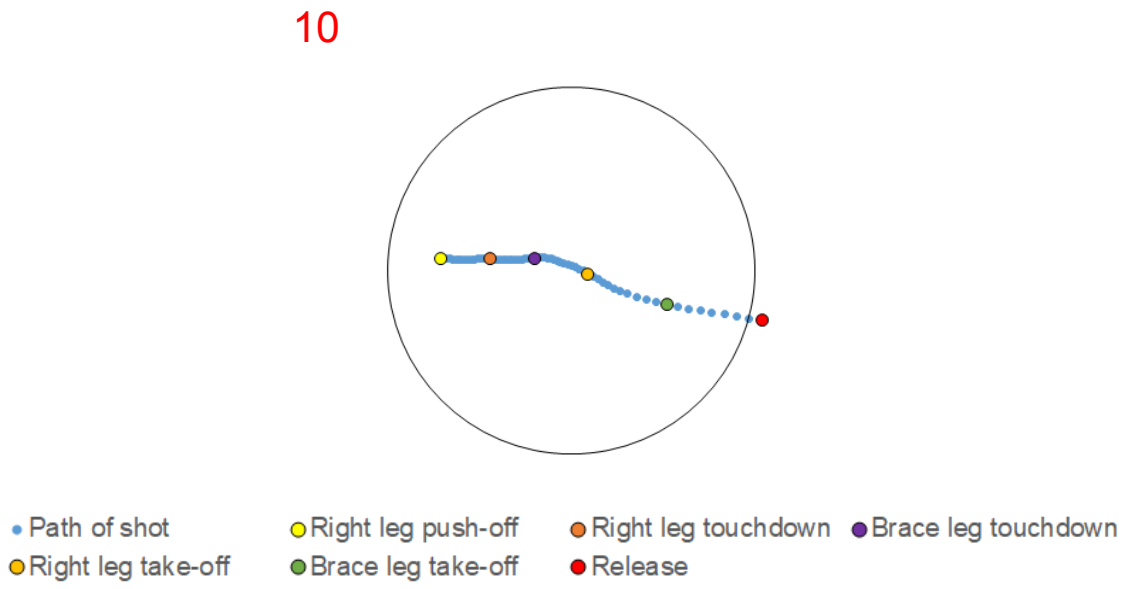

Figure 11. A visual representation from a superior view of the path of the shot from right leg push-off to release. Key. 10) Storl.

Table 8. The path length of the shot depicting the key phases of Storl's throw.

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)
STORL	0.80	0.26	1.70	2.76

Figure 12 details the total path length of the shot for the twelve finalists. Notably, Crouser's total path length was the largest with 3.04 m, whereas Walsh's path length was one of the smallest with 2.77 m.

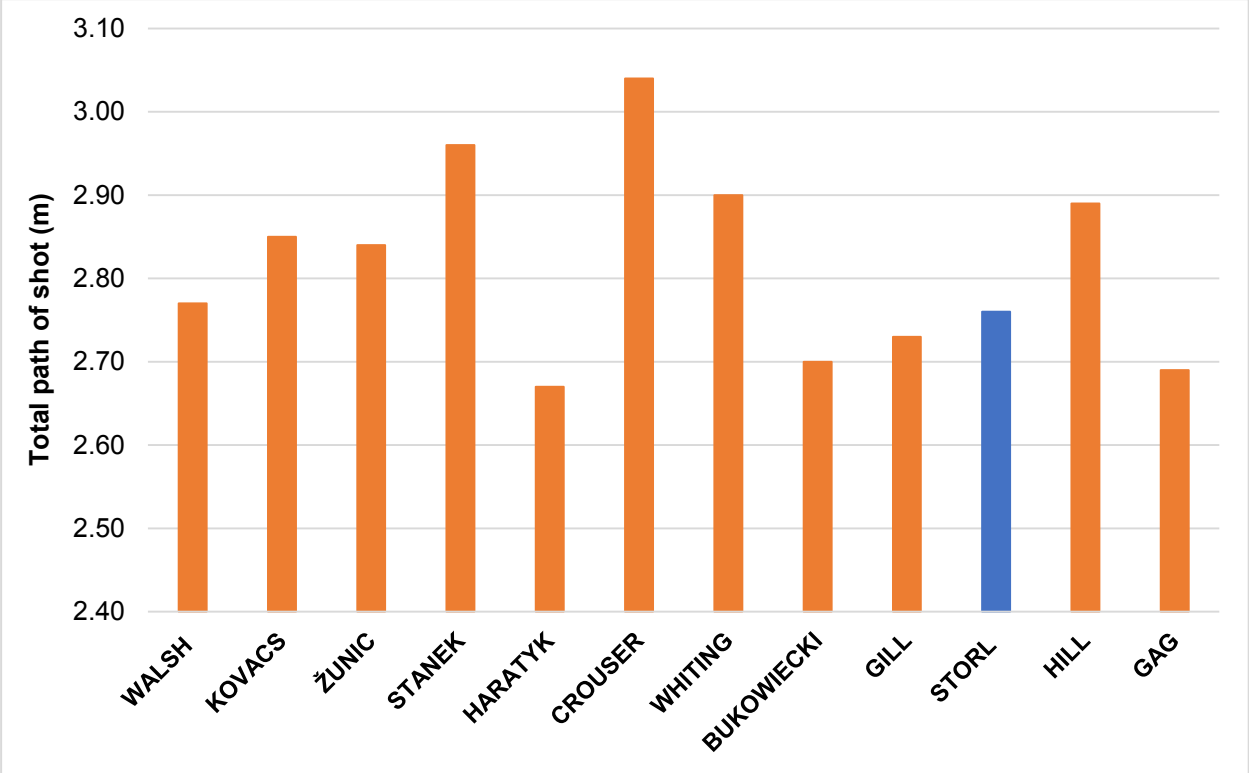

Figure 12. The total path length of the shot for the twelve finalists. The orange bars signify the athletes who utilised the rotational technique and the blue bar signifies the athlete who utilised the glide technique.

Figure 13 shows the individual motion paths (from a side-on view) for the athletes who utilised the rotational technique. Following Figure 13, Table 9 shows the vertical position of the shot through each key phase of the rotational technique. Whiting gained the most height (1.02 m) from the brace leg touchdown to release with respects to the ten other rotational athletes.

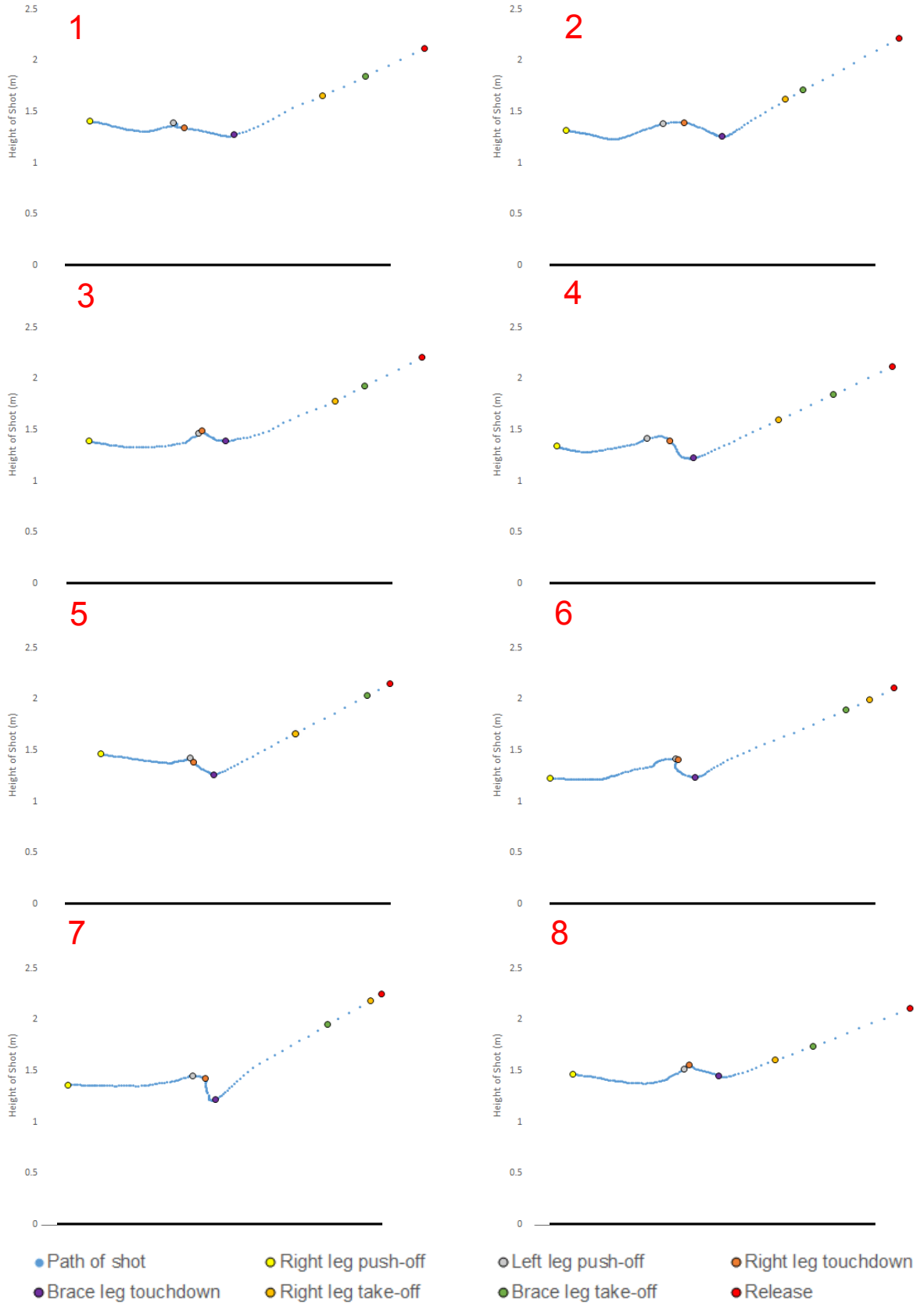

Figure 13. A visual representation from a side on view of the path of the shot from right leg push-off to release. Key: 1) Walsh, 2) Kovacs, 3) Žunić, 4) Stanek, 5) Haratyk, 6) Crouser, 7) Whiting, 8) Bukowiecki, 9) Gill, 11) Hill and 12) Gag.

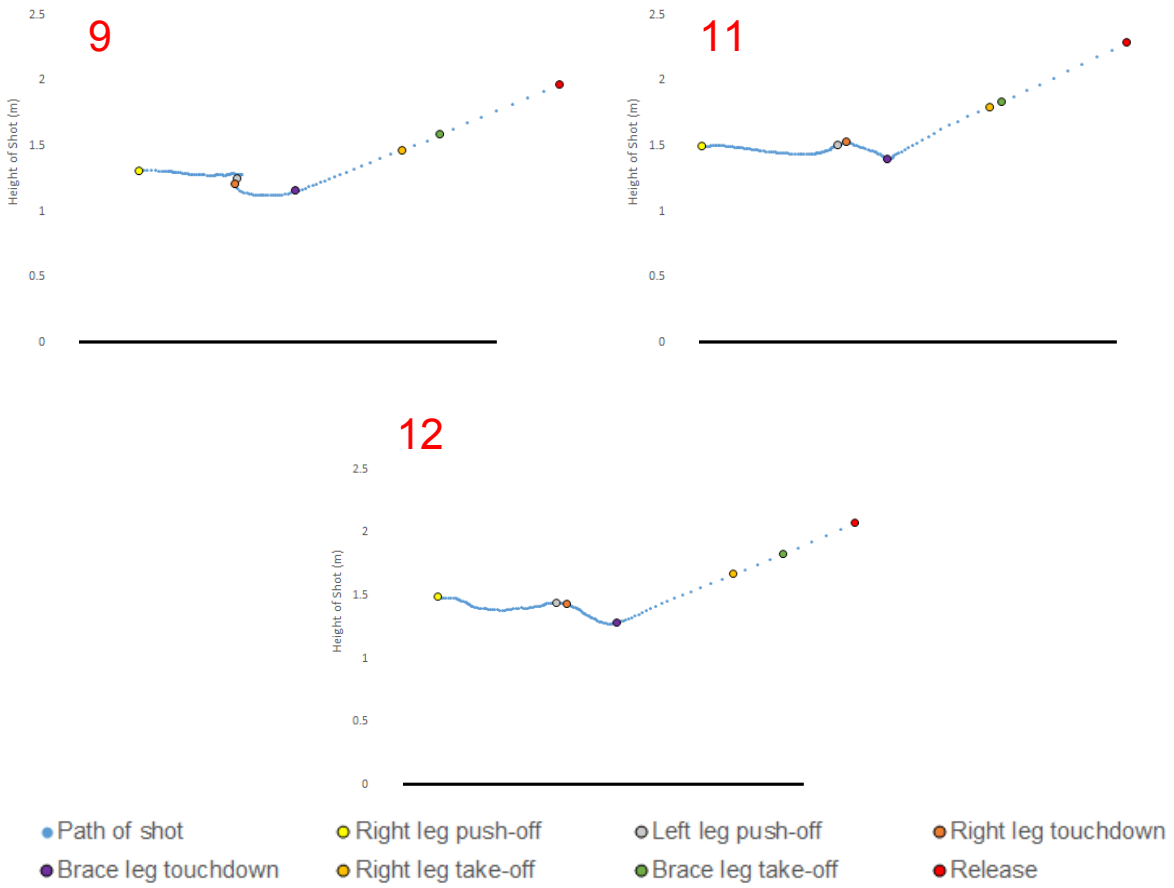

Figure 13 continued. A visual representation from a side on view of the path of the shot from the right leg push-off to release. Key: 1) Walsh, 2) Kovacs, 3) Žunić, 4) Stanek, 5) Haratyk, 6) Crouser, 7) Whiting, 8) Bukowiecki, 9) Gill, 11) Hill and 12) Gag.

Table 9. The height of the shot at key phases for the athletes that utilised the rotational techniques.

Athlete	Right leg push-off (m)	Left leg push-off (m)	Right leg touchdown (m)	Brace leg touchdown (m)	Release (m)
WALSH	1.40	1.39	1.34	1.27	2.12
KOVACS	1.32	1.38	1.39	1.26	2.22
ŽUNIC	1.39	1.47	1.48	1.39	2.20
STANEK	1.34	1.42	1.39	1.22	2.11
HARATYK	1.46	1.42	1.38	1.26	2.15
CROUSER	1.23	1.41	1.41	1.24	2.10
WHITING	1.36	1.45	1.42	1.22	2.24
BUKOWIECKI	1.46	1.51	1.55	1.45	2.11
GILL	1.31	1.25	1.21	1.15	1.97
HILL	1.49	1.50	1.53	1.40	2.29
GAG	1.48	1.44	1.43	1.28	2.08

Figure 14 shows the individual motion path (from a side-on view) for the athlete who utilised the glide technique. Following Figure 14, Table 10 shows the vertical position of the shot through each key phase of the glide technique.

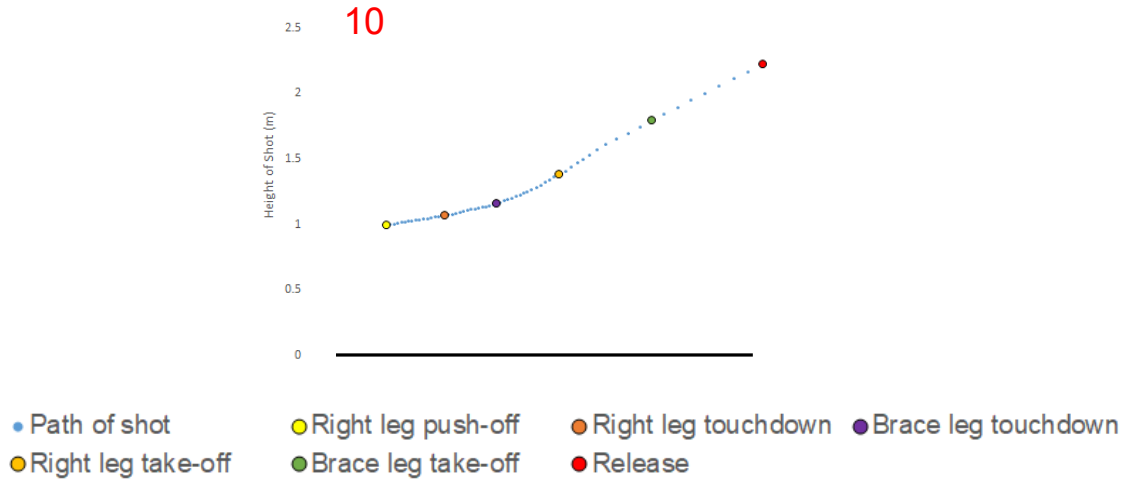

Figure 14. A visual representation from a side on view of the path of the shot from the right leg push-off to release. Key: 10) Storl.

Table 10. The height of the shot at key phases for Storl's throw.

Athlete	Right leg push-off (m)	Right leg touchdown (m)	Brace leg touchdown (m)	Release (m)
STORL	0.99	1.07	1.16	2.22

Notably, Figure 15 shows Storl gained the most height (1.06 m) from the brace leg touchdown in comparison to the other eleven finalists.

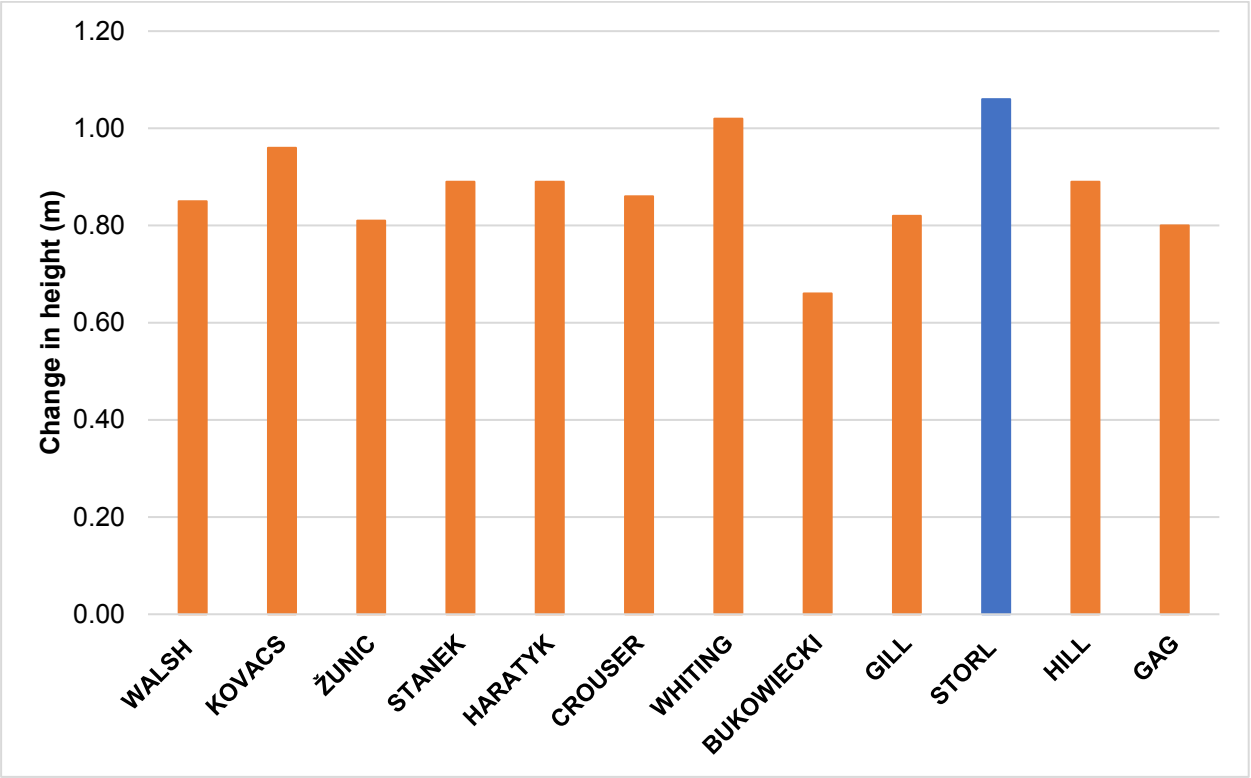

Figure 15. The height gained from the touchdown of the brace leg to release for the twelve finalists. The orange bars signify the athletes who utilised the rotational technique and the blue bar signifies the athlete who utilised the glide technique.

Duration of key phases

Table 11. The duration of the key phases for the athletes that utilised the rotational techniques.

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)
WALSH	0.447	0.100	0.193	0.167
KOVACS	0.433	0.067	0.206	0.220
ŽUNIC	0.420	0.080	0.180	0.206
STANEK	0.400	0.093	0.187	0.193
HARATYK	0.426	0.087	0.173	0.180
CROUSER	0.587	0.040	0.233	0.227
WHITING	0.407	0.067	0.226	0.200
BUKOWIECKI	0.446	0.074	0.193	0.193
GILL	0.487	0.040	0.200	0.193
HILL	0.513	0.067	0.200	0.226
GAG	0.454	0.046	0.254	0.206

Table 12. The duration of the key phases for Storl's throw.

Athlete	Right leg push-off to right leg touchdown (s)	Right leg touchdown to brace leg touchdown (s)	Brace leg touchdown to release (s)
STORL	0.106	0.094	0.226

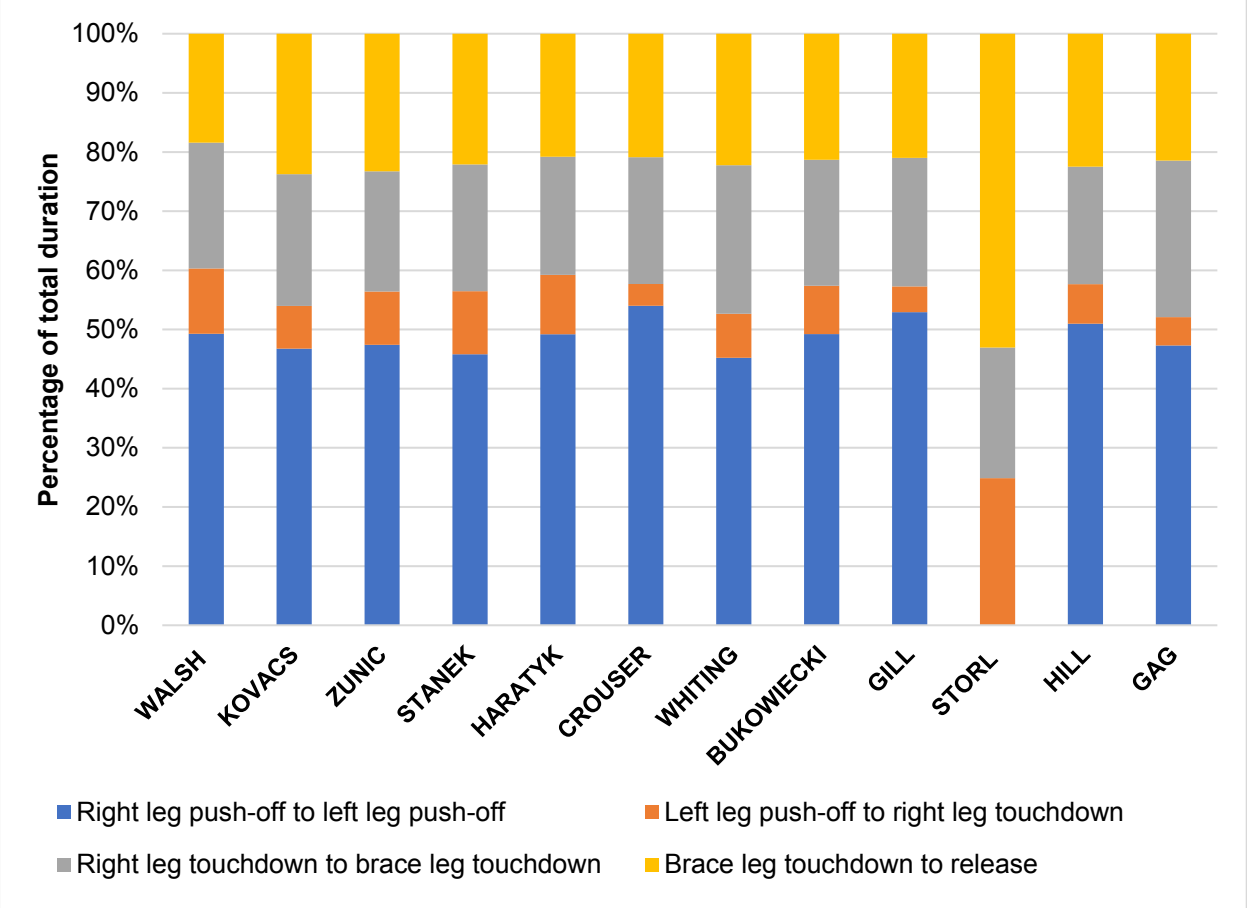

Figure 16. The time taken to perform each of the key phases, which is expressed as a percentage of the total duration for the twelve finalists. Please note, Storl utilised the glide technique and as such, the orange phase signifies a right leg push-off to right leg touchdown.

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 (%)
WALSH	0.99	0.89	53	47
KOVACS	1.13	0.65	63	37
ŽUNIC	1.50	0.27	85	15
STANEK	1.23	0.60	67	33
HARATYK	0.91	0.77	54	46
CROUSER	1.16	0.73	61	39
WHITING	1.10	0.76	59	41
BUKOWIECKI	0.99	0.63	61	39
GILL	0.81	0.82	50	50
STORL	0.78	1.26	38	62
HILL	0.86	0.70	55	45
GAG	1.36	0.45	75	25

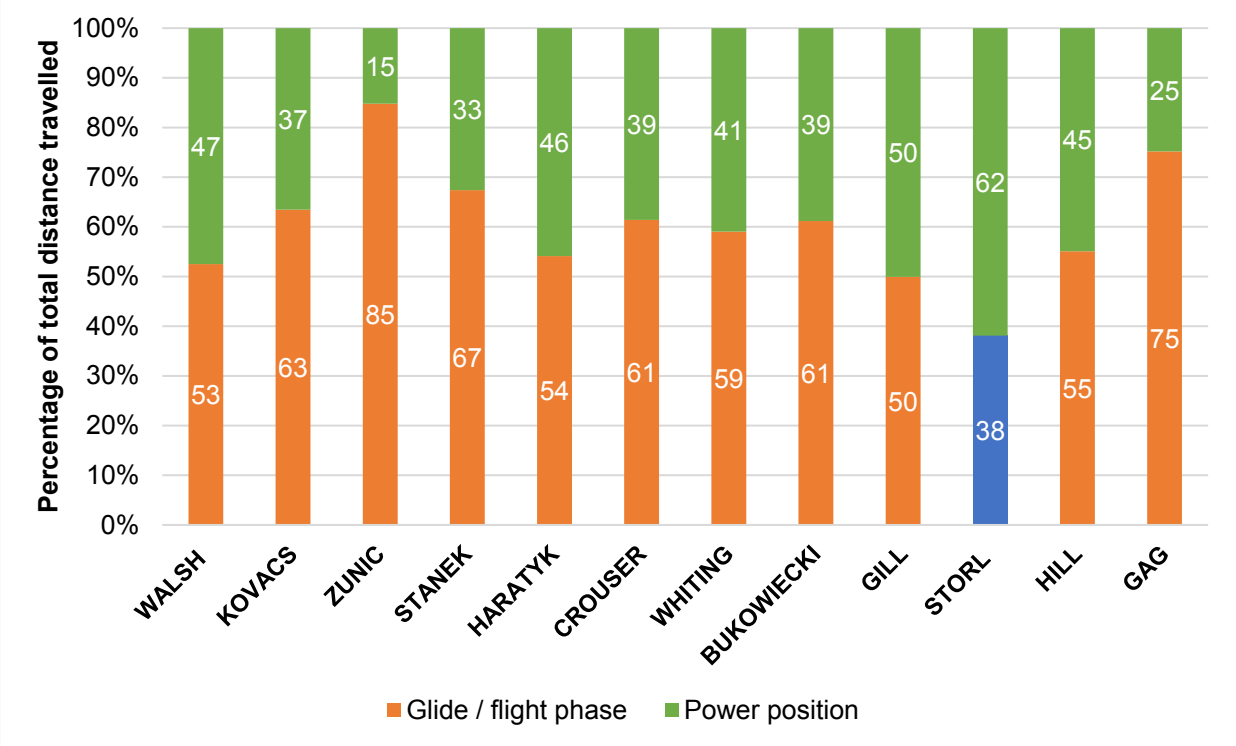

Figure 17. The percentage of total distance travelled in the glide/flight phase and power position for the twelve finalists. The orange bars signify the athletes that used the rotational technique and the blue bar signifies the athlete that used the glide technique.

Shoulder-hip separation angle

Tables 14 and 15, as well as Figures 18 and 19 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. In general, most 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, Walsh produced one of the smallest (51°) changes in shoulder-hip separation angle within the power position. In contrast, Žunić produced one of the largest (87°) change in shoulder-hip separation angle within the power position.

Table 14. The shoulder-hip separation angle at the key phases for the eleven rotational athletes.

Athlete	Right leg push-off (°)	Left leg push-off (°)	Right leg touchdown (°)	Brace leg touchdown (°)	Release (°)
WALSH	6	9	15	36	−15
KOVACS	20	67	64	57	−7
ŽUNIC	4	29	56	62	−25
STANEK	17	45	53	42	−10
HARATYK	5	35	41	42	−5
CROUSER	−25	27	47	63	−13
WHITING	13	46	29	48	−26
BUKOWIECKI	−7	30	39	71	9
GILL	−23	10	27	34	−19
HILL	−3	28	47	65	−17
GAG	22	54	44	53	−6

Table 15. The shoulder-hip separation angle at the key phases for Storl's throw (glide).

Athlete	Right leg push-off (°)	Right leg touchdown (°)	Brace leg touchdown (°)	Release (°)
STORL	31	58	47	−41

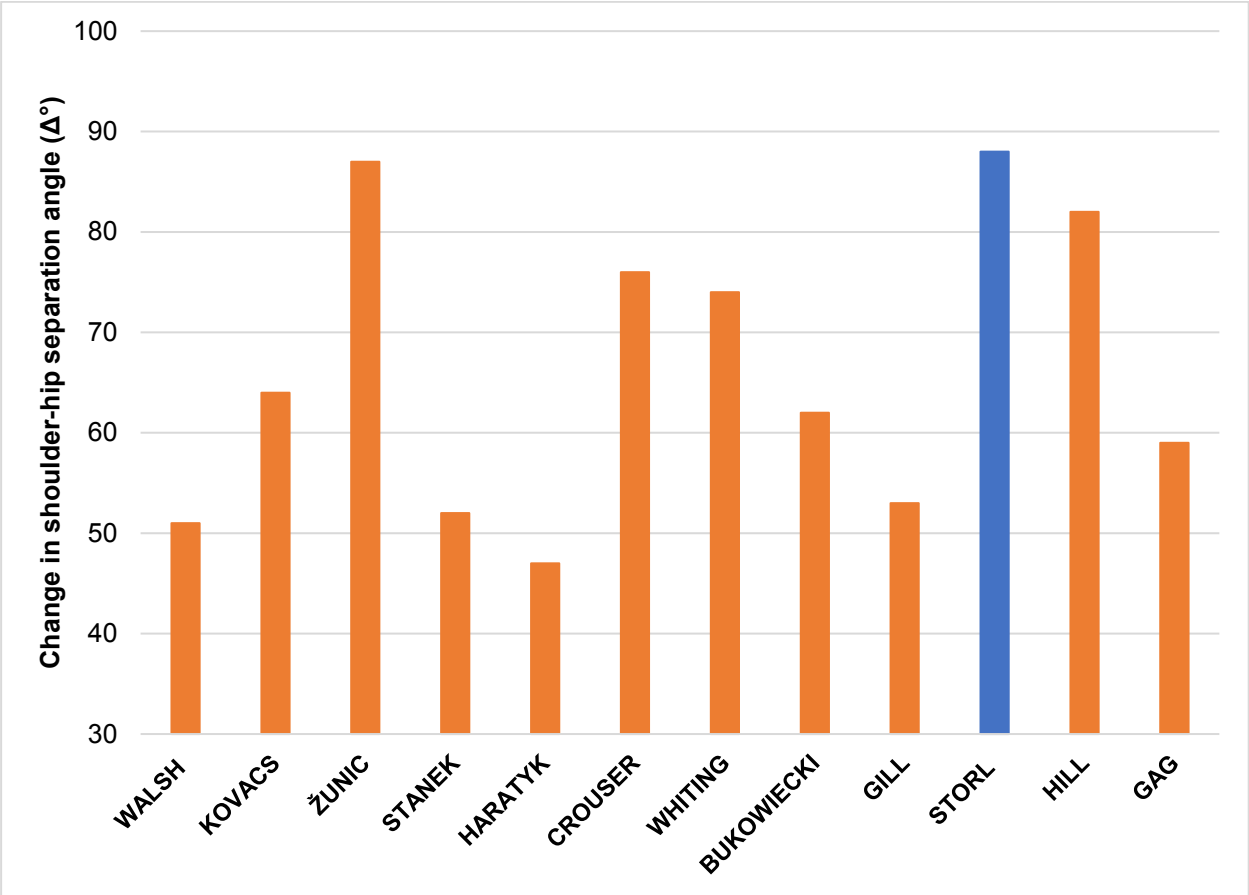

Figure 18. The change in shoulder-hip separation angle between the touchdown of the brace leg and release for the twelve finalists. The orange bars signify the athletes who utilised the rotational technique and the blue bar signifies the athlete who utilised the glide technique.

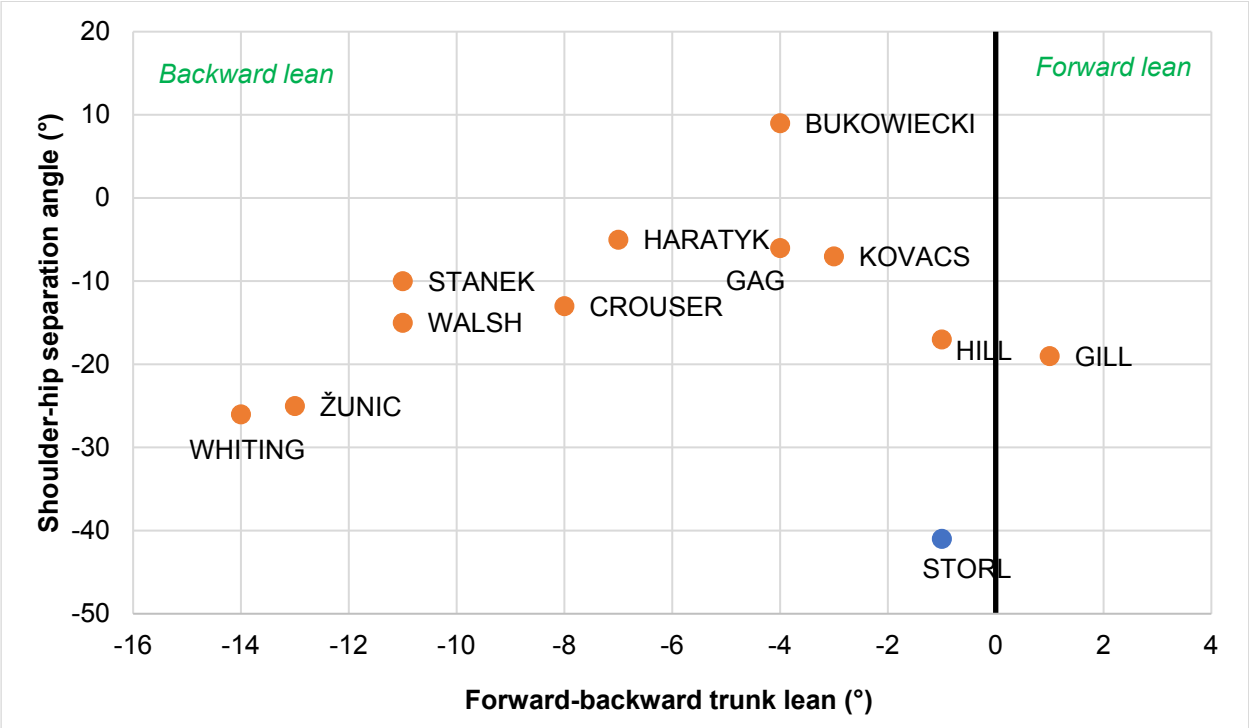

Figure 19. The relationship between forward-backward trunk lean and shoulder-hip separation at release for the twelve finalists. The orange circles signify the athletes who utilised the rotational technique and the blue circle signifies the athlete who utilised the glide technique.

COACH'S COMMENTARY

For anyone that was watching the men's shot put in London, this event more than any other throwing event at the championships, shows both the limitations of this initial biomechanics report, but also the interest and excitement about a potential deeper follow up study. While the winning throw of 22.03 m from Tom Walsh of New Zealand made him a very worthy champion, it was the disputed "foul" throws by two other competitors, Joe Kovacs and Olympic champion and world leader, coming into the competition, Ryan Crouser, which caused much of the discussion around the competition. Both athletes had throws beyond the 22 m line that were ruled as fouls by the officials, and from the point of view of direct performance comparison, the data from these throws would provide for some very interesting discussion from a coaching point of view.

This study focuses on the best registered marks of each competitor in the final, and so we can look at potential interesting technical cues or differences between competitors, but this is based only on a single throw, which may or may not be representative of what a particular athlete might typically do technically when based over a season. For the interested observer, Ryan Crouser who had been so technically consistent in the previous year's Rio Olympic final, setting a new Olympic Record of 22.52 m, and had established himself as the favourite for London 2017 with a new personal best of 22.65 m just weeks ahead of these championships, seemed to be struggling, technically, in London and the one massive throw that he connected with, was ruled a foul by brushing the inside edge of the circle at the back of the ring, a rule that has since been removed from the IAAF rules. Similarly, although Olympic silver medallist Joe Kovacs was more consistent in his throwing that day, the "big" throw in the final round was ruled a marginal foul by brushing the top edge of the stop-board. To look more deeply at what the differences between these big "foul" throws and their best recorded throws on the day may give us more insight into some key coaching cues that result in bigger performances.

The gold medal winning thrower, Tom Walsh from New Zealand, had the highest recorded release velocity of the measured throws at 14.15 m/s (see Table 4). The top six placers in the competition generated the highest release velocities as a group, supporting the notion that the release velocity is the most important release factor in determining distance. The one exception to this was the case of Bukowiecki, who finished 8th, who recorded a release velocity of 14.02 m/s. However, this effort was done with a below optimal release angle of 30.4° so the throwing distance was not optimised. It is possible to generate higher release velocities at lower angles, so finding the optimum balance between release velocity and release angle is the key.

The results for the third, fourth, and fifth positions were very close and these competitors each had a different combination of release velocity and release angle for their best throw. With only 5

cm separating fifth place from the bronze medal position, it appeared the release height may have been a larger than normal factor in putting Žunić (height of release was 2.20 m) into third place over Stanek (height of release of 2.11 m) and Haratyk (2.15 m). Another interesting observation with regard to release parameters was the reach over the stop board at the point of release. Within the finalist group, the three highest readings for reach over the stop board were also associated with the lowest release heights and angles of release suggesting there is an inverse relationship between the variables. However, the three medallists were able to record the next three highest readings for delivering past the stop board, while still finding a way to retain high values for height and angle of release.

An interesting point that came out of the data was that the shortest thrower on the competition, Joe Kovacs at 1.81 m, had one of the greatest height of release values at 2.22 m (122% of height) and one of the highest release angles of 39.9°, while the tallest competitor, with a conservative height given as 2.01 m had a height of release of 2.10 m (105% or height) and a lower angle of release of 36.4°.

In terms of throwing technique, the men's final saw 11 of the 12 finalists use the rotational technique, with only one competitor using the glide technique. This was the highest number of rotational throwers in a major championship final ever recorded, and goes in line with the trend of male shot putters switching over to the rotational technique; the inaugural 1983 World Championships saw 11 of the 12 men's finalists utilising the glide technique. The men's shot put medallists in 2017 were all practitioners of the rotational technique, which continued the trend of the rotational throwers sweeping the medals at a major championship that began at the 2016 Olympic Games.

The men's shot finalists as a group produced between 80-94% of their final release velocity in the delivery phase (DS_2). Interestingly, Walsh, the gold medallist, had the lowest percentage of final release velocity in the last phase, along with his countryman Jacko Gill, at 80%. This could be attributed to both Walsh and Gill's use of the transition phase with their given techniques, to nearly double their implement velocity through this portion of the throw (see Table 5). This manner of implement acceleration is similar with the pattern found in discus throwers who use a fixed foot delivery. The majority (9 out of 12) men's finalists also increased the shot velocity during the transition phase (DS_2), and produced mean of 85% of the final release velocity in the delivery phase. What is noticeable is that the three finalists who exhibited a marked decrease in implement velocity in the transition phase (Kovacs, Crouser, and Hill) were all American throwers who also recorded many of the highest increases in shot velocity in the delivery phase at 89%, 90%, and 94%, respectively. This approach to rotational throwing, which is centred upon a big delivery phase, is perhaps the closest example we can see of a national approach to the technique.

When looking at the data presented in Figure 20, we can see similarities that could be considered as representative of an “American Technique” in general terms, including the influence of the NCAA University system, and view some differences between the styles being practiced or developed in other areas. This American Technique may be characterised by a relatively high percentage of final release velocity developed in the Double Support (DS) phase of the delivery, from when the drive leg arrives at the front of the Circle into what is known as the Power Position, from where the powerful action of both legs are utilised into the Delivery and creating the final release velocity of the shot. This is slightly different among the non-US athletes, who are able to develop a slightly higher percentage of their final release velocity within the Single Support (SS) phase once, typically the drive leg, has come off the ground. This indicates that the Americans tend to stay back longer over the Drive leg during the delivery relative to the non-American throwers, with a smaller drift towards the front of the circle during the delivery phase. Crouser developed an incredible 83.6% of his release velocity within the DS phase, which is possibly why many people talk about him having such good technique because their image of good technique involves a great delivery. Hill, Whiting, and Crouser were all over 72%, along with a very small percentage of velocity developed in the SS phase. Kovacs was interesting because he had a low percentage in the SS phase like the other Americans while only 60% in DS. He developed 20% of his velocity after both feet were off the ground, which was different to the other Americans but it is still consistent with the “American” theme of very little velocity developed in SS in the rotational delivery.

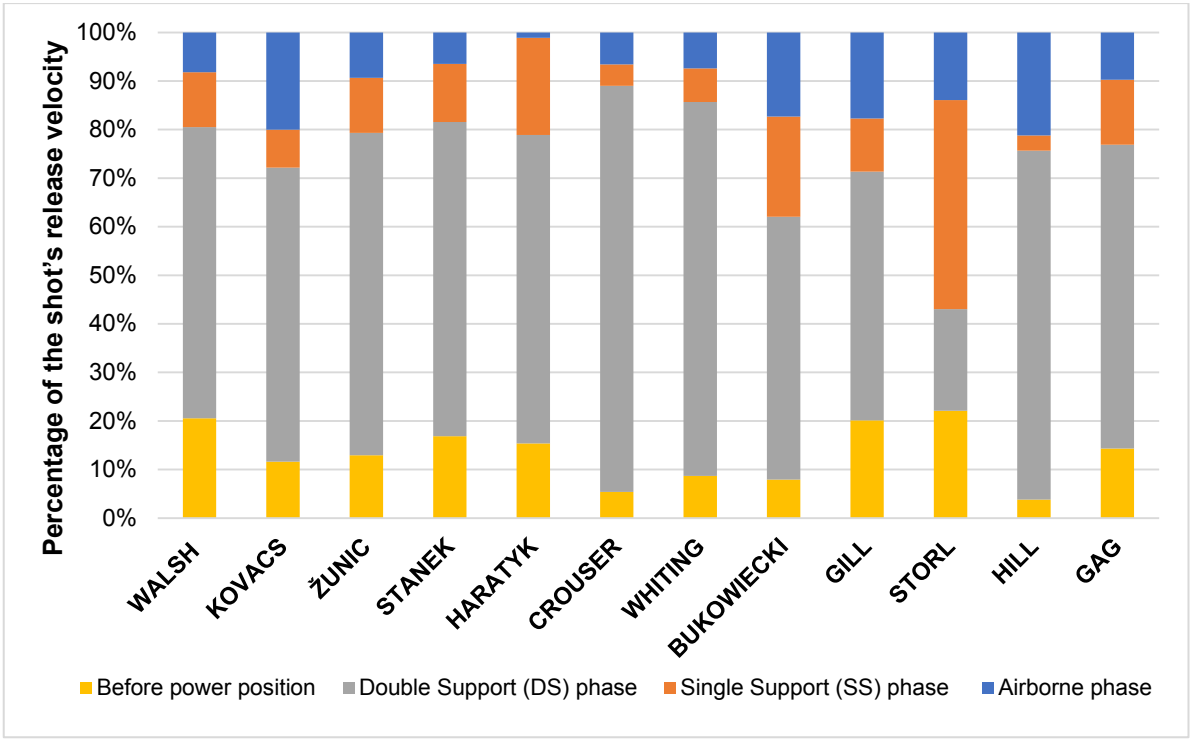

Figure 20. The percentage change in the velocity of the shot within the key phases of the movement for the twelve finalists.

The coaching take home here is how do you approach the stand throw in training with this technique. An American approach to the Stand Throw in training involves a focus on the importance of the drive leg as the primary source of power and to stay back over this drive leg and to lift straight up into delivery. Existing research tells us that a good (long) stand throw needs to have a good amount of velocity developed in SS to go far (as displayed by most Gliders, such as Storl), shifting the weight forwards during delivery which results in keeping the brace leg in contact for longer and higher ground-reaction forces in the block leg, which goes counter to what happens in this type of "American" rotational delivery. Many American Rotational Throwers display a relatively poor Stand Throw compared to particularly the European Throwers who have more background in developing efficient Stand Throws. Some of the current non-American throwers, such as Tom Walsh however, "downplay" the importance of the Stand throw completely in their training and pre-competition preparation.

Crouser and Whiting were noticeable in the fact that for these recorded throws, their brace (left) leg at the front of the circle came off before their drive leg, but they were still adding velocity to the shot at this point utilising their drive leg for longer than the others. Their drive leg lost contact with the circle very close to their release point as can be seen by the fact that they were very near to maximum release velocity at that point. When you look a little closer however, you can actually see that both legs actually leave the ground very close together, almost simultaneously, in an "active" reverse.

The lone practitioner of the glide technique, David Storl, produced only 78% of his final release velocity in the delivery phase which was lower than any of the readings for the rotational throwers. This could be due to the fact that the shot was already moving at 2.97m/s as he entered into the delivery phase, similar to the readings for Walsh and Gill at 2.91 m/s and 2.76 m/s, respectively.

When looking for trends of patterns that could perhaps be useful for coaches looking for technical models to develop their own throwers, this is always difficult based on data from a single throw, and even judging one athlete or styles against another. So much of these decisions must be based on the particular size and physical characteristics of the athlete but perhaps we can raise a few issues worthy of further discussion and investigation. Of course there is the obvious difference between the glide and rotational throwers, but we are now seeing less and less proponents of the glide technique among male throwers at major championships, so we are now looking for differences between styles and approach within the rotational technique used by different athletes. One area of interest is between the approach taken by a taller athlete, such as Ryan Crouser at 2.01 m, and the smaller generation of throwers that are having success currently, such as Tom Walsh at 1.86 m and Joe Kovacs at 1.81 m, although none can be considered small men, with conservative figures for their bodyweights between 123 kg and 132 kg!

Ryan Crouser, at 2.01 m height may be more limited by the constraints of the 2.13 m circle, which may have contributed to the foul called at the rear of the circle as he starts with a left foot right at the back of the circle, and while the distance of the flight phase of left foot push off to right foot landing in the middle of the circle was 1.16 m, the duration of this flight phase was the shortest of all the throwers at 0.040 s. This perhaps indicates an intention not to “jump” out of the back of the circle, but rather to “step down” with the right foot and get it down quickly and avoid the potential long flight phase that would take him across the circle. Crouser also has one of the longest total paths of the shot at 3.04 m, and when you look the graphical representation of this in Figure 13 (6) you can see that there is also a big variation from side to side in the path of the shot through the movement to give this long path.

If you compare this to Tom Walsh who at 1.86 m height is not so limited in the circle. He starts with his left foot quite far back from the back of the circle and while the distance of the flight phase was a relatively average 0.99 m, the time that it took to get to that right foot touchdown point in the middle of the circle, at 0.100 s was actually the longest of all the throwers, which perhaps shows an intended delay in placing this right foot, maybe even bringing the foot back underneath the athlete to provide an advantage in the delivery phase of the throw. It should also be noted that at right leg touchdown and indeed at brace leg touchdown (power position) Walsh demonstrated by far the least angle of shoulder-hip separation of all the rotational throwers with 15° (mean of others 44.7°) and 36° (mean of others 53.7°), respectively. This can perhaps be interpreted as downplaying the importance of the “Wrap” in the middle of the circle, in favour of maintaining velocity through the throw.

Another factor relating to Walsh that comes out of the study, and certainly worthy of further exploration, was the angle of the trunk at delivery. This is clearly seen in Table 4 and Figure 5, where Walsh demonstrates a pronounced backward lean of the trunk of −11°, which is not untypical as this allows a better (greater) angle of release while still using the strong muscles of the chest, but also a marked lean away to the left (−8°). Most athletes more typically displayed a positive angle of right-to-left lean at release, remaining more over the right leg at delivery. Further study, perhaps involving force plate data, would allow us to look more closely at this to see if it is an area of possible improvement, or a beneficial technical choice that Walsh and his coach see as a pathway to bigger throws in the future.

Finally, when looking at the graphical representation of the path of the shot from above in Figure 13 (1) and from the side in Figure 16 (1), you can see that Walsh displays one of the straightest and flattest pathway of the shot, with very little variation from the midline of the circle and also up and down, as he transitions from the entry to the power position, making for a very efficient path. It is noticeable also that Walsh has the shortest path from left foot touchdown (power position) to

release of all the throwers of 1.39 m, and as already noted he is carrying the greatest speed of the implement at this point with 2.91 m/s which then increases to the highest release speed of 14.15 m/s. When looking at Figure 11 of Walsh's velocity profile of his whole throw, it is noticeble that along that relatively straight delivery phase from power position to release, he continues to add speed after his right leg has come off the ground (11.39 m/s) and indeed the left leg has come off the ground (12.99 m/s), which backs up the old adage that "You cannot fire a cannon from a canoe!" and that the body mass of the athlete is perhaps important to be able to keep adding force once the athlete has left the ground.

CONTRIBUTORS

Dr Alex Dinsdale is a Senior Lecturer in Sport and Exercise Biomechanics specialising in the teaching of Strength and Conditioning. He is also the current course leader for the MSc in Strength and Conditioning. His main research interests are centred on acute preparation strategies, methods of resistance training, the transference of training and long term training strategies. Alongside his academic role, Alex has been a successful strength and conditioning coach for well over a decade, whereby he has worked with numerous sports at all levels of performance.

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