IAAF World Indoor Championships
BIRMINGHAM 2018
1–4 MARCH

BIOMECHANICAL REPORT

FOR THE

IAAF

WORLD INDOOR CHAMPIONSHIPS 2018

Shot Put Men

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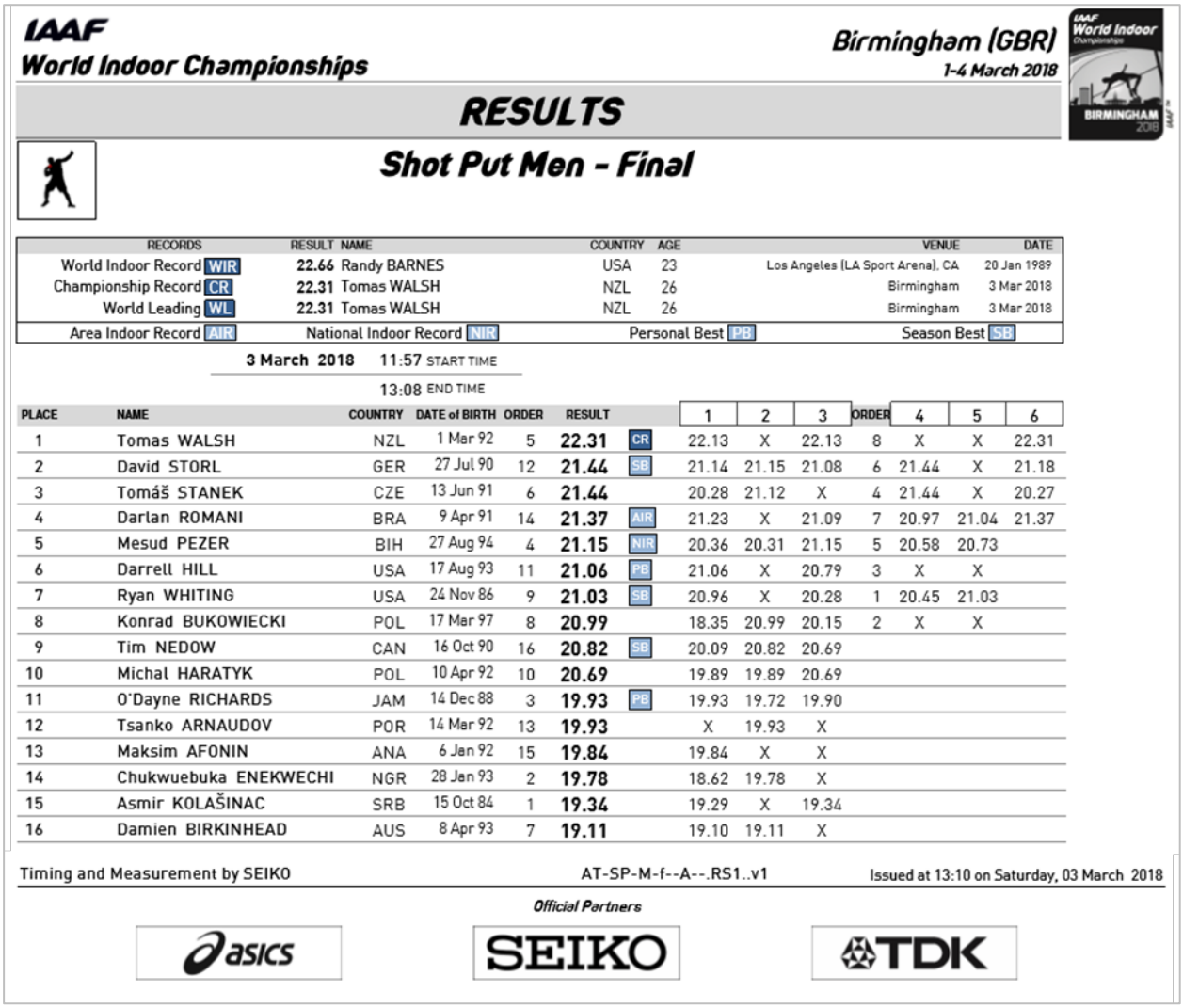
INTRODUCTION

The men's shot put took place during the daytime of Saturday 3rd March. Coming into the final, Tomáš Stanek from the Czech Republic was the favourite as he held the world leading throw in 2018. However, the world outdoor gold medallist Tomas Walsh from New Zealand took a commanding lead in the first round with a throw of 22.13 m, which he later bettered in the sixth round with a Championship record measured at 22.31 m. None of the other athletes could respond to Walsh's impressive world leading throws and as such he secured the gold medal. The silver medal was hotly contested between David Storl from Germany and Stanek. Remarkably, both athletes threw the same distance in the fourth round measured at 21.44 m, although neither athlete threw further and as such the silver medal was decided based on David Storl's superior second-best throw measured at 21.18 m. Hence, Stanek was awarded the bronze medal due to his slightly inferior second-best throw measured at 21.12 m.



IAAF World Indoor Championships — Birmingham (GBR) 1-4 March 2018

RESULTS

Shot Put Men - Final

RECORDS	RESULT	NAME	COUNTRY	AGE	VENUE	DATE
World Indoor Record WIR	22.66	Randy BARNES	USA	23	Los Angeles (LA Sport Arena), CA	20 Jan 1989
Championship Record CR	22.31	Tomas WALSH	NZL	26	Birmingham	3 Mar 2018
World Leading WL	22.31	Tomas WALSH	NZL	26	Birmingham	3 Mar 2018

Area Indoor Record AIR | National Indoor Record NIR | Personal Best PB | Season Best SB

3 March 2018 11:57 START TIME

13:08 END TIME

PLACE	NAME	COUNTRY	DATE of BIRTH	ORDER	RESULT		1	2	3	ORDER	4	5	6
1	Tomas WALSH	NZL	1 Mar 92	5	22.31	CR	22.13	X	22.13	8	X	X	22.31
2	David STORL	GER	27 Jul 90	12	21.44	SB	21.14	21.15	21.08	6	21.44	X	21.18
3	Tomáš STANEK	CZE	13 Jun 91	6	21.44		20.28	21.12	X	4	21.44	X	20.27
4	Darlan ROMANI	BRA	9 Apr 91	14	21.37	AIR	21.23	X	21.09	7	20.97	21.04	21.37
5	Mesud PEZER	BIH	27 Aug 94	4	21.15	NIR	20.36	20.31	21.15	5	20.58	20.73	
6	Darrell HILL	USA	17 Aug 93	11	21.06	PB	21.06	X	20.79	3	X	X	
7	Ryan WHITING	USA	24 Nov 86	9	21.03	SB	20.96	X	20.28	1	20.45	21.03	
8	Konrad BUKOWIECKI	POL	17 Mar 97	8	20.99		18.35	20.99	20.15	2	X	X	
9	Tim NEDOW	CAN	16 Oct 90	16	20.82	SB	20.09	20.82	20.69				
10	Michal HARATYK	POL	10 Apr 92	10	20.69		19.89	19.89	20.69				
11	O'Dayne RICHARDS	JAM	14 Dec 88	3	19.93	PB	19.93	19.72	19.90				
12	Tsanko ARNAUDOV	POR	14 Mar 92	13	19.93		X	19.93	X				
13	Maksim AFONIN	ANA	6 Jan 92	15	19.84		19.84	X	X				
14	Chukwuebuka ENEKWECHI	NGR	28 Jan 93	2	19.78		18.62	19.78	X				
15	Asmir KOLAŠINAC	SRB	15 Oct 84	1	19.34		19.29	X	19.34				
16	Damien BIRKINHEAD	AUS	8 Apr 93	7	19.11		19.10	19.11	X				

Timing and Measurement by SEIKO — AT-SP-M-f--A--.RS1..v1 — Issued at 13:10 on Saturday, 03 March 2018

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METHODS

Four vantage locations for camera placements were identified and secured at strategic locations around the arena. A total of four high-speed cameras were used to record the action during the shot put final. Four Sony PXW-FS5 cameras operating at 200 Hz (shutter speed: 1/1250; ISO: 2000-4000 depending on the light; FHD: 1920x1080 px) were positioned at the four locations to provide three-dimensional (3D) footage for the analysis of all key phases of the shot put throw.

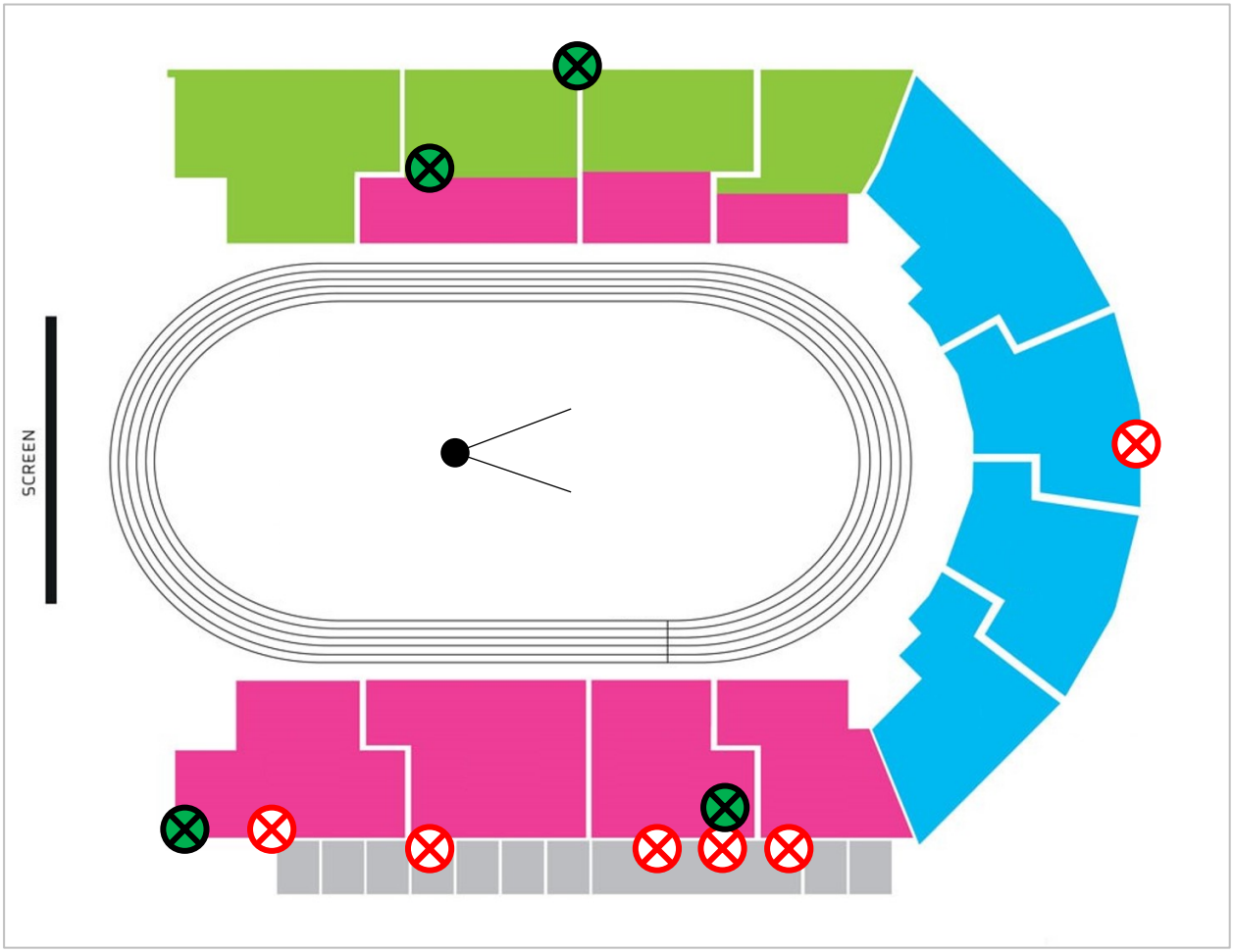

Figure 1. Camera layout for the men's shot put indicated by green-filled circles.

Before and after the 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.

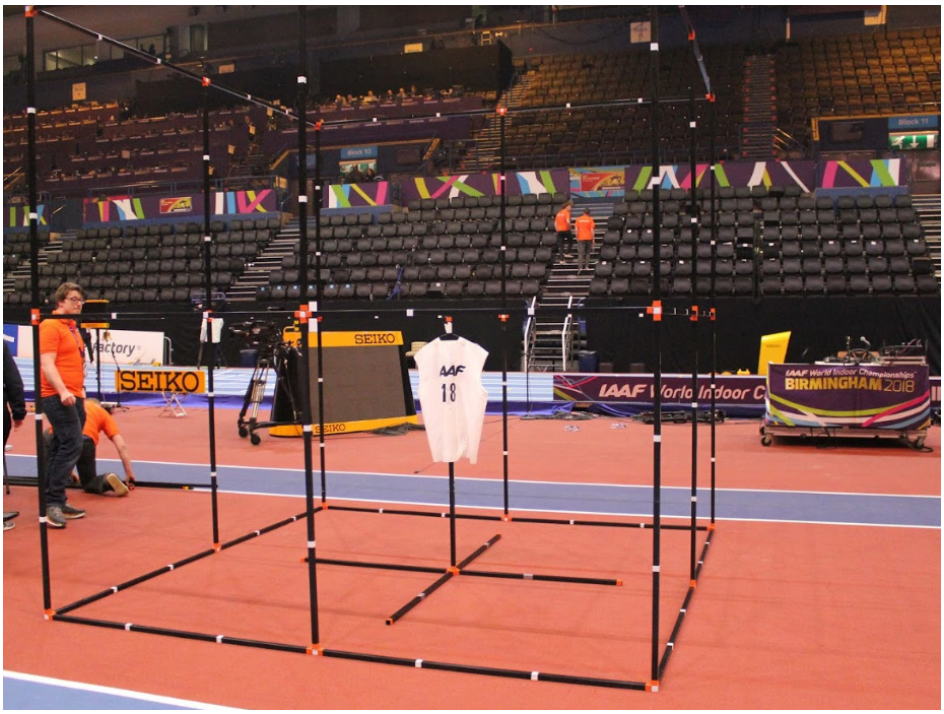

Figure 2. The calibration frame was constructed and recorded before and after the competition.

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. Definition of variables.

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.

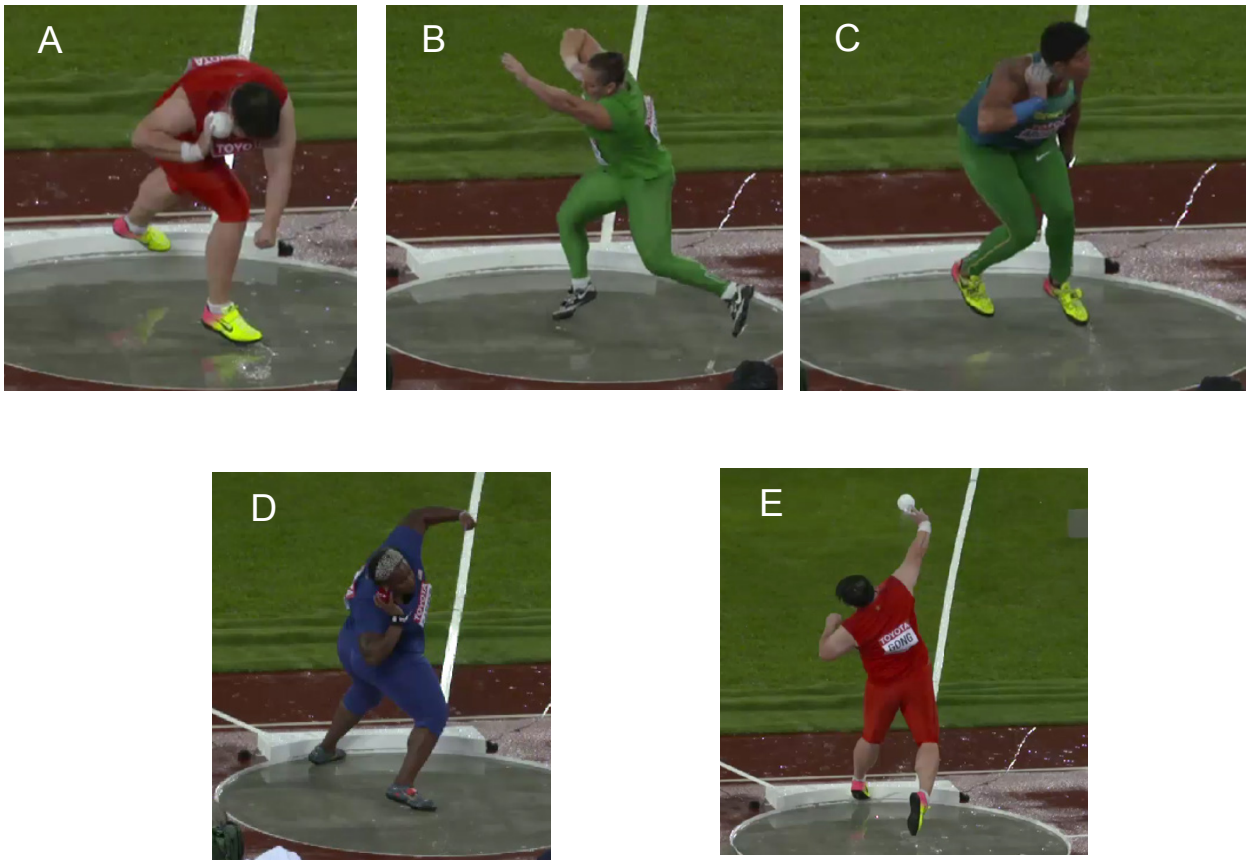

Figure 3. Visual representation of the phases for the three different techniques implemented, the power position and release. A) glide, B) rotational, C) switch glide, D) the power position and E) release.

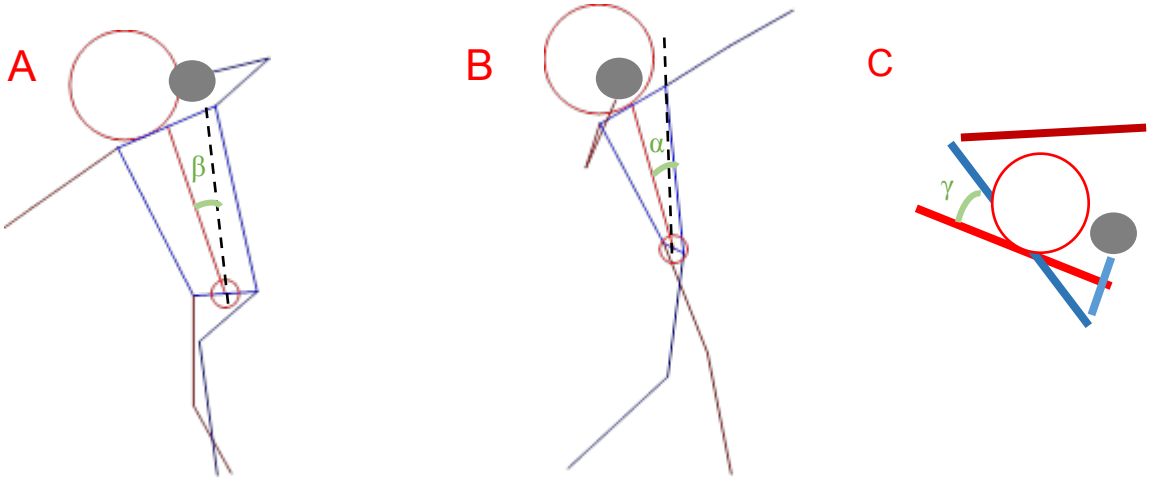

Figure 4. Visual representation of A) left trunk lean (β), B) forward-backward trunk lean (α) and C) shoulder-hip separation angle (γ).

RESULTS

Performance

Table 2 details the sixteen competitors' season's (SB) and indoor personal best (PB) throw before the World Championships, as well as a comparison with their performance in the final. Seven of the finalists threw a season's best with five throwing indoor personal bests over the course of the championship. Notably this included Walsh's Championship record put in the final round, beating Timmerman's previous best set in Indianapolis in 1987. In addition, Romani threw a South American and Brazilian Indoor Record and Pezer threw a National Indoor Record for Bosnia & Herzegovina.

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

Athlete	SB (m)	PB (m)	FP (m)	SB vs. FP (m)	PB vs. FP (m)
WALSH	21.87	21.78	22.31	0.44	0.53
STORL	21.19	21.88	21.44	0.25	−0.44
STANEK	22.17	22.17	21.44	−0.73	−0.73
ROMANI	21.68	18.50	21.37	−0.31	2.87
PEZER	20.77	20.77	21.15	0.38	0.38
HILL	20.83	20.83	21.06	0.23	0.23
WHITING	20.65	22.23	21.03	0.38	−1.20
BUKOWIECKI	22.00	22.00	20.99	−1.01	−1.01
NEDOW	20.82	21.33	20.82	0.00	−0.51
HARATYK	21.47	21.47	20.69	−0.78	−0.78
RICHARDS	19.86	19.77	19.93	0.07	0.16
ARNAUDOV	21.27	21.27	19.93	−1.34	−1.34
AFONIN	21.39	21.39	19.84	−1.55	−1.55
ENEKWECHI	20.89	20.89	19.78	−1.11	−1.11
KOLAŠINAC	20.11	20.91	19.34	−0.77	−1.57
BIRKINHEAD	20.02	21.35	19.11	−0.91	−2.24

Anthropometric data and implemented technique

Table 3 identifies that fifteen of the sixteen competitors utilised the rotational technique, whereas only Storl utilised the glide technique.

Table 3. The anthropometric data and implemented technique for the sixteen competitors.

Athlete	Height (m)	Body mass (kg)	Technique
WALSH	1.86	123	Rotational
STORL	1.99	123	Glide
STANEK	1.90	122	Rotational
ROMANI	1.88	127	Rotational
PEZER	1.96	140	Rotational
HILL	1.93	120	Rotational
WHITING	1.91	135	Rotational
BUKOWIECKI	1.91	134	Rotational
NEDOW	2.00	129	Rotational
HARATYK	1.94	140	Rotational
RICHARDS	1.78	136	Rotational
ARNAUDOV	1.98	155	Rotational
AFONIN	1.84	115	Rotational
ENEKWECHI	1.81	107	Rotational
KOLAŠINAC	1.85	132	Rotational
BIRKINHEAD	1.90	140	Rotational

Release parameters

Table 4, Figures 5 and 6 detail the release parameters of the best throws for the sixteen finalists, although because of technical challenges when recording Richards' best throw, the data presented within this report is based on his second-best throw of the finals (round 3). Walsh produced the highest release velocity (14.12 m/s) coupled with an impressive 0.33 m reach over the stop board. Stanek produced the second highest release velocity (13.76 m/s), whereas Storl produced the fourth highest release velocity (13.64 m/s). Notably, Storl optimised his angle and height of release (39.4° and 2.35 m) in comparison to Walsh (37.3° and 2.11 m) and Stanek (37.6° and 2.19 m). Romani demonstrated the greatest height of release expressed as a percentage of body height (124.4%), as well as the greatest angle of release (43.0°), although he produced the lowest release velocity (13.54 m/s) in comparison to the other top eight finalists (top eight mean

release velocity: 13.70 ± 0.18 m/s). Interestingly, all finalists leant slightly backwards at release (finalist mean: −7 ± 7°) and the majority (n = 9) leant to the right at release (finalist mean: −0 ± 5°).

Table 4. The release parameters of the best throws for the sixteen 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	22.31	14.12	37.3	2.11	113.5	0.33	−10	4
STORL	4	21.44	13.64	39.4	2.35	118.2	0.07	−3	−11
STANEK	4	21.44	13.76	37.6	2.19	115.2	0.03	−21	1
ROMANI	6	21.37	13.54	43.0	2.34	124.4	0.24	−4	−8
PEZER	3	21.15	13.69	36.1	2.19	111.7	0.34	−3	3
HILL	1	21.06	13.63	35.2	2.31	119.7	0.33	−7	8
WHITING	5	21.03	13.62	35.8	2.23	116.9	0.17	−12	−7
BUKOWIECKI	2	20.99	13.63	36.5	2.22	116.2	0.16	−19	−1
NEDOW	2	20.82	13.51	35.0	2.40	120.2	0.19	−3	0
HARATYK	3	20.69	13.49	36.4	2.17	112.0	0.24	−5	1
RICHARDS	3*	19.90	13.27	36.6	2.12	119.0	0.27	7	−4
ARNAUDOV	2	19.93	13.15	35.9	2.36	119.4	0.24	−5	2
AFONIN	1	19.84	13.24	35.6	2.11	114.5	0.23	−9	5
ENEKWECHI	2	19.78	13.24	39.4	2.08	114.9	−0.01	−11	−5
KOLAŠINAC	3	19.34	13.43	30.9	2.00	108.3	0.20	−7	7
BIRKINHEAD	2	19.11	13.31	30.7	2.16	113.7	0.23	−1	−1

***Key**: FB = forward-backward, LR = left-right lean and * = second best throw.*

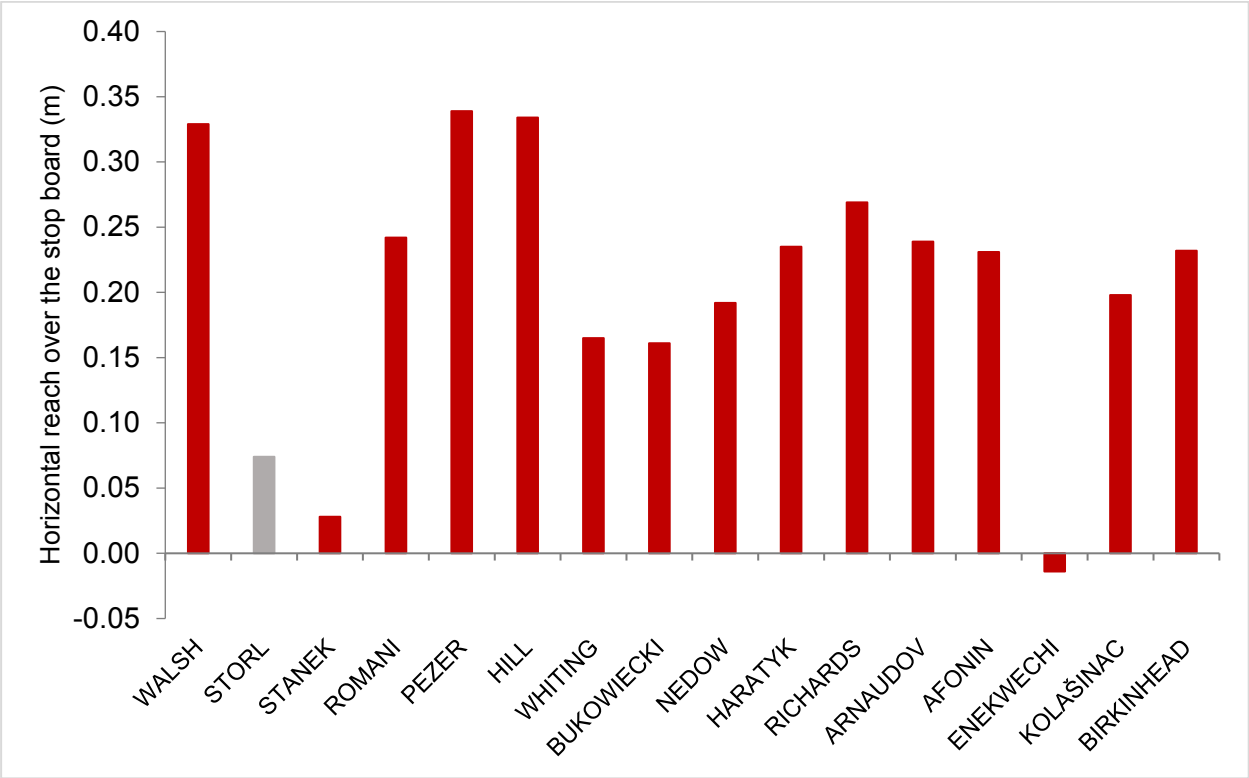

Figure 5. The reach over stop board for the sixteen athletes. The red bars signify the athletes who utilised the rotational technique and the grey bar signifies the athlete who utilised the glide technique.

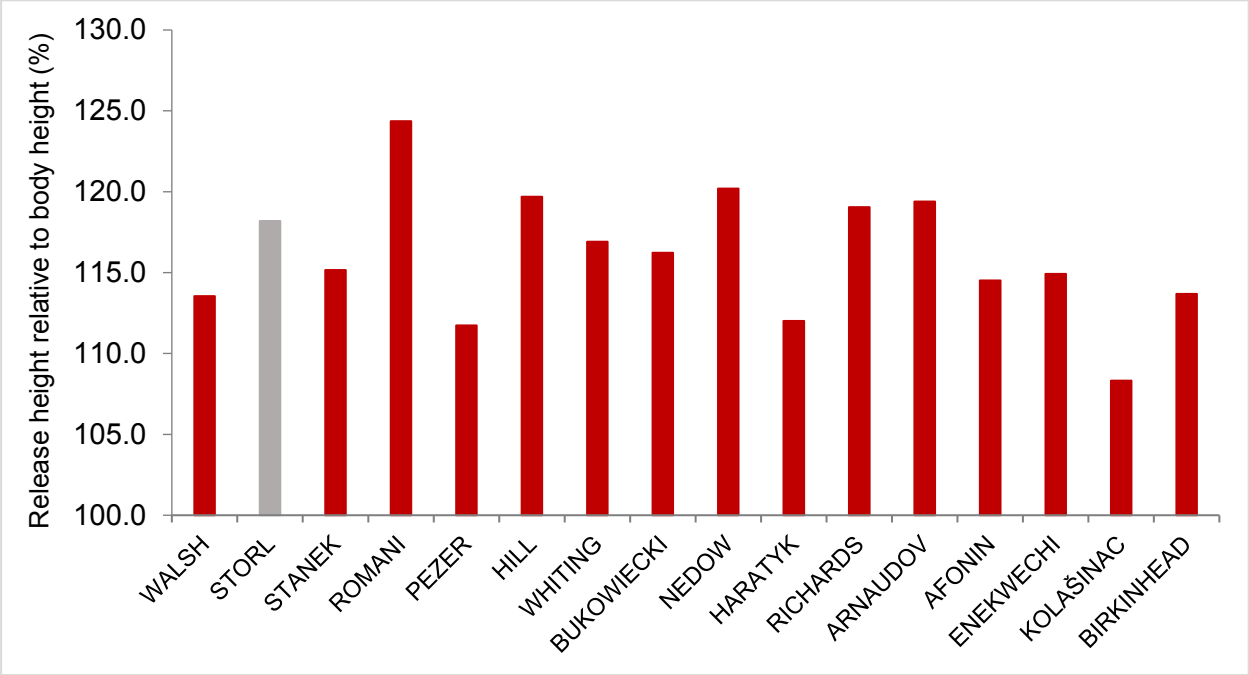

Figure 6. The height of release expressed as a percentage of body height for the sixteen athletes. The red bars signify the athletes who utilised the rotational technique and the grey bar signifies the athlete who utilised the glide technique.

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	2.78	1.16	1.51	2.74	11.21	12.96	14.12
STANEK	2.33	2.88	1.69	1.93	12.49	11.96	13.76
ROMANI	2.54	1.07	1.35	1.09	11.95	12.32	13.54
PEZER	2.23	1.76	1.27	1.04	10.32	10.32	13.69
HILL	2.85	1.71	1.55	0.95	10.32	11.48	13.63
WHITING	2.24	2.72	0.74	1.27	13.23	13.51	13.62
BUKOWIECKI	2.77	1.59	1.05	1.50	10.10	10.89	13.63
NEDOW	1.60	1.83	2.33	1.68	9.91	8.58	13.51
HARATYK	2.02	1.33	1.21	2.73	9.88	12.55	13.49
RICHARDS	2.19	1.29	1.18	1.19	11.57	12.44	13.27
ARNAUDOV	1.55	2.62	1.11	1.52	10.27	10.27	13.15
AFONIN	2.09	1.32	1.64	2.55	10.76	9.36	13.24
ENEKWECHI	1.67	1.90	0.94	1.68	12.91	11.79	13.24
KOLAŠINAC	2.39	2.14	1.79	1.77	10.94	10.94	13.43
BIRKINHEAD	1.81	2.04	1.65	2.16	8.12	11.88	13.31

Table 5 and 6 show the velocity of the shot at key phases. Notably, Hill and Pezer gained the most velocity (12.68 and 12.65 m/s) within the power position in comparison to the other finalists who utilised the rotational technique. Interestingly, Walsh gained the least velocity (11.38 m/s)

within the power position in comparison to the top eight rotational athletes. However, Walsh entered the power position with the highest velocity (2.74 m/s) in comparison to the fifteen other finalists who utilised the same technique (finalists mean: 1.72 ± 0.6 m/s). Only Storl entered the power position with a higher velocity (2.89 m/s) using the glide technique although he was unable to gain as much velocity before release (10.74 m/s). Interestingly, all finalists delivered the shot without being in contact with the ground and most of the athletes delivered the shot with this sequence: right leg take-off, brace leg take-off and release. However, both Nedow and Enekwechi delivered the shot with a different sequence, whereby their brace leg took-off before their right leg. Furthermore, Pezer, Arnaudov and Kolašinac demonstrated a simultaneous double-footed take-off.

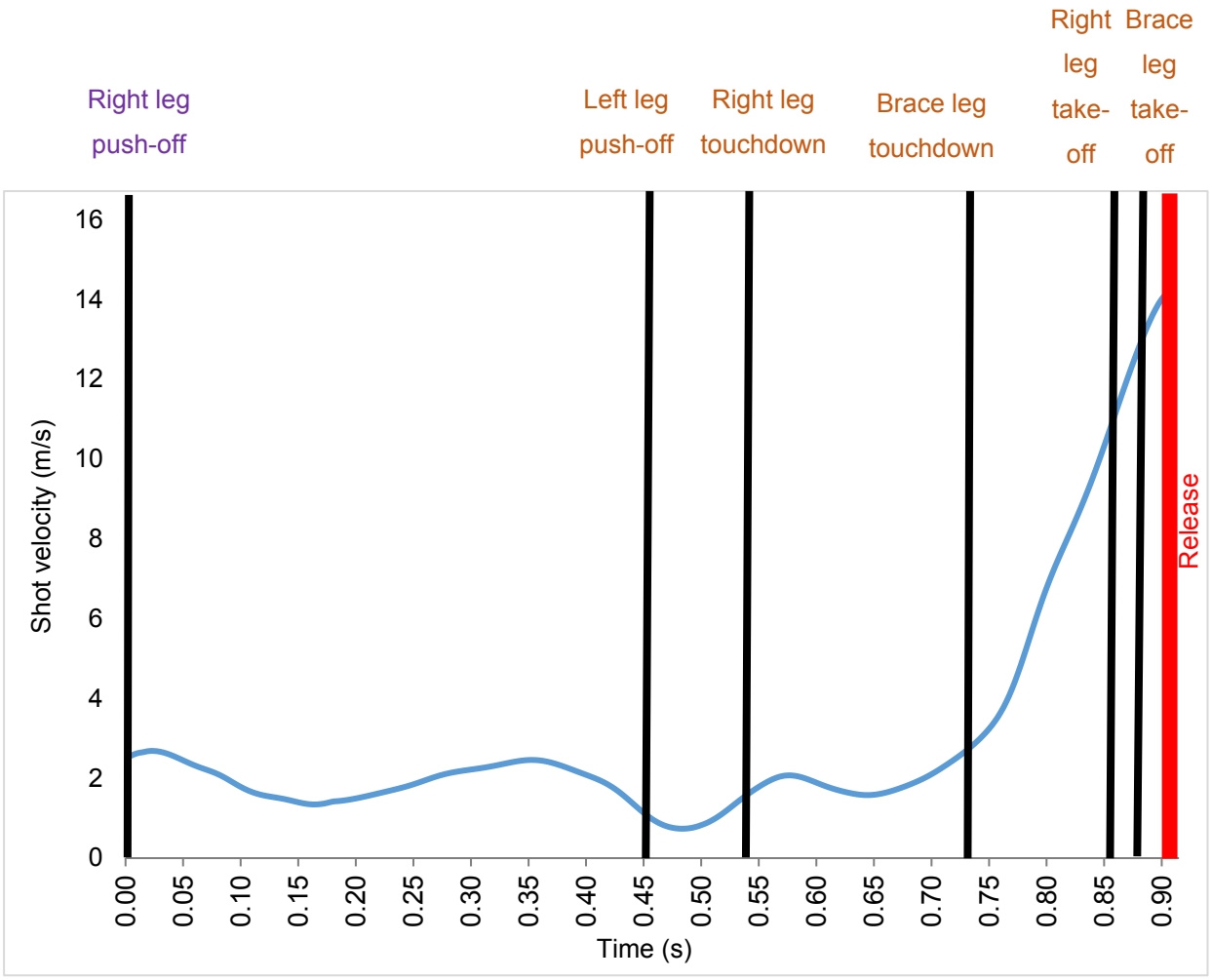

Figure 8. Walsh's velocity profile of the shot from right leg push-off to release.

Figure 9 provides a visual description of each key phase in the glide technique. Table 6 details the 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.

Athlete	Right 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)
STORL	3.49	2.69	2.89	9.79	11.43	13.64

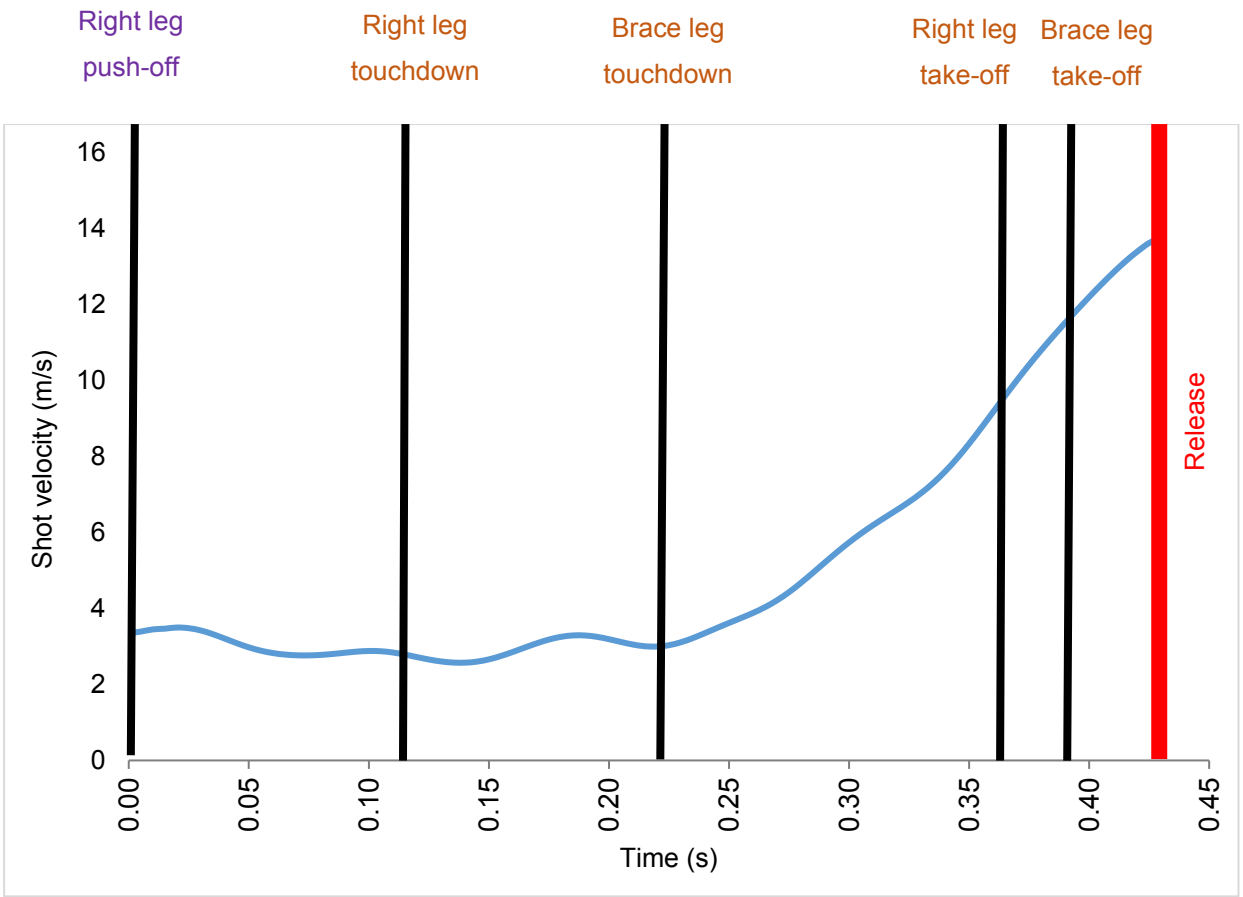

Figure 10. Storl's velocity profile of the shot from right leg push-off to release.

Path of the shot during the key phases

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

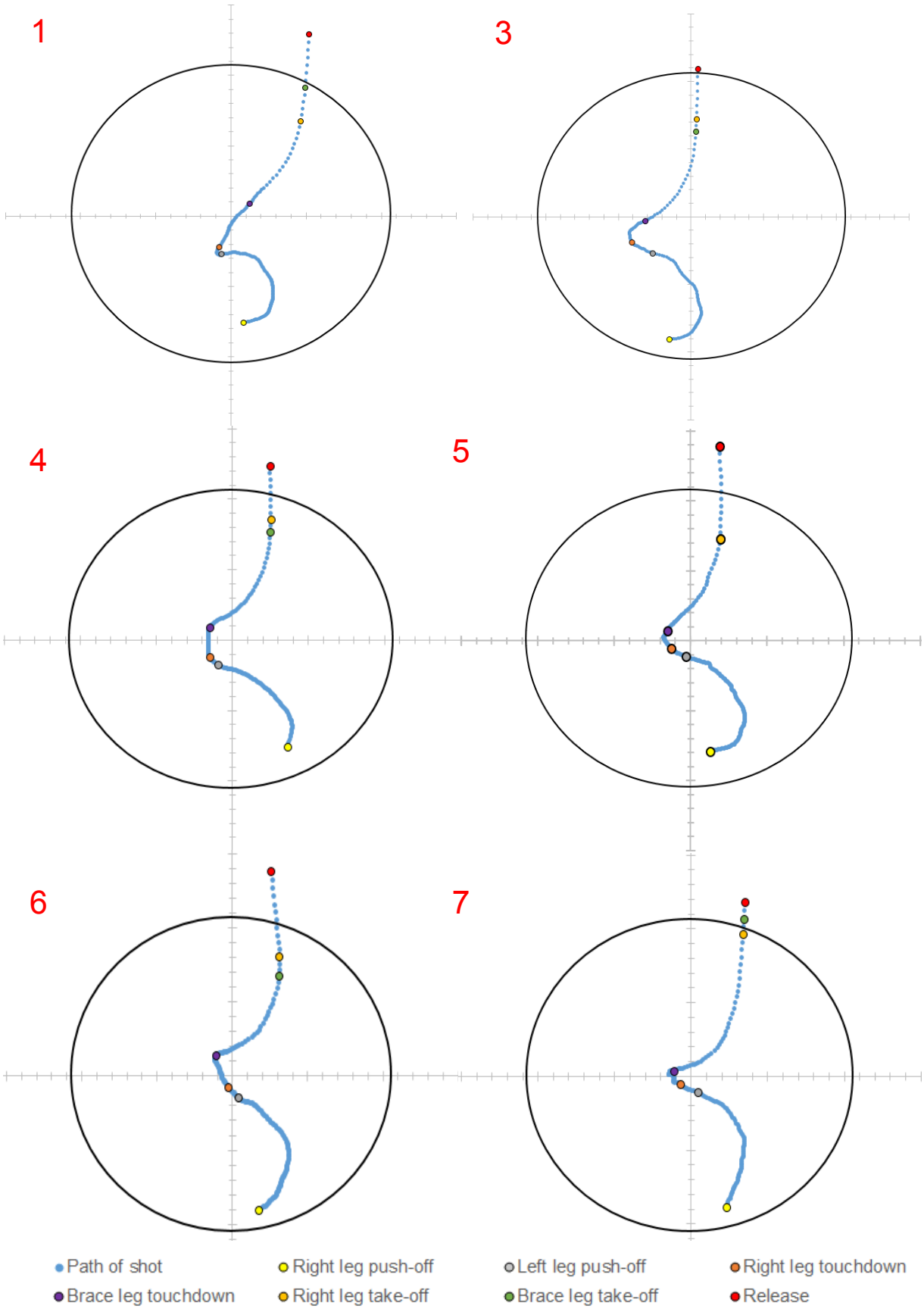

Figure 11. A visual representation from a superior view of the path of the shot from right leg push-off to release. Key: 1) Walsh, 3) Stanek, 4) Romani 5) Pezer, 6) Hill, 7) Whiting, 8) Bukowiecki, 9) Nedow, 10) Haratyk 11) Richards, 12) Arnaudov, 13) Afonin, 14) Enekwechi, 15) Kolašinac 16) Birkinhead.

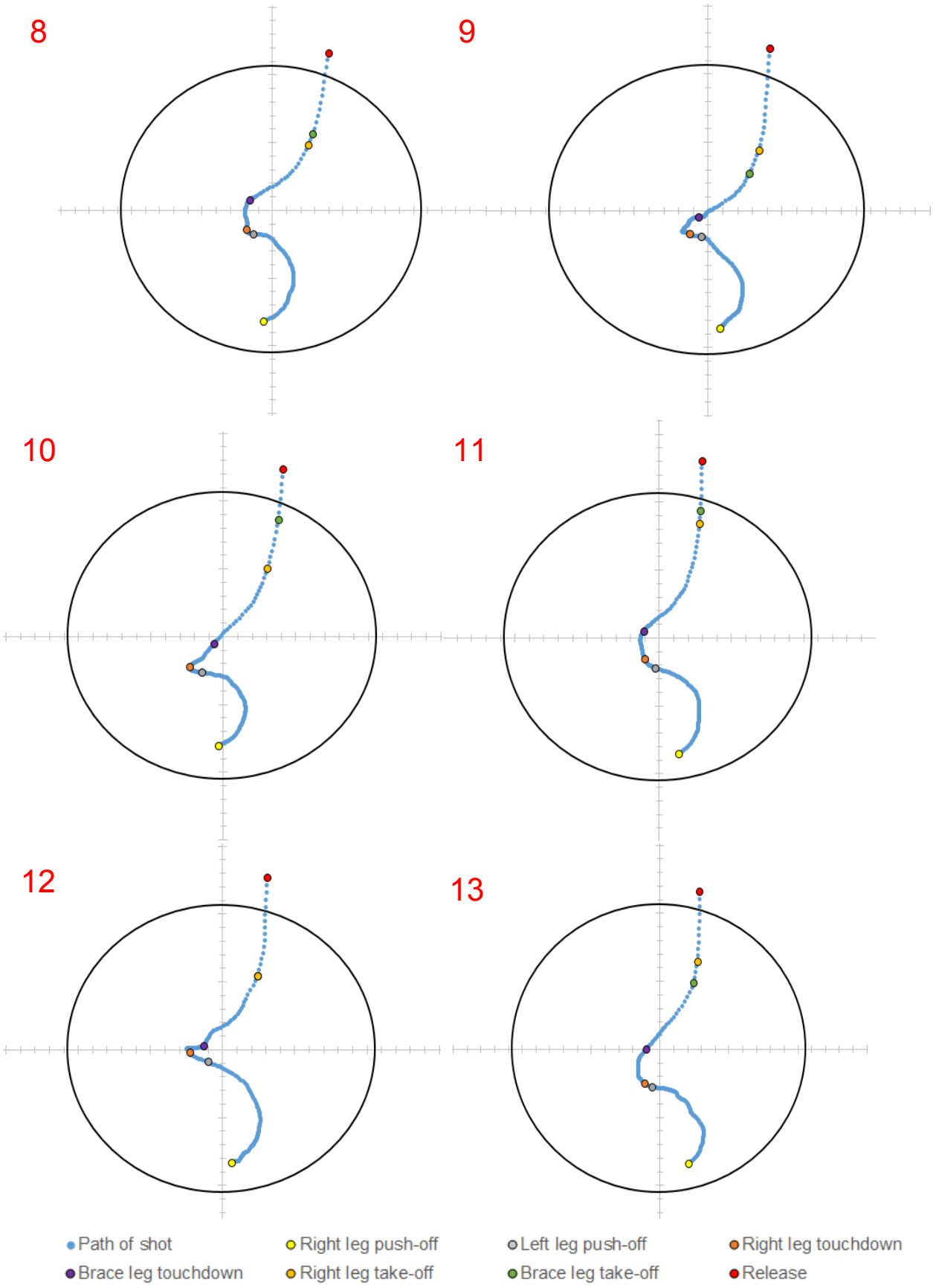

Figure 11 continued. A visual representation from a superior view of the path of the shot from right leg push-off to release. Key: 1) Walsh, 3) Stanek, 4) Romani 5) Pezer, 6) Hill, 7) Whiting, 8) Bukowiecki, 9) Nedow, 10) Haratyk 11) Richards, 12) Arnaudov, 13) Afonin, 14) Enekwechi, 15) Kolašinac 16) Birkinhead.

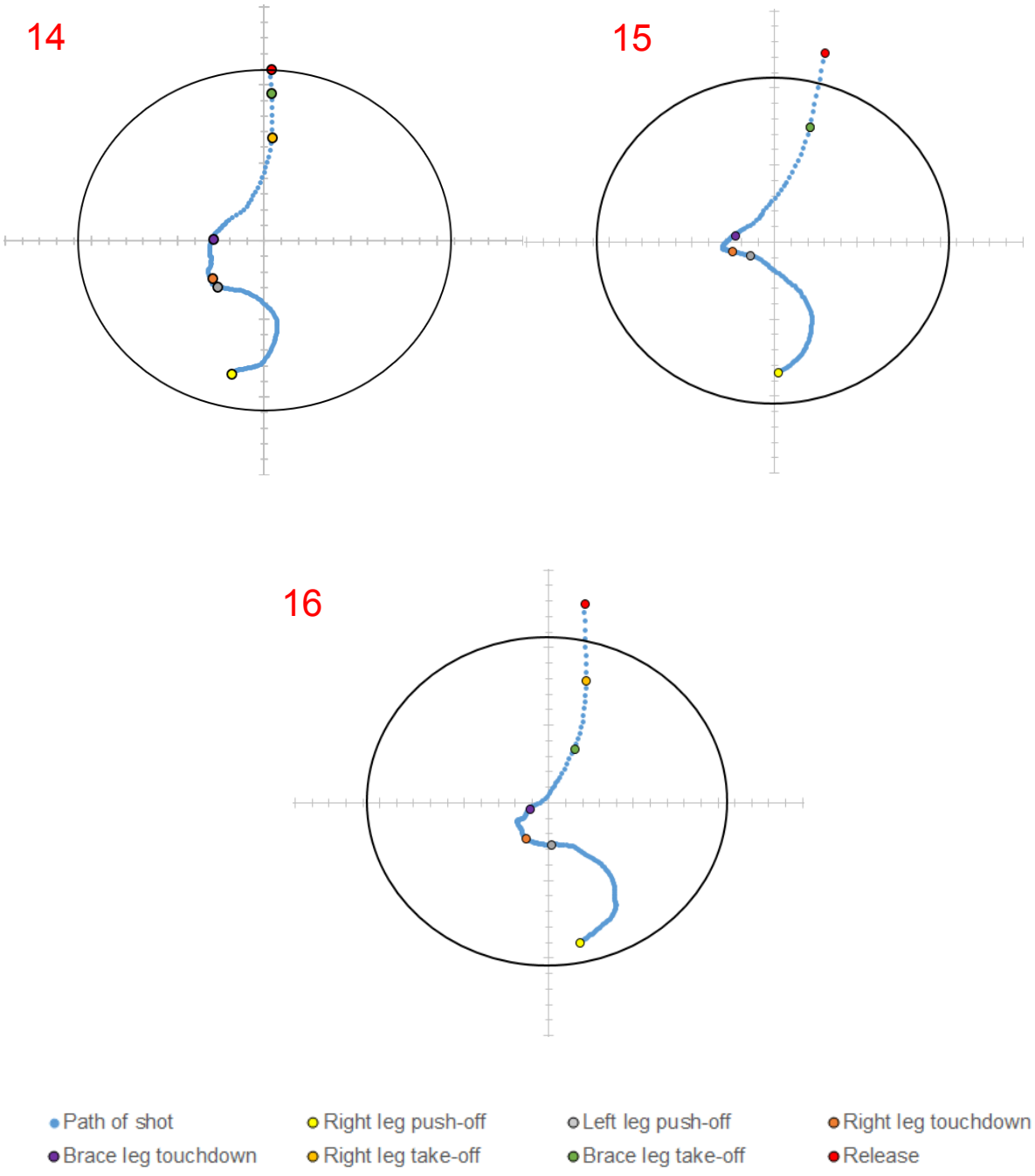

Figure 11 continued. A visual representation from a superior view of the path of the shot from right leg push-off to release. Key: 1) Walsh, 3) Stanek, 4) Romani 5) Pezer, 6) Hill, 7) Whiting, 8) Bukowiecki, 9) Nedow, 10) Haratyk 11) Richards, 12) Arnaudov, 13) Afonin, 14) Enekwechi, 15) Kolašinac 16) Birkinhead.

Table 7. The path length of the shot depicting the key phases for the athletes who 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 touchdown to left leg touchdown (m)	Left leg touchdown to release (m)	Total path (m)
WALSH	0.87	0.10	0.40	1.59	2.96
STANEK	0.98	0.18	0.27	1.55	2.98
ROMANI	0.88	0.08	0.26	1.73	2.95
PEZER	1.03	0.11	0.17	1.67	2.98
HILL	0.99	0.10	0.27	1.75	3.11
WHITING	0.99	0.15	0.31	1.59	3.04
BUKOWIECKI	0.94	0.07	0.25	1.54	2.80
NEDOW	0.87	0.09	0.24	1.75	2.95
HARATYK	0.82	0.15	0.28	1.68	2.93
RICHARDS	0.88	0.10	0.25	1.65	2.88
ARNAUDOV	1.03	0.16	0.24	1.72	3.15
AFONIN	0.85	0.07	0.31	1.50	2.73
ENEKWECHI	0.95	0.07	0.29	1.49	2.80
KOLAŠINAC	1.02	0.11	0.20	1.54	2.87
BIRKINHEAD	1.01	0.17	0.31	1.62	3.11

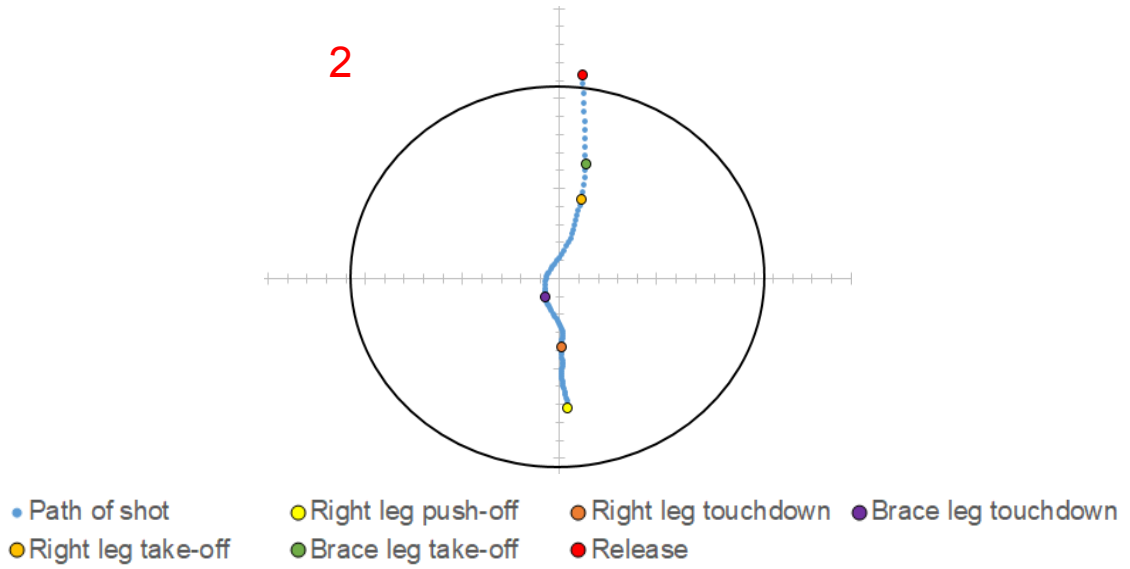

Figure 12. A visual representation from a superior view of the path of the shot from right leg push-off to release. Key. 2) Storl.

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

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	0.36	0.31	1.70	2.37

Figure 13 details the total path length of the shot for the sixteen athletes. Notably, Arnaudov's total path length was the largest with 3.15 m, whereas Walsh's path length was relatively modest with 2.96 m. Storl's total path length utilising the glide technique was by far the shortest with 2.37 m.

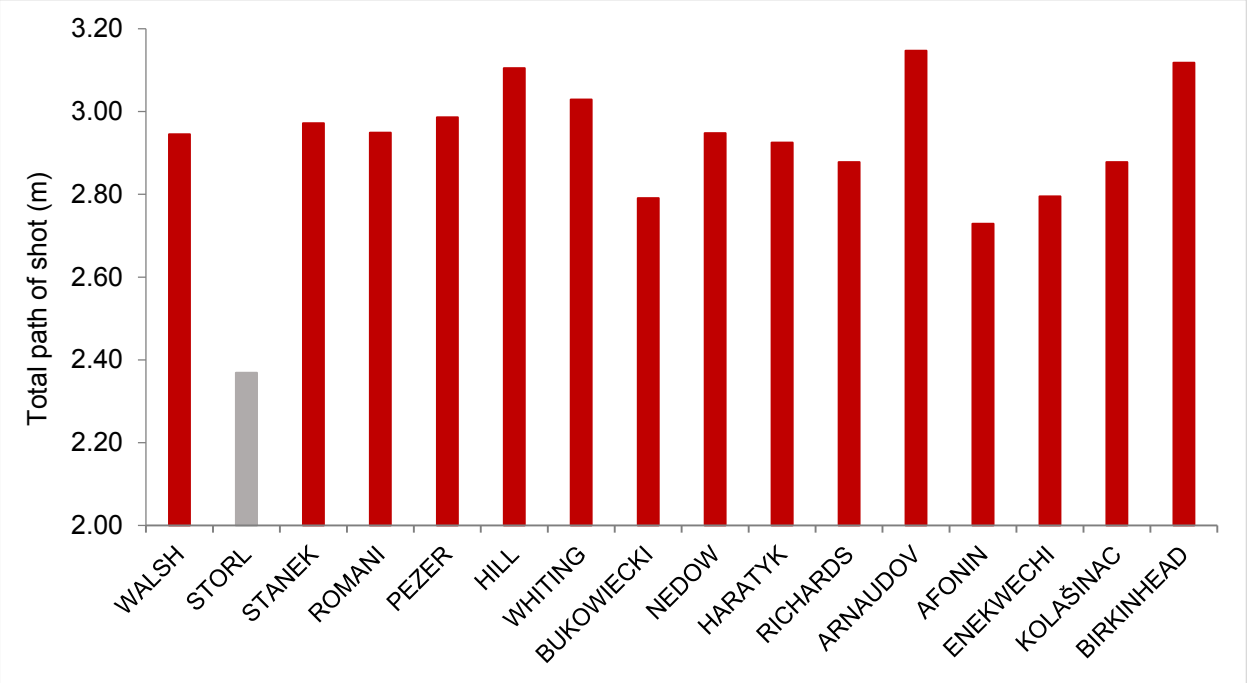

Figure 13. The total path length of the shot for the sixteen finalists. The red bars signify the athletes who utilised the rotational technique and the grey bar signifies the athlete who utilised the glide technique.

Figure 14 shows the individual motion paths (from a side-on view) for the athletes who utilised the rotational technique. Following Figure 14, Table 9 shows the vertical position of the shot through each key phase of the rotational technique. Romani gained the most height (1.14 m) from the brace leg touchdown to release with respects to the other rotational athletes.

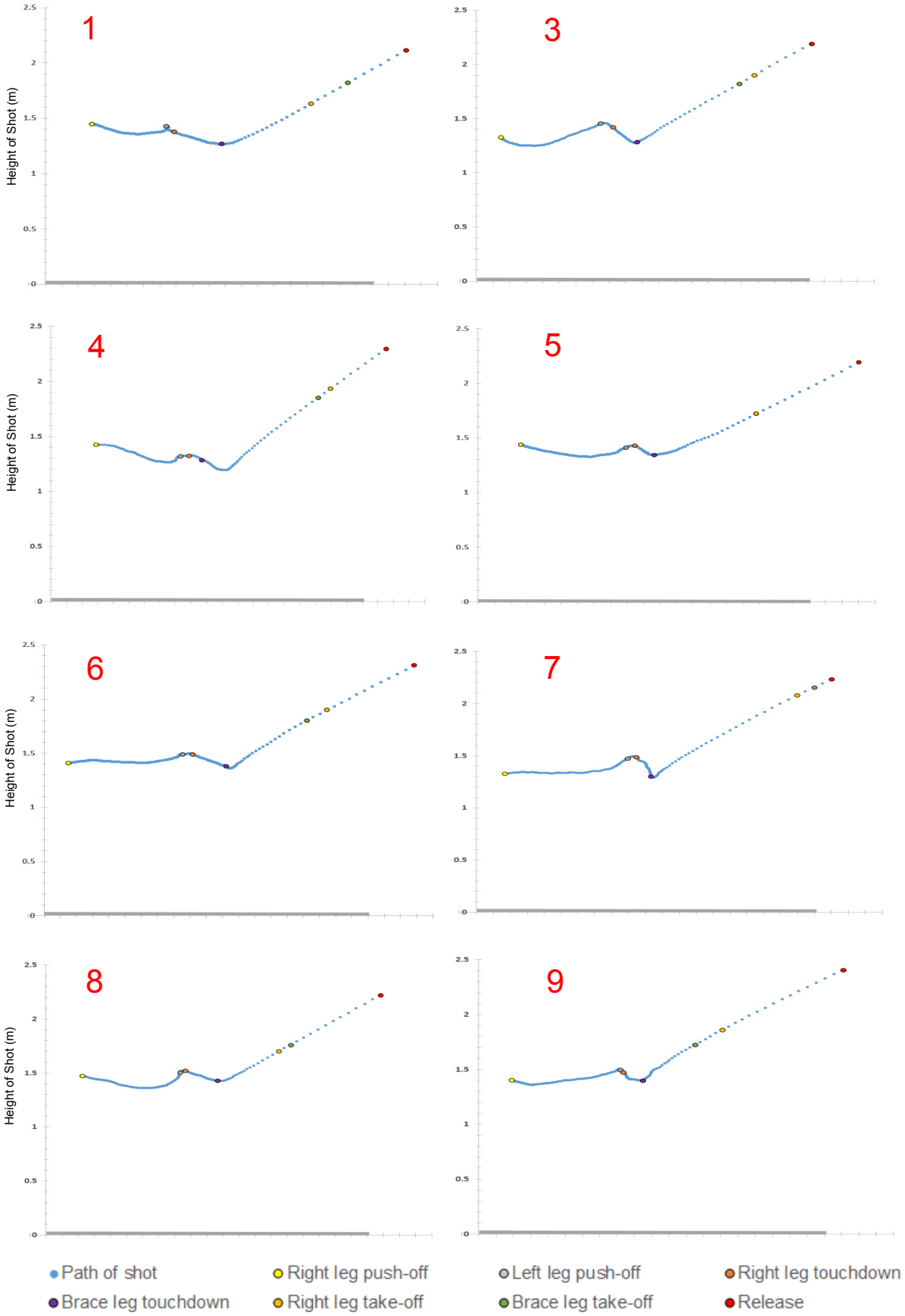

Figure 14. A visual representation from a side on view of the path of the shot from right leg push-off to release. Key: 1) Walsh, 3) Stanek, 4) Romani 5) Pezer, 6) Hill, 7) Whiting, 8) Bukowiecki, 9) Nedow, 10) Haratyk, 11) Richards, 12) Arnaudov, 13) Afonin, 14) Enekwechi, 15) Kolašinac,16) Birkinhead.

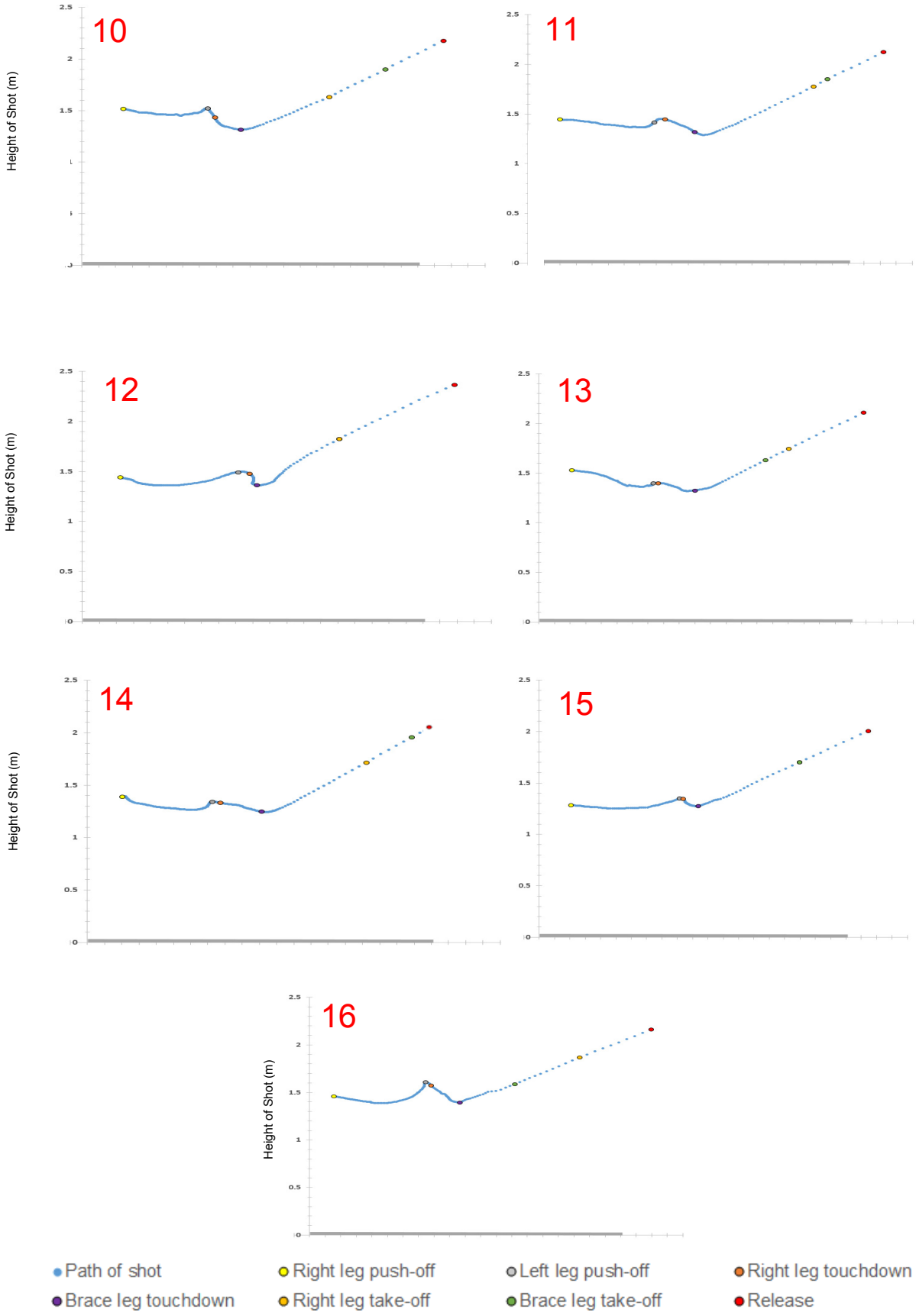

Figure 14 continued. A visual representation from a side on view of the path of the shot from the right leg push-off to release. Key: 1) Walsh, 3) Stanek, 4) Romani 5) Pezer, 6) Hill, 7) Whiting, 8) Bukowiecki, 9) Nedow, 10) Haratyk,11) Richards, 12) Arnaudov, 13) Afonin, 14) Enekwechi, 15) Kolašinac, 16) Birkinhead.

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	1.45	1.43	1.37	1.27	2.11
STANEK	1.33	1.45	1.42	1.28	2.19
ROMANI	1.42	1.32	1.32	1.20	2.34
PEZER	1.44	1.41	1.42	1.34	2.19
HILL	1.41	1.49	1.49	1.38	2.31
WHITING	1.33	1.47	1.49	1.30	2.23
BUKOWIECKI	1.47	1.50	1.52	1.43	2.22
NEDOW	1.40	1.49	1.47	1.40	2.40
HARATYK	1.52	1.52	1.43	1.31	2.17
RICHARDS	1.45	1.42	1.44	1.32	2.12
ARNAUDOV	1.44	1.49	1.48	1.36	2.36
AFONIN	1.53	1.40	1.40	1.32	2.11
ENEKWECHI	1.39	1.34	1.33	1.25	2.08
KOLAŠINAC	1.28	1.35	1.34	1.28	2.00
BIRKINHEAD	1.46	1.61	1.57	1.39	2.16

Figure 15 shows the individual motion path (from a side-on view) for the athlete who utilised the glide technique. Following Figure 15, Table 10 shows the vertical position of the shot through each key phase of the glide technique.

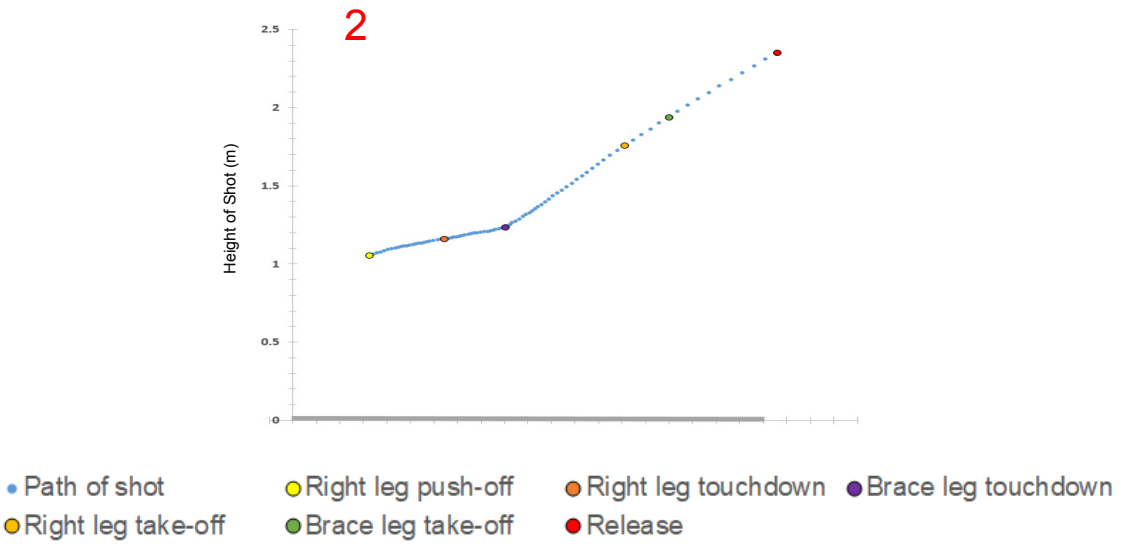

Figure 15. A visual representation from a side on view of the path of the shot from the right leg push-off to release. Key: 2) Storl.

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	1.06	1.16	1.23	2.35

Notably, Figure 16 shows Romani and Storl gained the most height (1.14 m and 1.12 m, respectively) from the brace leg touchdown in comparison to the other finalists.

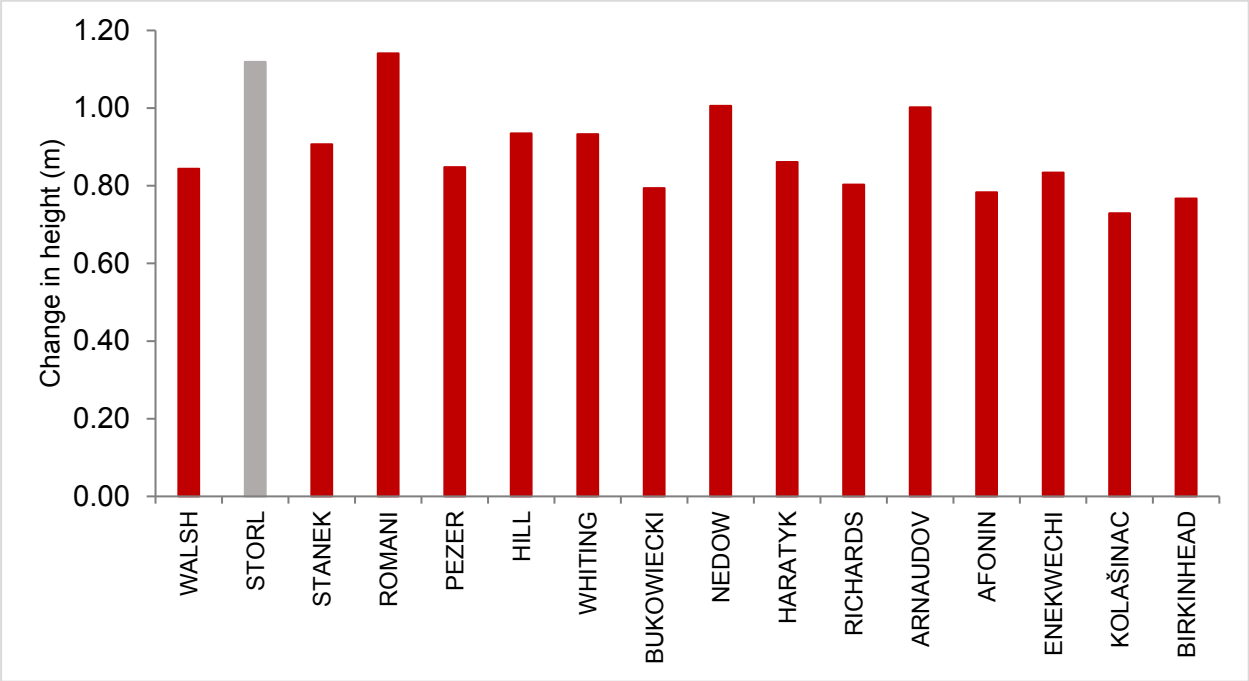

Figure 16. The height gained from the touchdown of the brace leg to release for the sixteen athletes. The red bars signify the athletes who utilised the rotational technique and the grey bar signifies the athlete who utilised the glide technique.

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	0.445	0.095	0.195	0.180
STANEK	0.420	0.090	0.185	0.185
ROMANI	0.490	0.070	0.205	0.255
PEZER	0.530	0.075	0.200	0.245
HILL	0.490	0.060	0.200	0.250
WHITING	0.395	0.070	0.180	0.225
BUKOWIECKI	0.455	0.065	0.225	0.195
NEDOW	0.460	0.035	0.205	0.255
HARATYK	0.455	0.120	0.150	0.200
RICHARDS	0.445	0.085	0.165	0.245
ARNAUDOV	0.480	0.070	0.210	0.255
AFONIN	0.535	0.045	0.215	0.205
ENEKWECHI	0.455	0.065	0.190	0.215
KOLAŠINAC	0.390	0.055	0.215	0.205
BIRKINHEAD	0.445	0.100	0.190	0.205

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	0.115	0.105	0.215

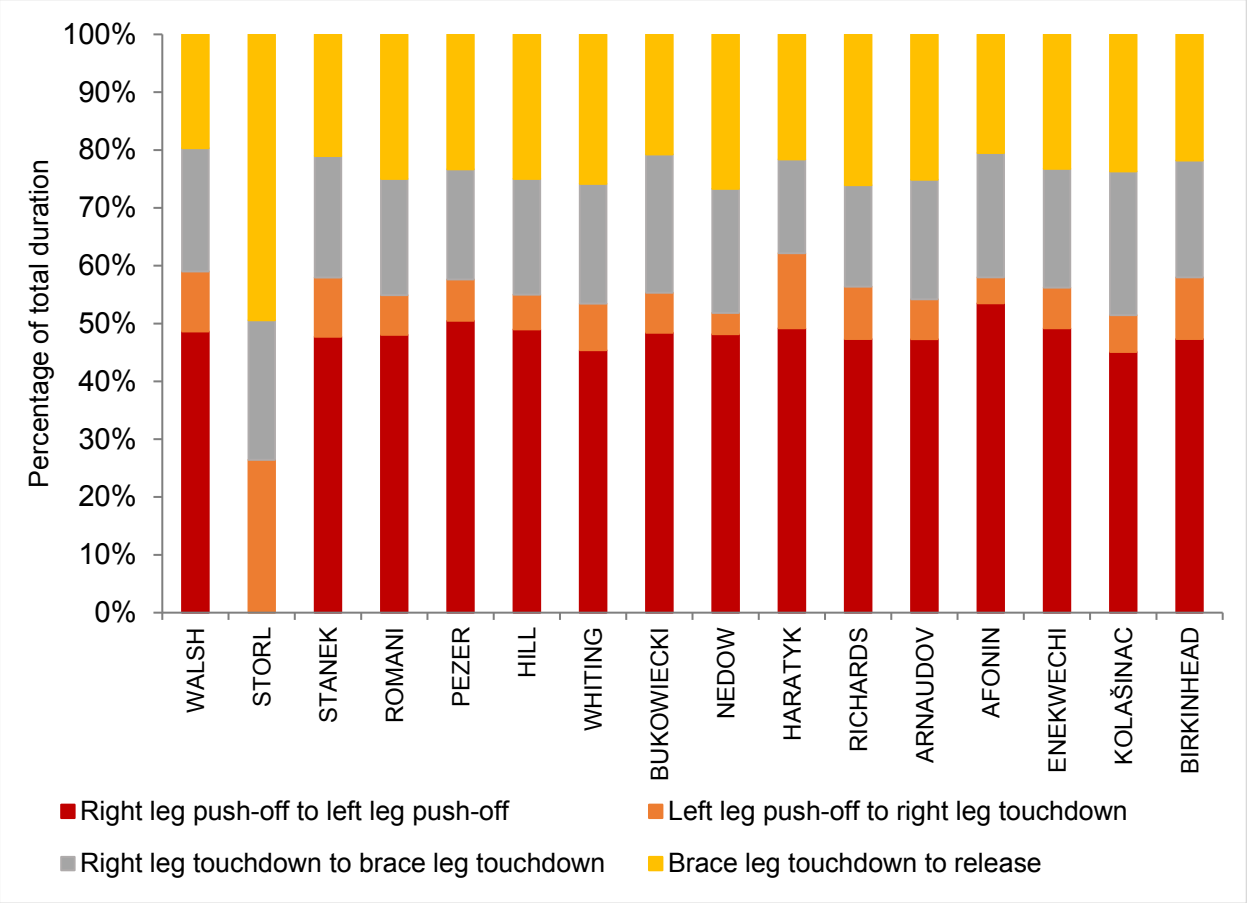

Figure 17. The time taken to perform each of the key phases, expressed as a percentage of the total duration for the sixteen athletes. Please note, Storl utilised the glide technique and as such, the orange phase signifies a right leg push-off to right leg touchdown.

Distance travelled across the circle

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

Athlete	Distance of glide / flight phase (m)	Distance in power position (m)	Distance in glide / flight phase (%)	Distance in power position (%)
WALSH	0.99	0.88	53	47
STORL	0.92	1.11	45	55
STANEK	1.20	0.66	65	35
ROMANI	1.02	0.87	54	46
PEZER	0.98	0.77	56	44
HILL	1.04	0.80	57	43
WHITING	1.07	0.66	62	38
BUKOWIECKI	1.06	0.67	61	39
NEDOW	1.01	0.68	60	40
HARATYK	0.82	0.95	46	54
RICHARDS	1.04	0.77	57	43
ARNAUDOV	1.17	0.67	64	36
AFONIN	1.09	0.80	58	42
ENEKWECHI	1.16	0.78	60	40
KOLAŠINAC	1.03	0.64	62	38
BIRKINHEAD	0.79	0.85	48	52

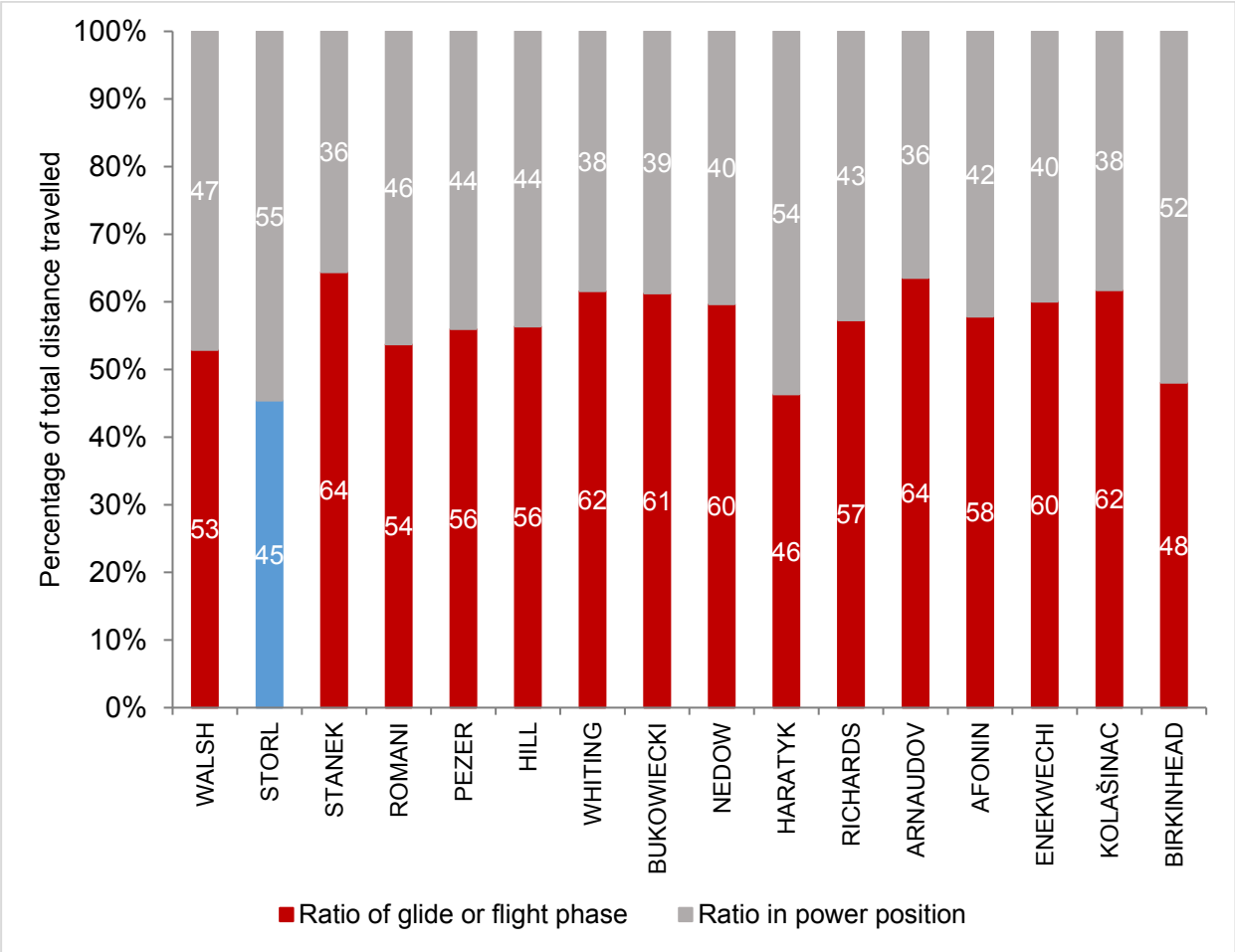

Figure 18. The percentage of total distance travelled in the glide/flight phase and power position for the sixteen athletes. The red bars signify the athletes that used the rotational technique and the blue bar signifies the athlete that used the glide technique.

Shoulder-hip separation angle

Tables 14 and 15, as well as Figures 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. 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, the three medallists Walsh (54°), Storl (36°) and Stanek (40°) produced the smallest changes in shoulder-hip separation angle within the power position. In contrast, Hill produced the largest (116°) change in shoulder-hip separation angle within the power position.

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

Athlete	Right leg push-off (°)	Left leg push-off (°)	Right leg touchdown (°)	Brace leg touchdown (°)	Release (°)
WALSH	4	8	14	30	−24
STANEK	−22	18	26	33	−7
ROMANI	−7	3	15	66	−17
PEZER	1	3	3	82	−4
HILL	−8	10	9	85	−31
WHITING	−35	10	14	31	−24
BUKOWIECKI	0	11	18	61	1
NEDOW	−8	17	1	67	−3
HARATYK	−5	13	17	35	−25
RICHARDS	−35	25	17	81	−21
ARNAUDOV	−7	9	12	52	−25
AFONIN	−9	4	−1	46	−6
ENEKWECHI	−10	8	−5	48	−19
KOLAŠINAC	−31	24	13	53	−4
BIRKINHEAD	−17	5	18	43	−10

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	38	19	25	−11

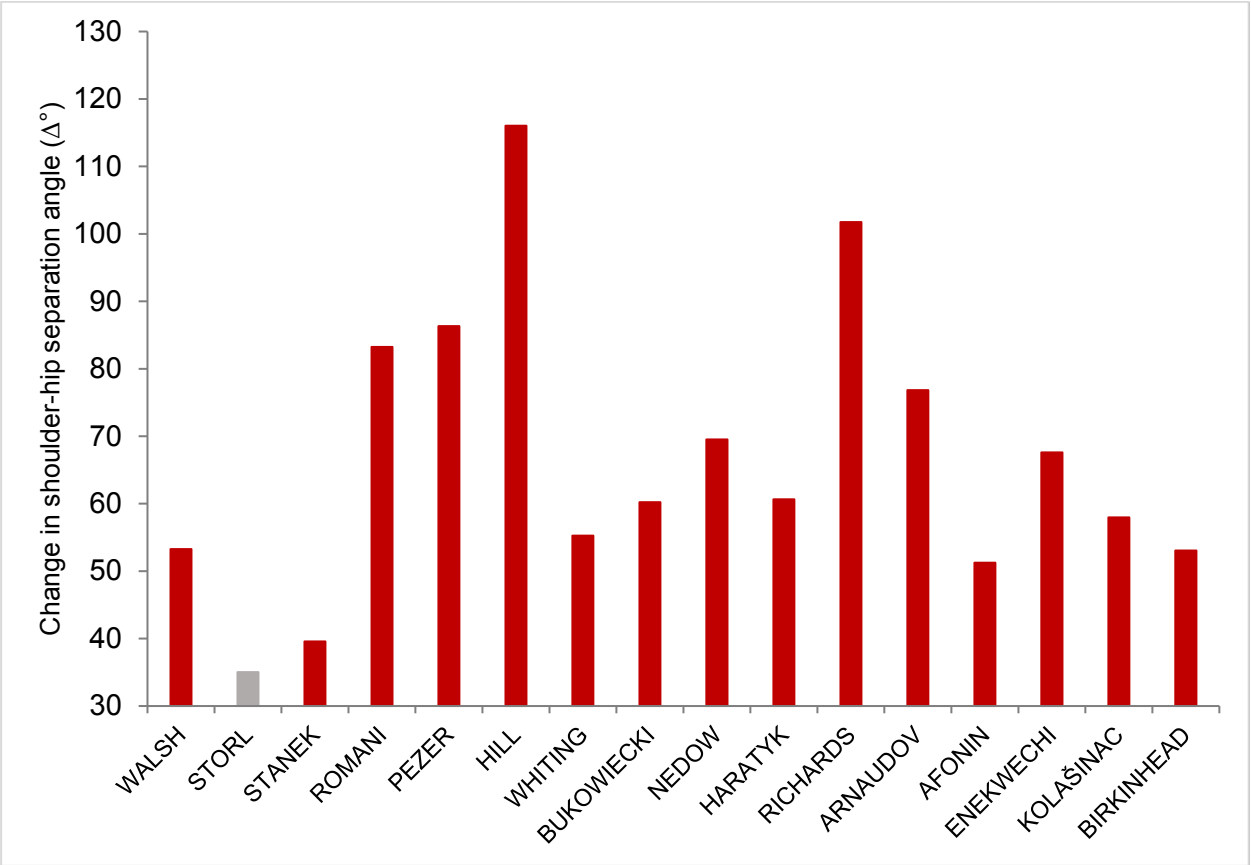

Figure 19. The change in shoulder-hip separation angle between the touchdown of the brace leg and release for the sixteen athletes. The red bars signify the athletes who utilised the rotational technique and the grey bar signifies the athlete who utilised the glide technique.

COACH'S COMMENTARY

The men's shot put competition at IAAF World Indoor Championships Birmingham 2018 was run as a straight final, and this report contained data from the best attempt of each of an invited field of 16 athletes. This provided additional data points to the report from the IAAF World Championships London 2017, where only 12 athletes that qualified for the final were studied. This also offered the opportunity to compare some of the data points of the same athlete between the two championships and look for any significant differences or changes between the two competitions.

The most obvious point that came out of these two competitions was that only the single glider: David Storl, was representative of this technique in both competitions, reflective of the continued development of the rotational technique among top male athletes. In addition to Storl, a further 6 athletes took part in both the London 2017 Final and Birmingham 2018, allowing for some comparisons of these athletes over the two competitions, looking at any noticeable differences or similarities, as well as any notable performances by newcomers that were not part of the London 2017 study.

Notably, it was Tom Walsh of New Zealand who won both competitions, but in Birmingham he threw 28 cm further, (22.31 m vs. 22.03 m) with a 2.2° increase in release angle, (37.3° vs 35.1°) while only losing 0.03 m/s (14.12 m/s vs. 14.15 m/s) on the speed of delivery. Basically, he was able to time the throw to get more lift and throw higher than what he did on his best throw in London. This was evidenced by a relative increase of 12° to his LR trunk lean at release. The question is what factors cause the adjustment of the delivery position to get the increase in these variables (along with a 10 cm increase in reach over the stop-board).

When looking at the timing and rhythm of Walsh's best throws from both competitions, as determined by the velocity of the shot at key phases (Table 5) and his velocity profile (Figure 8), they are remarkably similar showing a very stable technique. The only significant difference was a slight increase in the speed of the implement of 0.4 m/s at right leg push-off at the start of the throw in Birmingham over London (2.78 m/s vs 2.38 m/s). This indicates that he was applying more speed at the start of the throw, but interestingly all relative velocities at the other key points through the throw, were marginally down on his London throw by up to 0.1-0.2 m/s, and the resultant release velocity being 14.12 m/s compared to 14.15 m/s.

The increase in release angle was clearly a significant factor here, being 2.2° closer to the theoretical optimum. However, when also looking at the path length of the implement through the key phases (Table 7) we can see another significant factor, namely a large increase on path length at the key delivery phase from left leg touchdown to release of 0.2 m over Walsh's London

throw (1.59 m vs. 1.39 m). This also contributed to an overall increase in the total path length of the shot from 2.77 m in London where Walsh had one of the shortest overall path length of all the rotational throwers, to a much longer 2.96 m. When we take into consideration the major improvement in the left/right trunk lean at release from −8° in London, indicating that he was pulling his left shoulder away at delivery. This compares to the +4° in Birmingham, which allowed a longer contact with the shot at delivery and led to a 10 cm improvement in the reach over the stop-board at release, or in simple terms he was “better connected” to the shot all the way through to release.

David Storl, the only glider to feature in either competition had the biggest increase in performance between the two competitions with a 64 cm improvement. Both his release velocity (+0.21 m/s) and angle of release were increased (+1.2°) up to a near optimal 39.4°. From what we hear when speaking to coaches and athletes and what we witnessed in London 2017, this was not due to increased fitness since training appeared to indicate that he was in 22 m shape in 2017. It was due to execution. In terms of delivery position, Storl’s LR trunk lean decreased by 10°, and his height of release was an amazing 13 cm higher than his best throw of 2017 at 2.35 m.

Most importantly, a coaching change after London 2017, and perhaps a difference in philosophy in the physical preparation, meant that Storl notably switched back from a fixed foot delivery, with a slow reverse only well after release, to a more active (jump) reverse where he was able to carry more speed through the final delivery. This technique change was also marked by a more deliberate and powerful start as depicted in Table 6, where a marked increase of 0.6 m/s in the velocity of the shot at the initial key phase of right foot push-off was 3.49 m/s in Birmingham compared to 2.89 m/s in London. This was continued through the throw, but most significantly at the point where the right foot leaves the ground in the power position. Here, there was a massive 4.01 m/s increase (9.79 m/s vs. 5.78 m/s) in the throw in Birmingham over London 2017. It therefore carried more speed through the middle of the throw by utilising the active jump into the delivery phase, and an increased release velocity of 13.64 m/s vs. 13.43 m/s.

This more aggressive start allowed Storl to stay relatively taller through each phase of the throw (Table 10) by 7-9 cm and ultimately a 13 cm increase in the release height of the throw in Birmingham over London. However, the path length of the implement as depicted in Figure 12 and Table 8 was significantly shorter and straighter (2.37 m vs. 2.76 m). This ultimately lead to a more efficient and direct path, with most of this improvement coming from less movement of the implement in the initial drive phase out of the back of the circle (0.36 m vs. 0.80 m), thus leaving the shot further behind when landing in the power position. Storl also displayed a longer glide phase (0.92 m vs. 0.78 m) and a narrower base at power position (1.11 m vs. 1.26 m) in Birmingham compared to London. Another major contributing factor here was the relative

reduction of the shoulder-hip separation angle during the middle of the throw from right foot touchdown of −39° (19° vs. 58°) and −22° at left leg touchdown (25° vs. 47°). This allowed the hip to strike earlier and faster into the final delivery, where at the point of delivery there is a marked improvement in the hip/shoulder separation of 30° (−11° vs. −41°), indicating that the hips came further around to the front and allowing a longer strike on the ball.

Another interesting finding was that of Konrad Bukowiecki who had only a 10 cm difference in best performance from 2017, but with very different release parameters, and body positions. Basically, he threw about the same distance from 2017 to 2018 with two very different types of execution. In London, he threw 20.89 m with an outstanding release velocity of 14.02 m/s, but with an extremely low angle of release of 30.4° and relatively little forward-backward trunk lean at release (−4°). In Birmingham, he threw 10 cm further with 20.99 m, but a much more optimal 36.5° angle of release for a rotational thrower, thanks in part to a more noticeable −19□ of forward-backward trunk lean at release. This may indicate he could throw a lot further if he could really execute and maximize one very synchronised technique as we have seen on occasions when he gets it right and is able to throw beyond 22 m, but he remains a bit more unstable in his technique, so is a little “hit or miss” in the major competitions.

One athlete that did seem to benefit from a steep angle of release was Darlan Romani of Brazil, who with a 4th place finish in Birmingham established himself as one of the key throwers to watch in the 2018 Season. Romani demonstrated the highest release angle of all competitors with 43.0°, steeper even than Storl with the glide technique. With a release speed of 13.54 m/s and a release height of 2.34 m, Romani’s technique seems to demonstrate extremely powerful use of the legs in the delivery phase, as shown in Table 5 with the velocity of the shot at various key points. At the point of brace leg touchdown at the front of the circle, or the power position, he displays one of the lowest velocities (1.09 m/s), but this increases rapidly to 11.95 m/s at right leg take off. At this power position, Romani displayed the lowest height of the shot among all the competitors at both right leg and left leg touchdown, but quickly transitioned to one of the highest release heights at 2.34 m, gaining the most height of all throwers through delivery.

When conducting a further analysis on the data provided from both 2017 and 2018 reports, we have found interesting relationships within the performance of the rotational technique for both male and female athletes. Notably, when analysing the relationship between the shot’s velocity and the amount of hip-shoulder separation at the point of right foot touchdown (RFTD), male throwers (of which 26 throws were analysed) provided a significant inverse relationship ($r = -0.77$, $p<0.01$). The throwers that landed more “open” such as Tom Walsh, Michal Haratyk, and Jacko Gill had higher shot velocities at RFTD, while throwers who landed more “wrapped”, like Ryan

Crouser, Darrell Hill, and O'Dayne Richards had slower shot velocities at RFTD. The men's rotational technique also exhibits a longer continuum of technical variations when compared with women's rotational throwers in that they tend to "wrap up" more on one end, and land more open with higher shot velocities at RFTD at the other end of the technical spectrum. Interestingly, the women's rotational throwers (of which there were 11 throws measured) did not have a significant relationship between these two variables at all ($r = -0.35$, $p>0.05$). The lack of significance may point to the idea that the women's rotational technique as a whole is still developing and that it is not quite clear if it produces as steady or predictable results as the men's rotational technique. This may be a reason why a higher percentage of men practice the rotational technique compared with women, however, the trend does appear to be moving toward a greater utilisation of the rotational technique by female competitors.

CONTRIBUTORS

Aaron Thomas is a Senior Learning Support Officer in Biomechanics, with technical expertise in biomechanical data collection and analysis and over ten years' experience providing sports science research and consultancy services to elite and developing athletes. Aaron is also a successful athletics coach having coached athletes to World, European and Commonwealth Championships. He has consulted in coach development for England Athletics as an Area Coach Mentor and received the British Milers Club Coach of the Year Award, 2015.

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Don Babbitt is an Associate Head Track & Field Coach at the University of Georgia (USA), where he has coached since 1996. Additionally, Don has been CECS Editor for the throwing event for the IAAF since 2010. Don has coached three World champions and one Olympic champion amongst over 50 athletes who have appeared in the World Championships or Olympic Games across the four throwing disciplines. Don has also conducted clinics across six continents and published over 60 articles or book chapters in seven different languages.

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.