IAAF World Championships
LONDON 2017

BIOMECHANICAL REPORT

FOR THE

IAAF World Championships
LONDON 2017

Discus Throw Women's

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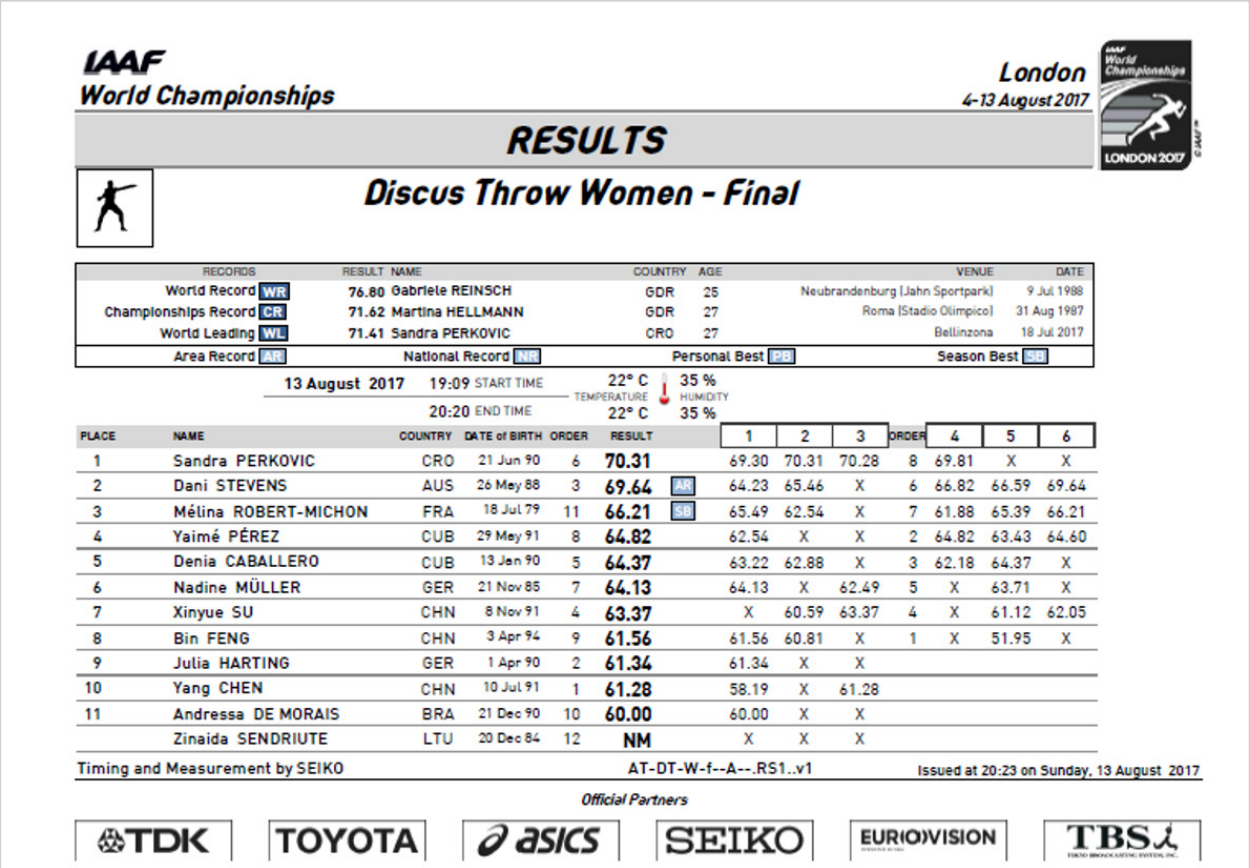
INTRODUCTION

The women's discus final took place on the evening of August 13th in favourable weather conditions. Sandra Perkovic from Croatia was a strong favourite going into the final having produced a personal best and world leading throw of 71.41 m before the championships. Perkovic displayed a dominant performance from the start with a leading throw of 69.30 m in the first round, before consolidating victory with an improved throw of 70.31 m in the second round. The closest challenger to Perkovic was Dani Stevens from Australia, who produced a national record throw of 69.64 m in the final round to win the silver medal. The bronze medal went to Mélina Robert-Michon from France with a season's best throw of 66.21 m in the final round.



IAAF World Championships — London 4-13 August 2017

RESULTS

Discus Throw Women - Final

RECORDS	RESULT	NAME	COUNTRY	AGE	VENUE	DATE
World Record WR	76.80	Gabriele REINSCH	GDR	25	Neubrandenburg (Jahn Sportpark)	9 Jul 1988
Championships Record CR	71.62	Martina HELLMANN	GDR	27	Roma (Stadio Olimpico)	31 Aug 1987
World Leading WL	71.41	Sandra PERKOVIC	CRO	27	Bellinzona	18 Jul 2017

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

13 August 2017 — 19:09 START TIME — 22° C TEMPERATURE — 35 % HUMIDITY

20:20 END TIME — 22° C — 35 %

PLACE	NAME	COUNTRY	DATE of BIRTH	ORDER	RESULT		1	2	3	ORDER	4	5	6
1	Sandra PERKOVIC	CRO	21 Jun 90	6	**70.31**		69.30	70.31	70.28	8	69.81	X	X
2	Dani STEVENS	AUS	26 May 88	3	**69.64**	AR	64.23	65.46	X	6	66.82	66.59	69.64
3	Mélina ROBERT-MICHON	FRA	18 Jul 79	11	**66.21**	SB	65.49	62.54	X	7	61.88	65.39	66.21
4	Yaimé PÉREZ	CUB	29 May 91	8	**64.82**		62.54	X	X	2	64.82	63.43	64.60
5	Denia CABALLERO	CUB	13 Jan 90	5	**64.37**		63.22	62.88	X	3	62.18	64.37	X
6	Nadine MÜLLER	GER	21 Nov 85	7	**64.13**		64.13	X	62.49	5	X	63.71	X
7	Xinyue SU	CHN	8 Nov 91	4	**63.37**		X	60.59	63.37	4	X	61.12	62.05
8	Bin FENG	CHN	3 Apr 94	9	**61.56**		61.56	60.81	X	1	X	51.95	X
9	Julia HARTING	GER	1 Apr 90	2	**61.34**		61.34	X	X				
10	Yang CHEN	CHN	10 Jul 91	1	**61.28**		58.19	X	61.28				
11	Andressa DE MORAIS	BRA	21 Dec 90	10	**60.00**		60.00	X	X				
	Zinaida SENDRIUTE	LTU	20 Dec 84	12	**NM**		X	X	X				

Timing and Measurement by SEIKO — AT-DT-W-f--A--.RS1..v1 — Issued at 20:23 on Sunday, 13 August 2017

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METHODS

Three camera positions were secured at vantage locations around the stadium. A total of three high-speed cameras were used to record the action during the discus 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 discus throw.

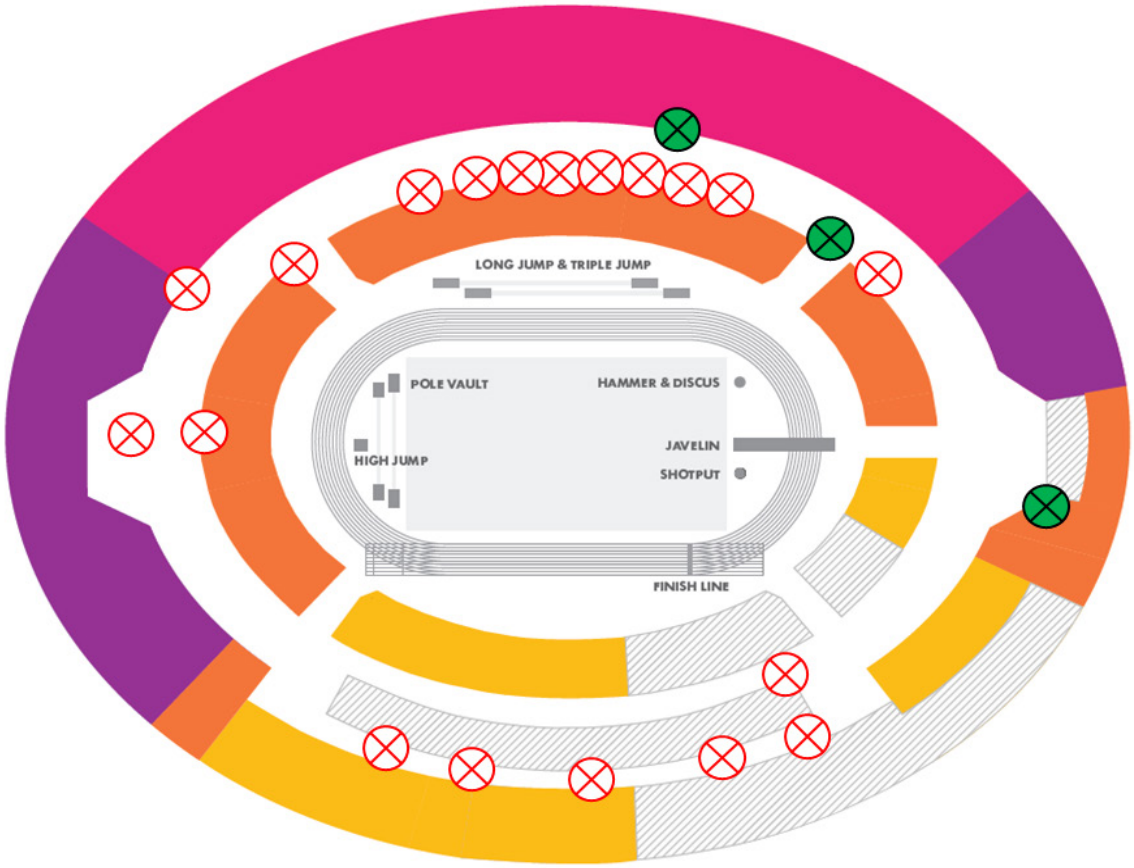


Figure 1. Stadium layout with camera locations for the women's discus throw (shown in green).

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.

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 four critical instants to synchronise the two-dimensional coordinates from each camera involved in the recording. The discus was digitised

15 frames before the beginning of preparation phase 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 discus was tracked at each point through the full motion.

Figure 2. Discus calibration frame during construction at the London Stadium.

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.

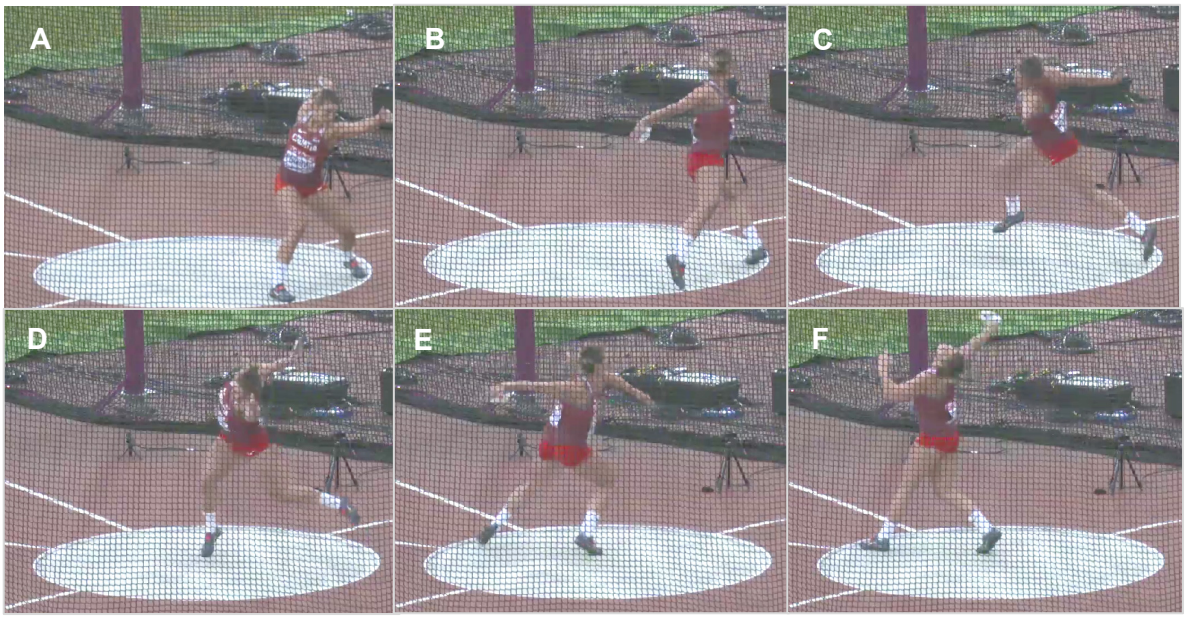


Figure 3. Key events during throw: A = peak backswing position (PBP); B = right foot take-off (RFO); C = left foot take-off (LFO); D = right foot touchdown (RFD); E = left foot touchdown (LFD); and F = release.

Table 1. Definition of each key phase.

Key Phase	**Definition**
Preparation	From PBP to RFO.
Entry	From RFO to LFO.
Airborne	From LFO to RFD.
Transition	From RFD to LFD.
***Delivery / Block / Power**	From LFD to release.

Note: ** For the purpose of this report, this phase will be referred to as the 'Delivery Phase' throughout the methods and results sections.*

Table 2. List of variables.

Variable	Definition
Absolute velocity	The resultant velocity of the discus at each key event from entry. Preparation not included as discus velocity is zero at PBP.
Horizontal release velocity	The horizontal (anteroposterior) component of the discus release velocity at release.
Vertical release velocity	The vertical component of the discus release velocity at release.
Angle of release	The angle between the discus direction of travel and the horizontal at release.
Release height	The vertical distance from the discus centre to the ground at release.
Relative release height	The vertical distance between the shoulder joint of the throwing arm and the discus centre at release.
Aerodynamic quality	The difference between official distance and theoretical distance. ***Note:*** *The theoretical distance only takes into account the following discus parameters: Height of release, absolute velocity at release and angle of release.*
Flight distance	The distance between ground contact points at LFO and RFD (or RFO and LFD for left-handers).
Delivery base of support	The distance between position of RFD and position of LFD.
Throwing arm elevation angle	The angle between the discus, throwing shoulder, and horizontal ground (0° = parallel to the horizontal ground).
Hip-shoulder separation (RFO, LFO, RFD, LFD and release)	The angle between a vector joining the right and left hips and a vector connecting the right and left shoulders.
Shoulder-arm separation (RFO, LFO, RFD, LFD and release)	The angle between a vector joining the right and left shoulder and a vector between the throwing shoulder and the discus.

Trunk tilt (forward-backward) (RFO, LFO, RFD, LFD and release)	The angle between the trunk and the vertical (0° = perpendicular to the horizontal ground).
Duration of key phases	The duration of preparation, entry, airborne, transition and delivery phases.
Style of release	Reverse = either one of no feet in contact with the ground at release. Fixed foot = both feet in contact with the ground at release.

Note: *CM = centre of mass.*

RESULTS

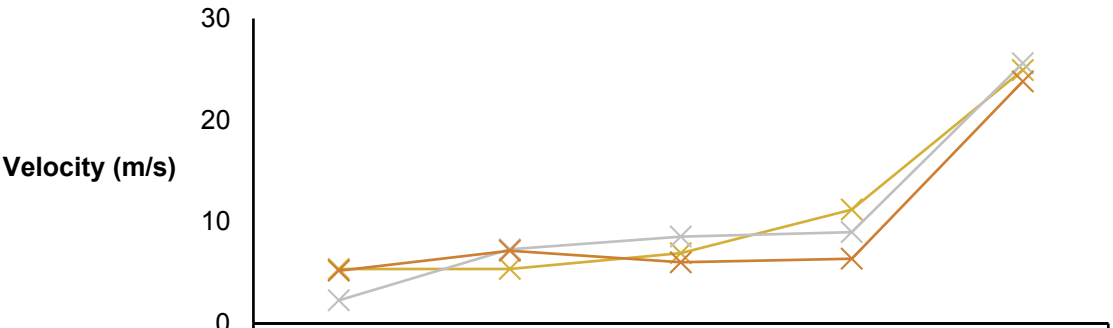
The following section of the report shows key outcome measures of the women's discus final. This includes biomechanical parameters of the implement at release and the motion path of the discus across all key phases.

Table 3. Attempts analysed for each athlete, the distance thrown and the style of released used.

Athlete	Attempt analysed	Distance (m)	% Season's best	% Personal best	Style of release
PERKOVIC	2	70.31	−1.54	−1.54	Fixed foot
STEVENS	6	69.64	+4.28	+2.43	Fixed foot
ROBERT-MICHON	6	66.21	+3.50	−0.78	Fixed foot
PÉREZ	4	64.82	−6.32	−6.32	Fixed foot
CABALLERO	5	64.37	−3.98	−8.89	Reverse (NS)
MÜLLER	1	64.13	−2.48	−6.91	Fixed foot
SU	3	63.37	−1.11	−3.38	Fixed foot
FENG	1	61.56	−2.38	−5.50	Reverse (NS)
HARTING	1	61.34	−3.60	−10.44	Fixed foot
CHEN	3	61.28	−2.58	−3.66	Fixed foot
DE MORAIS	1	60.00	−7.24	−7.24	Fixed foot
SENDRIUTE	NM	NM	NM	NM	NM

Note: *Distances also displayed as percentages of previous season and personal best throws. As Zinaida Sendruite recorded no measurement during the final, no attempts were analysed. NS = no support at release.*

Analysis of implement parameters



	Entry	Airborne	Transition	Delivery	Release
PERKOVIC	5.35	5.36	6.92	11.20	24.93
STEVENS	2.28	7.29	8.54	8.99	25.60
ROBERTS-MICHON	5.19	7.16	6.02	6.37	23.81
PÉREZ	4.71	7.02	4.52	8.52	23.29
CABALLERO	6.35	7.43	8.12	10.42	22.61
MÜLLER	5.01	4.70	6.14	9.25	23.95
SU	3.96	10.58	7.28	10.71	23.98
FENG	6.35	7.10	8.63	9.85	23.30
HARTING	4.23	5.86	6.93	9.11	24.01
CHEN	6.73	6.56	6.86	12.78	22.59
DE MORAIS	7.17	6.93	6.11	8.81	22.82

Figure 4. Absolute velocity of the discus at the beginning of each of the key phases from entry and release. All athletes can be seen in the table, however the three medallists can also be seen on the line graph. All values in the table are presented in metres per second (m/s).

Table 4. Other release parameters.

	Release angle (°)	Release height / Relative to shoulder (m)	Aerodynamic quality (%)
PERKOVIC	38.9	1.61 / 0.19	9.2
STEVENS	35.2	1.40 / 0.00	6.9
ROBERTS-MICHON	34.4	1.52 / 0.12	15.4
PÉREZ	38.0	1.27 / −0.03	14.8
CABALLERO	39.0	1.30 / −0.08	18.4
MÜLLER	33.7	1.28 / −0.13	12.9
SU	35.6	1.34 / 0.01	9.5
FENG	36.6	1.67 / 0.06	10.4
HARTING	31.4	1.64 / 0.13	10.6
CHEN	32.6	1.23 / −0.17	19.9
DE MORAIS	39.1	1.31 / −0.01	10.8

Note: *A negative relative release height indicates that the height of release was less than the height of the shoulder at the time of release.*

Figure 5 shows the respective contributions of the horizontal and vertical components of the discus release velocity, highlighting the potential trade-off between horizontal and vertical velocities. Initials indicate each athlete and medallists have been highlighted by filled circles with medal colours.

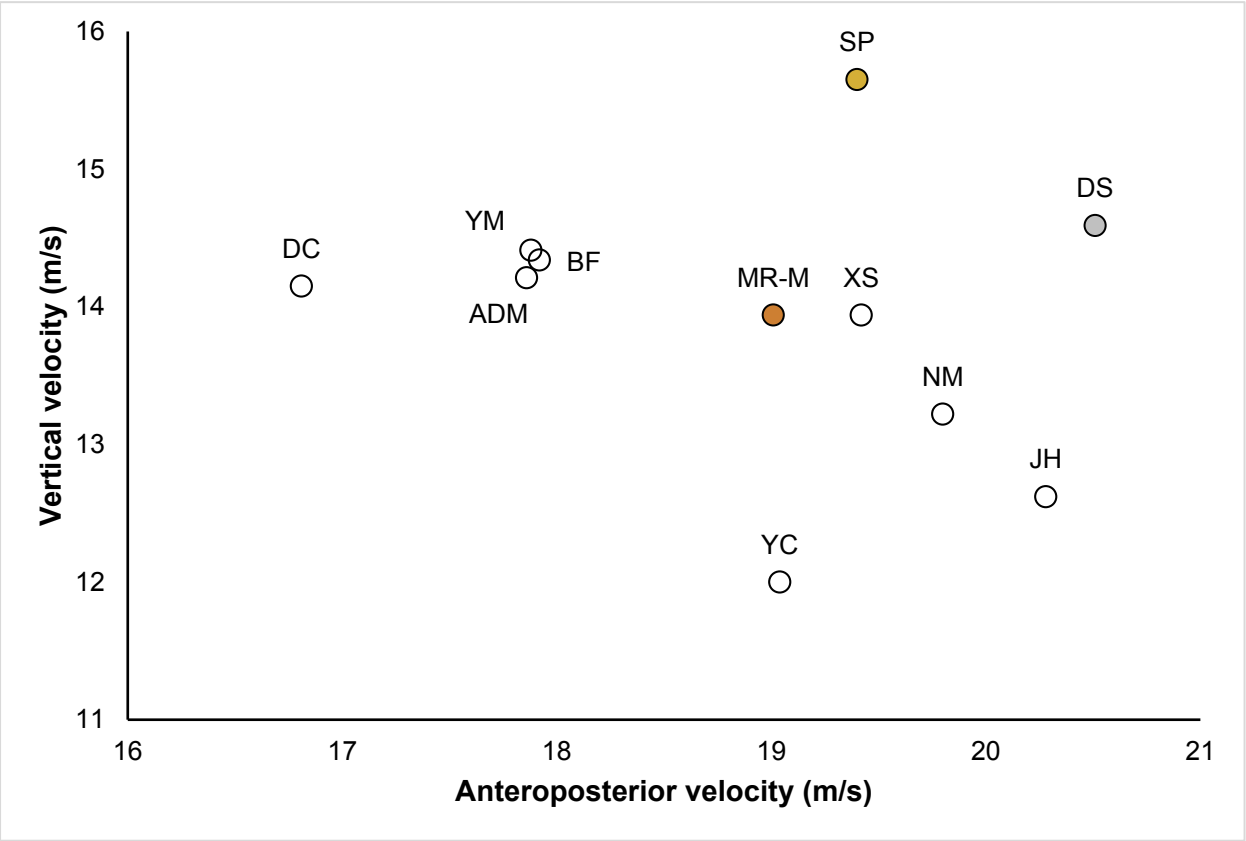


Figure 5. Horizontal (anteroposterior) and vertical components of discus release velocity.

The following six pages contain individual graphs for each athlete, displaying the motion path for the discus through each key phase from a superior view. Phases are displayed according to the key found in Figure 6.1.

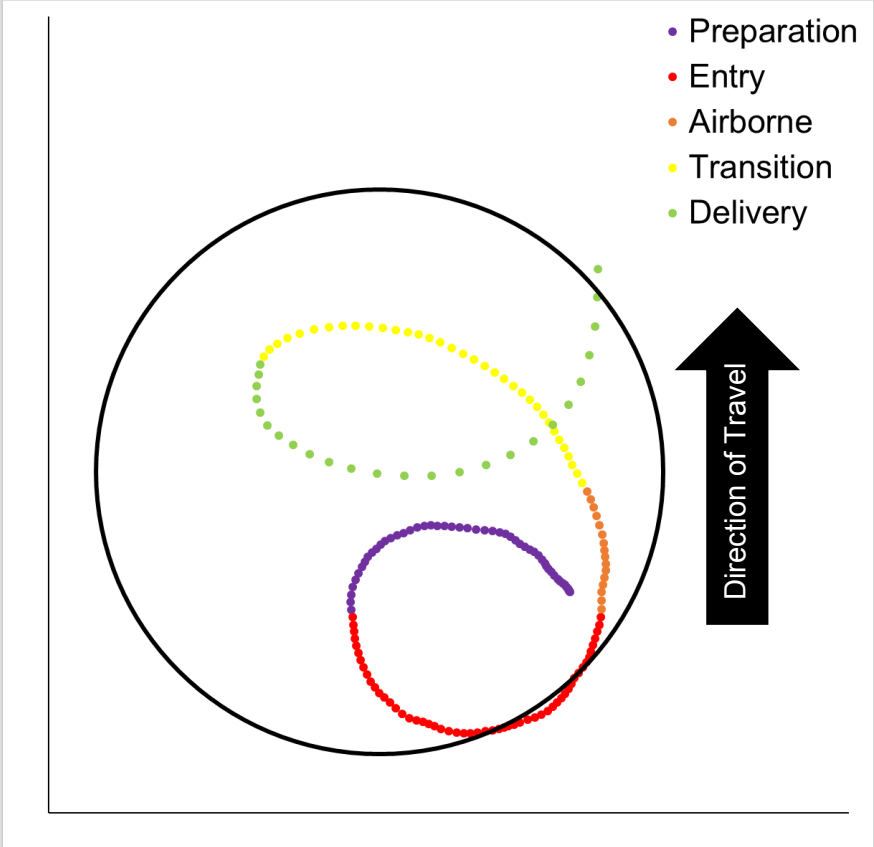


Figure 6.1. Discus motion path for Sandra Perkovic from the beginning of the preparation phase to release. Figure includes colour key for each phase, which is consistent throughout this figure series (Figures 6.1 to 6.12).

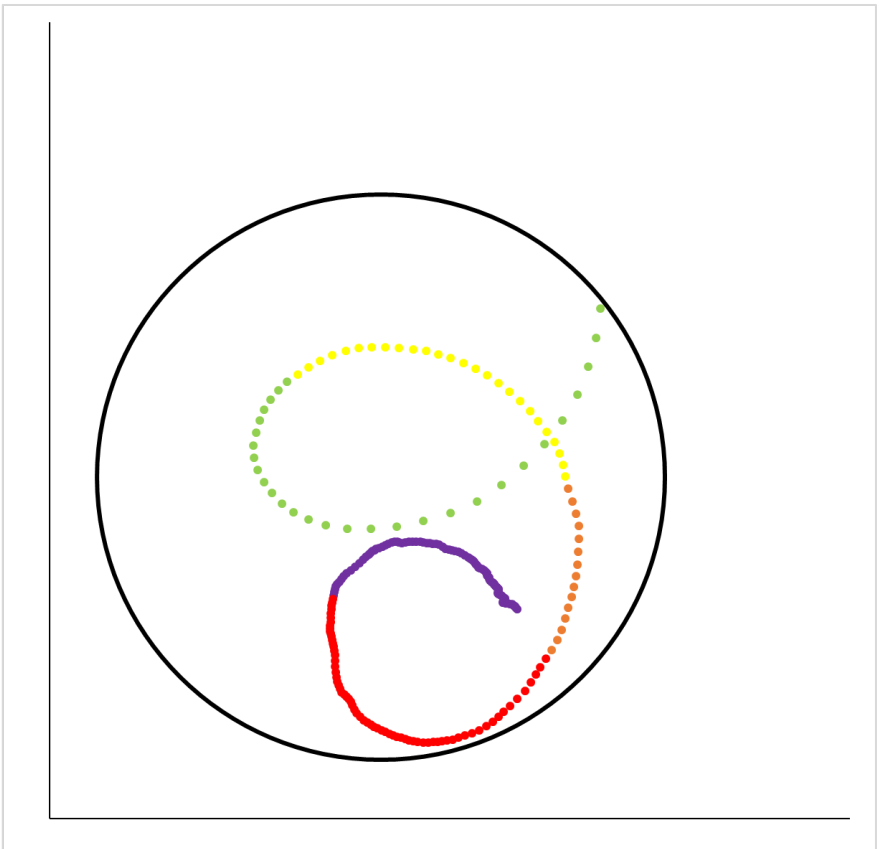


Figure 6.2. Discus motion path for Dani Stevens from the beginning of the preparation phase to release.

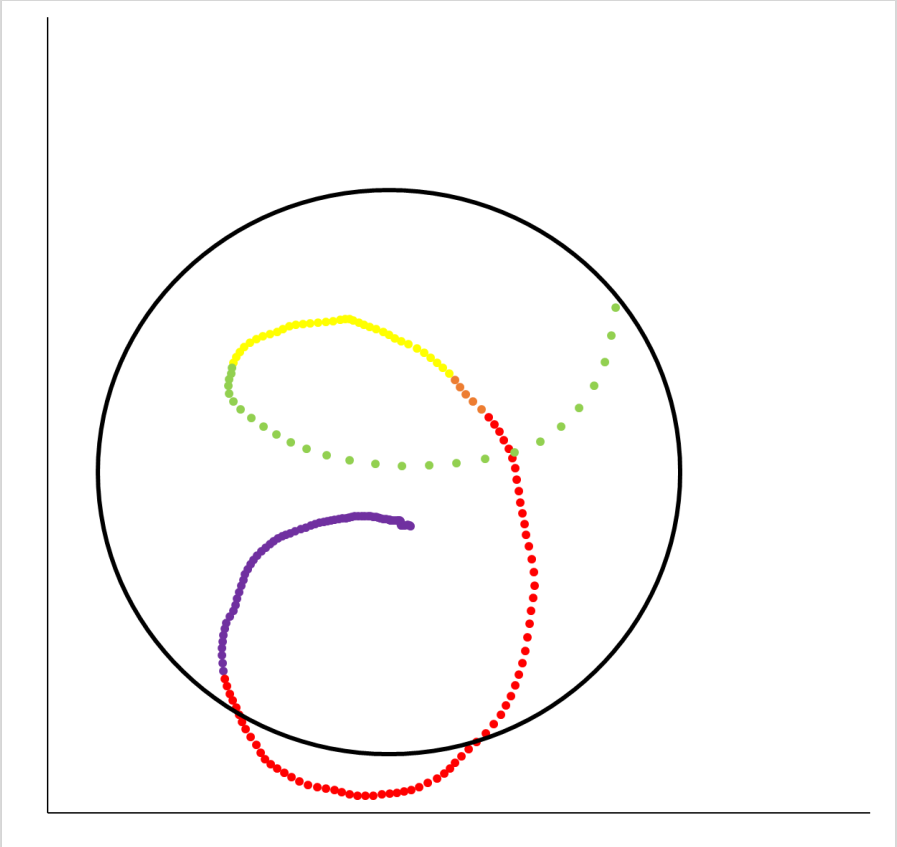


Figure 6.3. Discus motion path for Melina Robert-Michon from the beginning of the preparation phase to release.

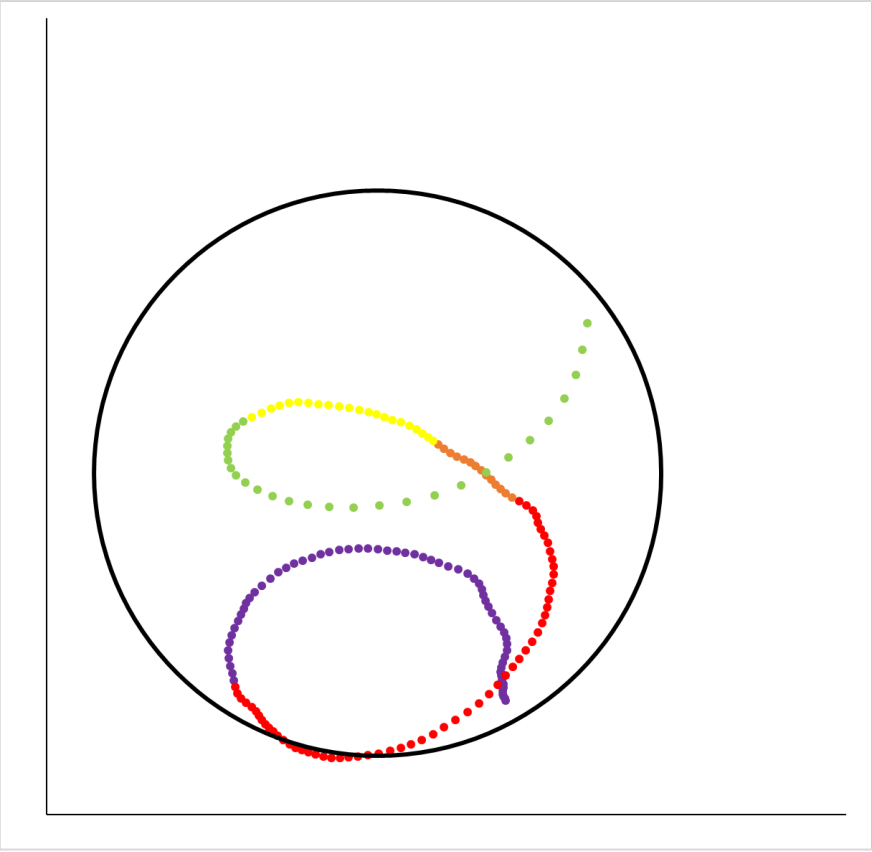


Figure 6.4. Discus motion path for Yaimé Pérez from the beginning of the preparation phase to release.

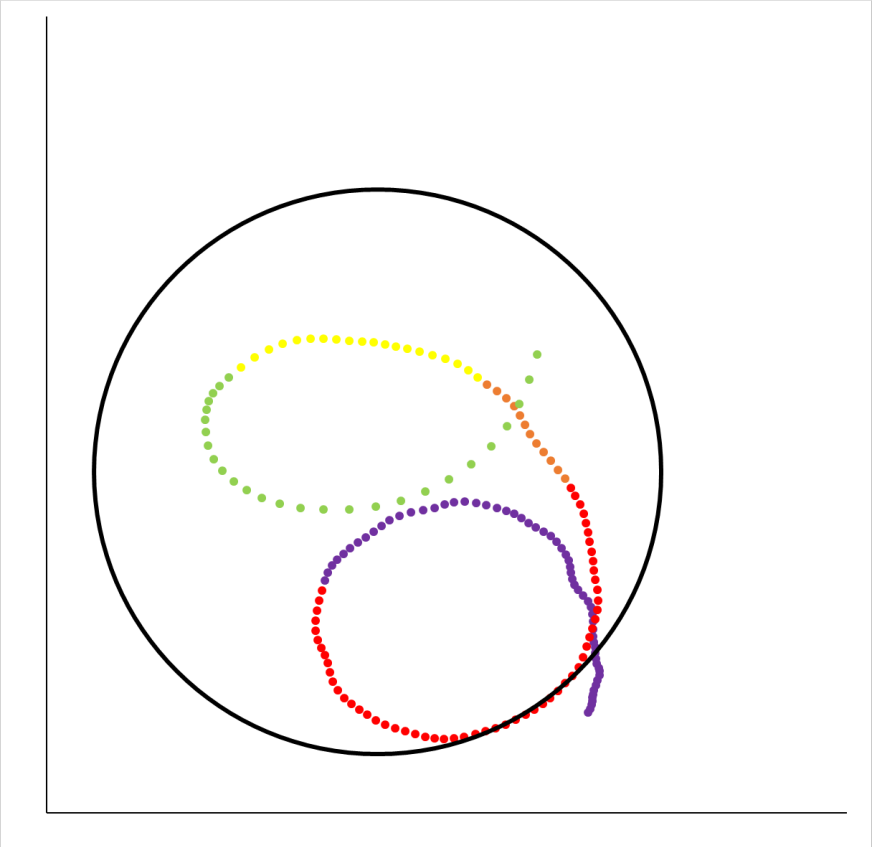


Figure 6.5. Discus motion path for Denia Caballero from the beginning of the preparation phase to release.

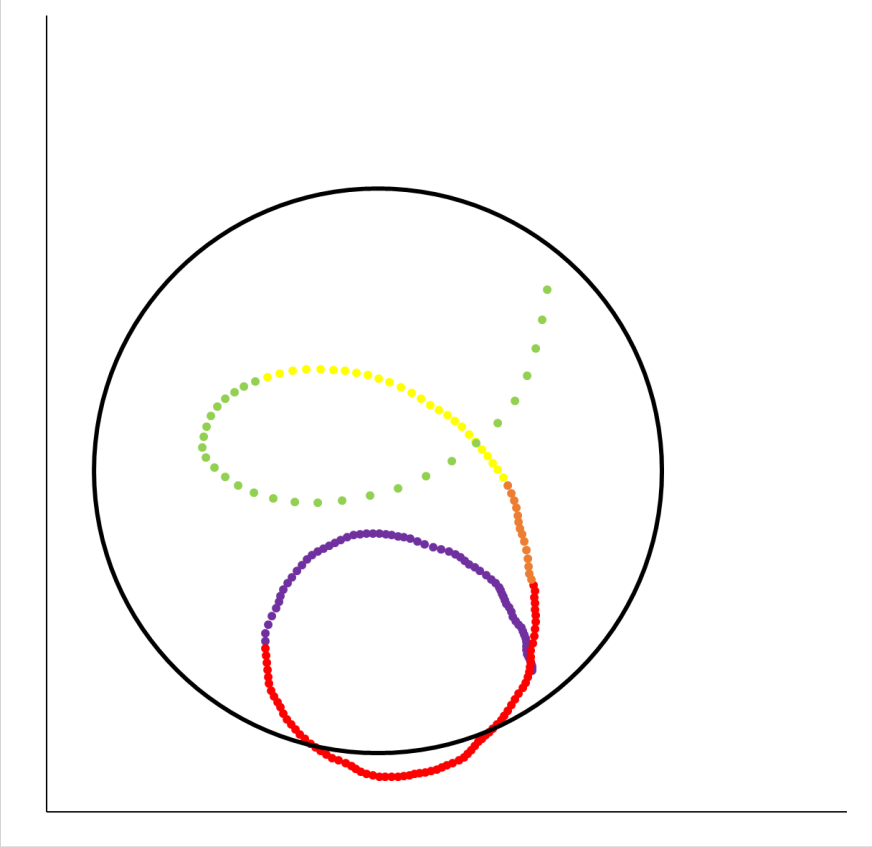


Figure 6.6. Discus motion path for Nadine Müller from the beginning of the preparation phase to release.

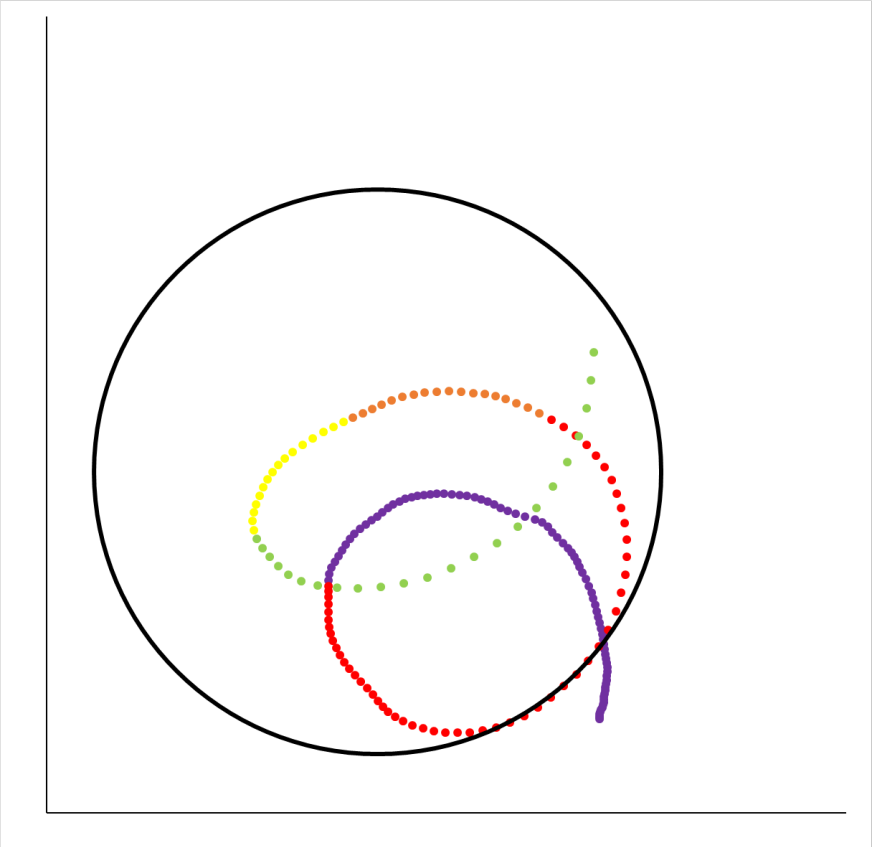


Figure 6.7. Discus motion path for Xinyue Su from the beginning of the preparation phase to release.

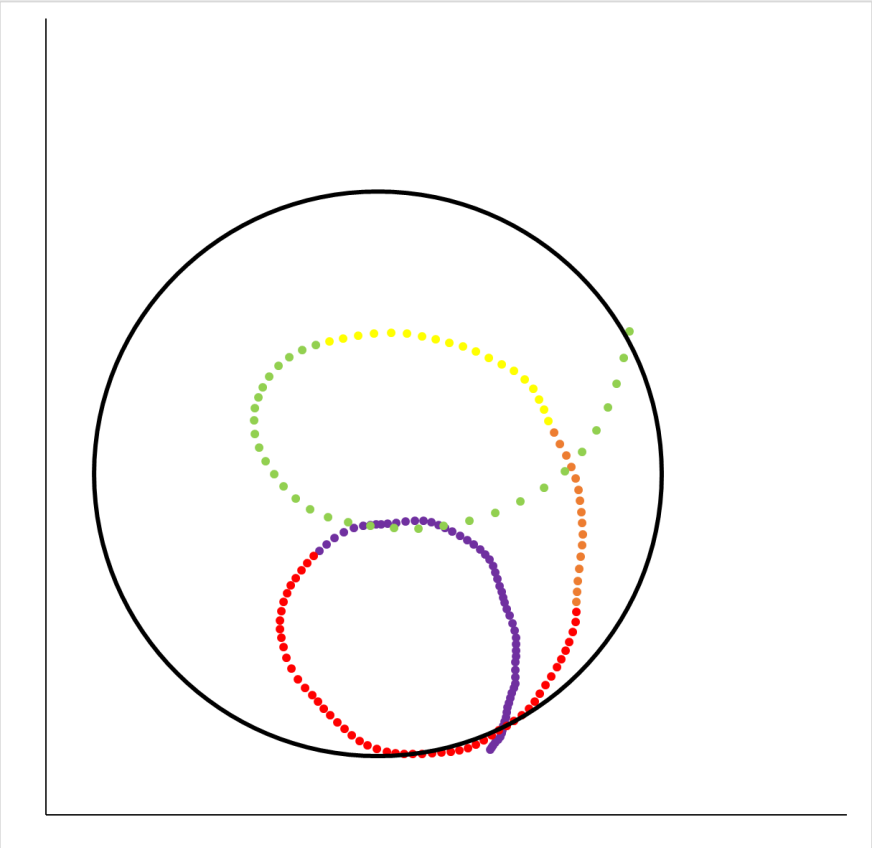


Figure 6.8. Discus motion path for Bin Feng from the beginning of the preparation phase to release.

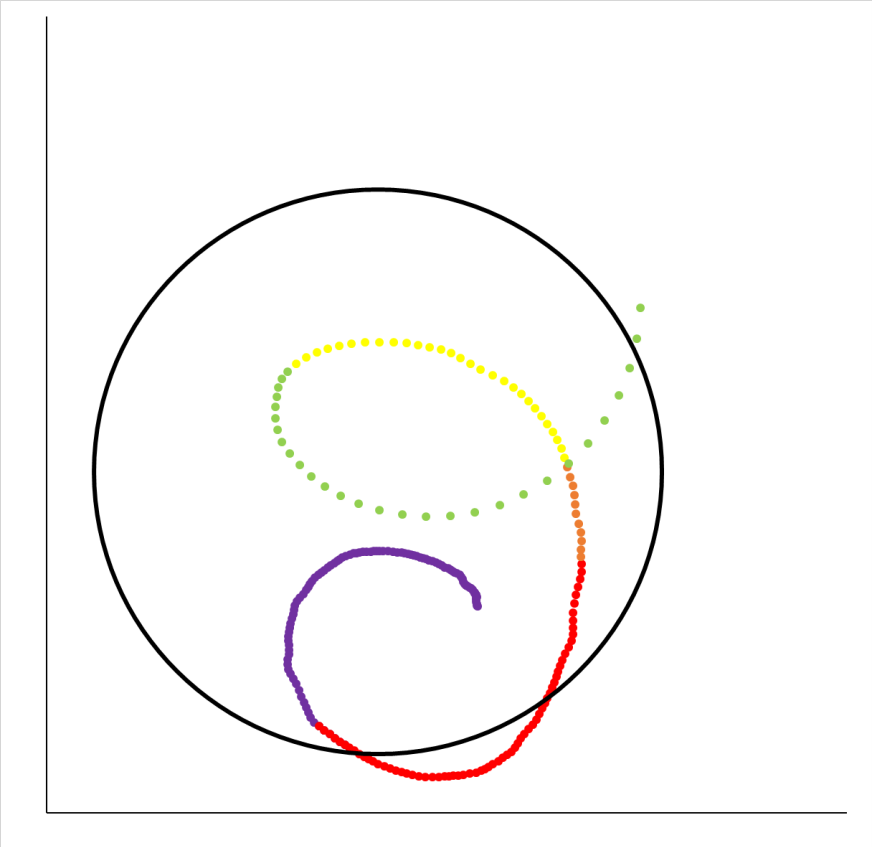


Figure 6.9. Discus motion path for Julia Harting from the beginning of the preparation phase to release.

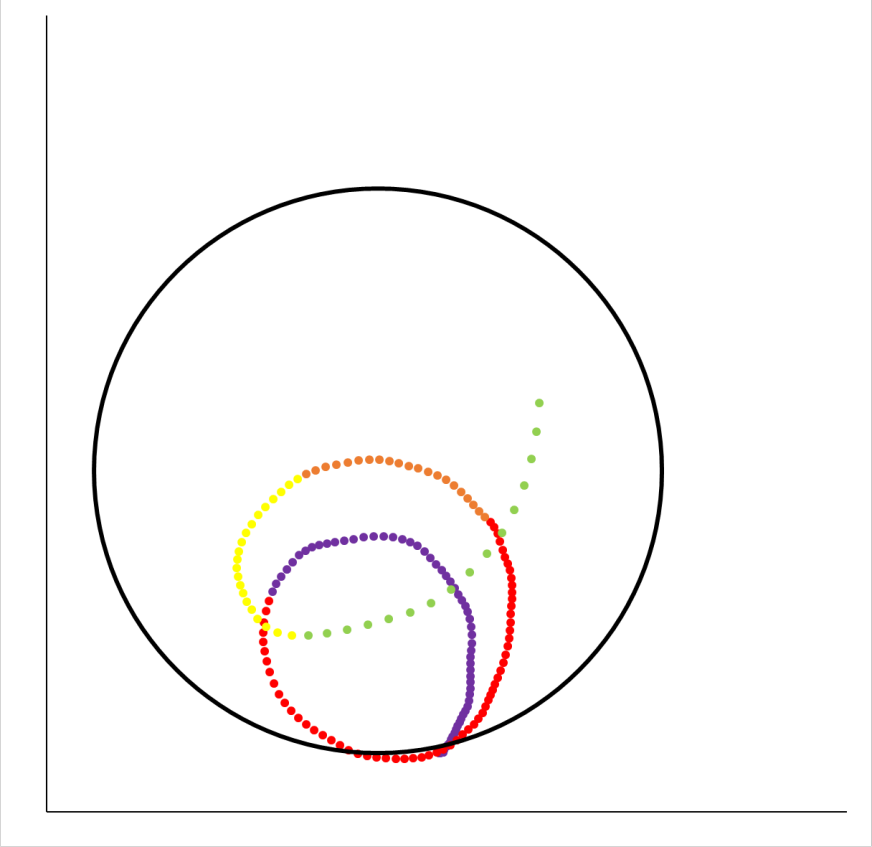


Figure. 6.10. Discus motion path for Yang Chen from the beginning of the preparation phase to release.

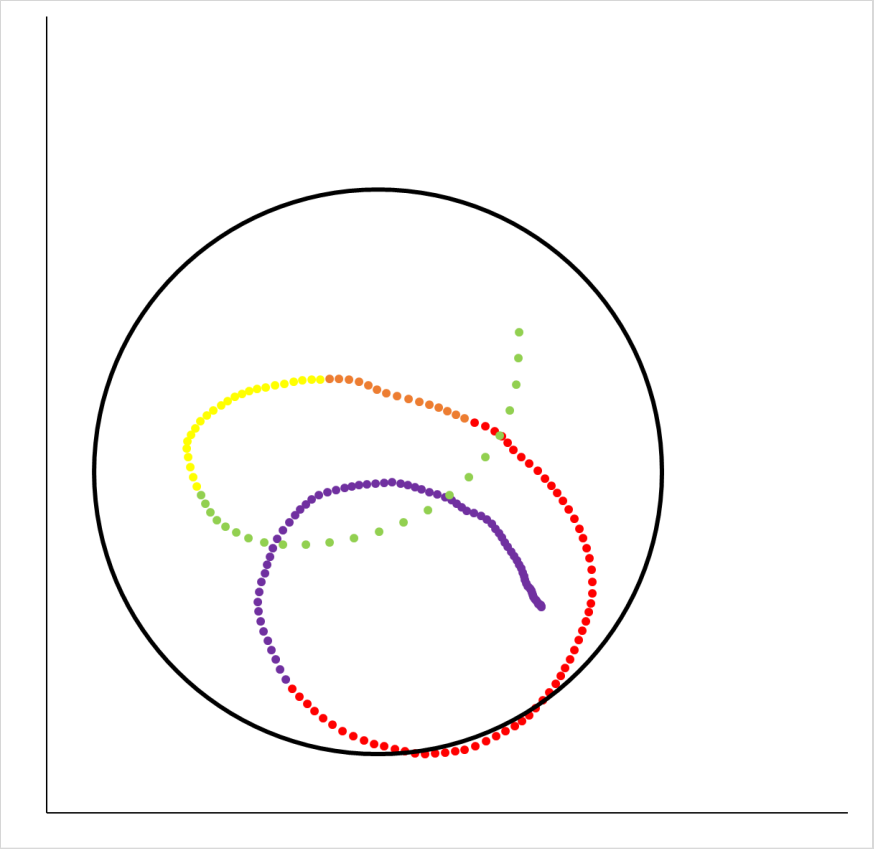


Figure 6.11. Discus motion path for Andressa De Morais from the beginning of the preparation phase to release.

Temporal characteristics of the athletes' movement

Table 5. Absolute duration of each analysed key phase before release.

	Preparation (ms)	Entry (ms)	Airborne (ms)	Transition (ms)	Delivery (ms)
PERKOVIC	353	413	53	240	167
STEVENS	687	473	93	167	200
ROBERTS-MICHON	520	480	20	233	180
PÉREZ	427	413	80	147	187
CABALLERO	407	460	73	133	180
MÜLLER	467	520	87	173	193
SU	547	367	113	107	153
FENG	400	373	93	133	220
HARTING	713	460	73	187	200
CHEN	447	427	133	147	107
DE MORAIS	507	413	93	160	153

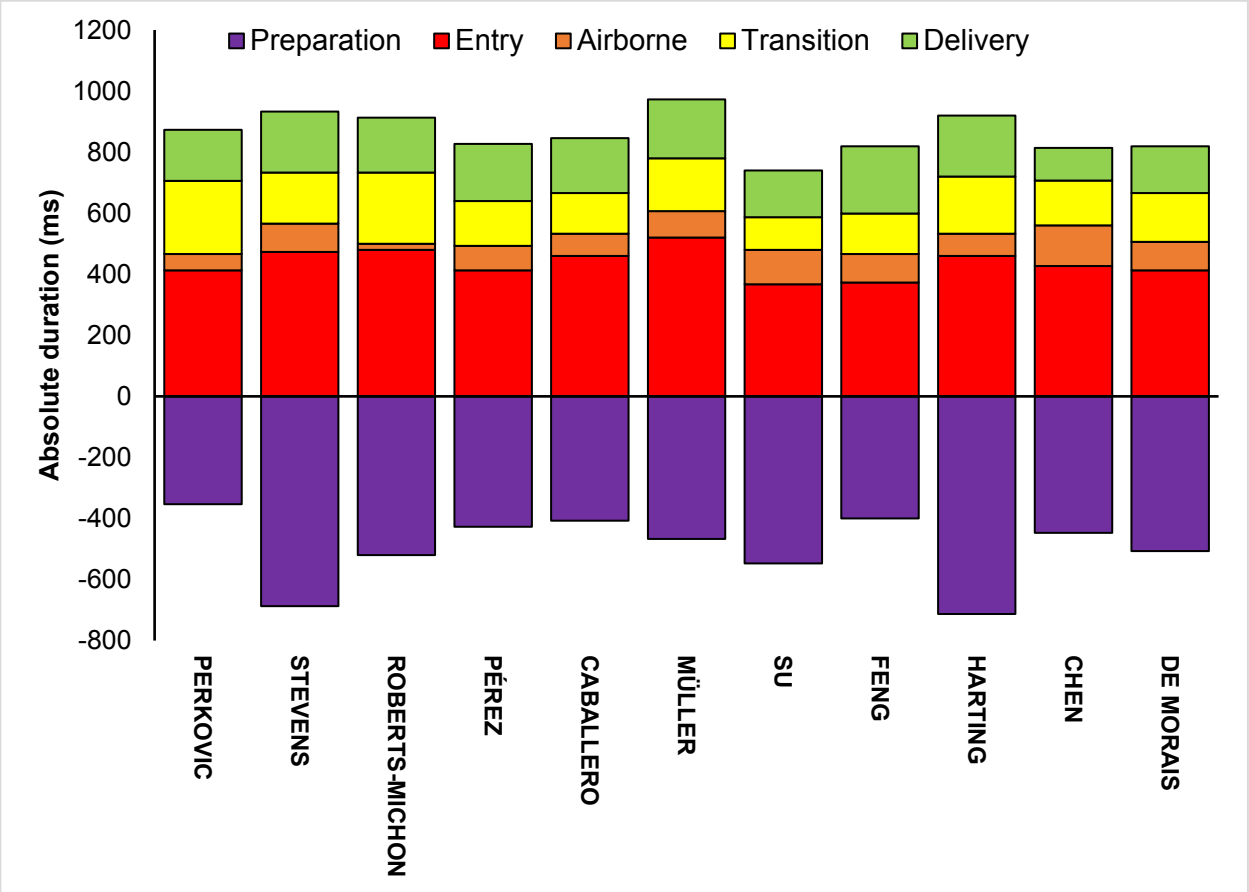


Figure 7. Absolute durations for each key phase before release. Entry phase starts at 0 ms.

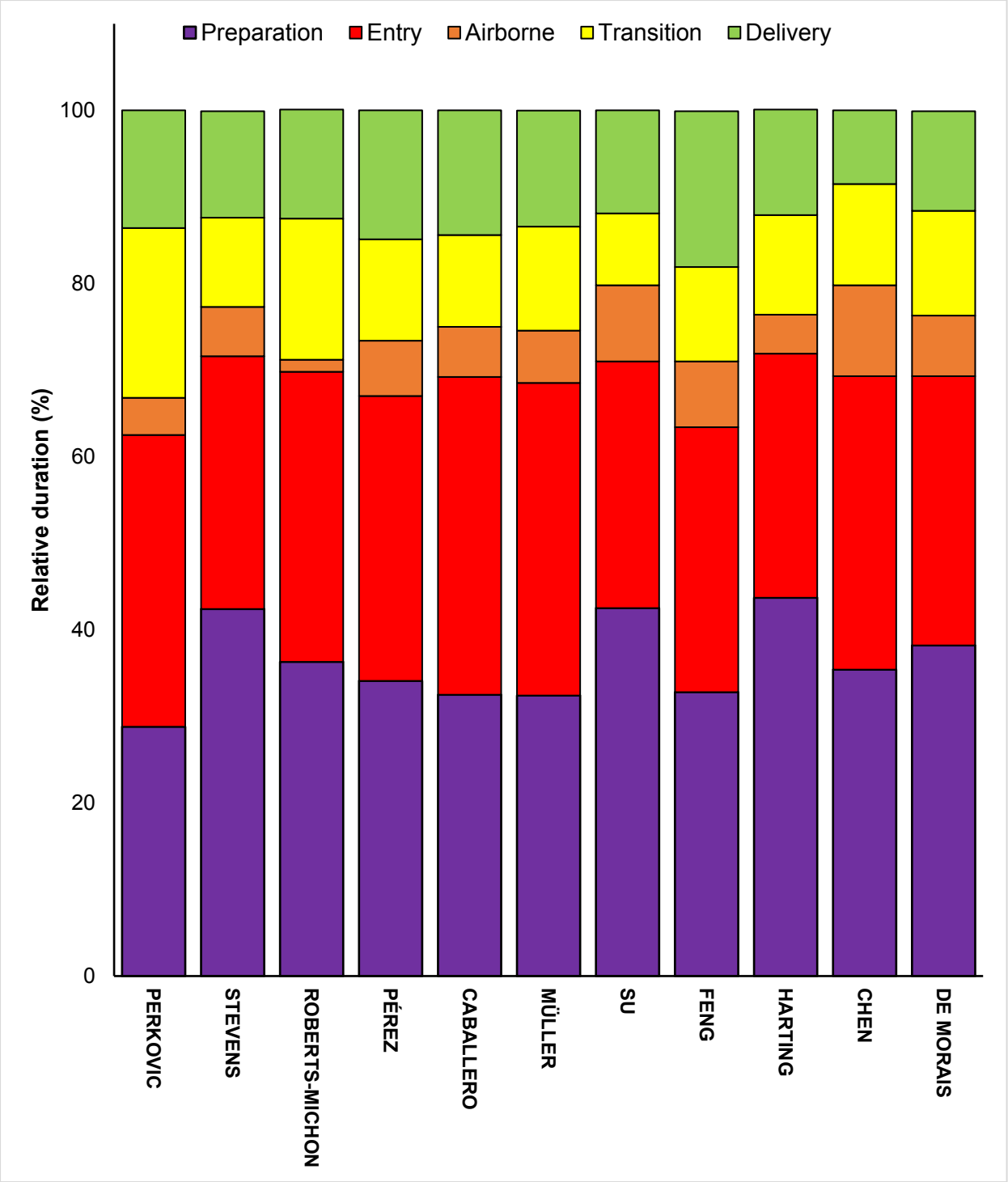


Figure 8. Relative duration of each key phase before release. 0 % indicates the start of the preparation phase and 100 % indicates release of the discus.

Kinematics of the athletes' techniques

The athletes' technique kinematics are shown in this section, both at release and key events across the throwing motion.

Table 6. Hip-shoulder separation angles at key events before and including release.

	RFO (°)	LFO (°)	RFD (°)	LFD (°)	Release (°)
PERKOVIC	25.7	79.9	50.5	94.4	−24.9
STEVENS	−33.0	92.8	71.3	95.8	−17.2
ROBERTS-MICHON	−1.2	25.7	18.3	69.0	−10.4
PÉREZ	10.2	50.5	−3.9	86.3	−32.8
CABALLERO	37.5	52.7	21.2	69.5	−5.93
MÜLLER	6.1	56.0	44.1	28.7	−21.1
SU	39.1	55.2	36.2	37.3	−15.3
FENG	42.1	87.2	50.0	84.0	−16.3
HARTING	8.1	76.0	44.0	65.6	−4.9
CHEN	20.2	53.0	57.3	16.9	6.6
DE MORAIS	−1.9	22.9	50.1	45.0	−2.7

Note: *Negative separation angles indicate that the shoulder axis is ahead of the hip axis in the angular motion path.*

Table 7. Shoulder-arm separation angles at key events before and including release.

	RFO (°)	LFO (°)	RFD (°)	LFD (°)	Release (°)
PERKOVIC	50.5	22.0	47.8	38.2	−10.9
STEVENS	36.9	39.2	43.8	38.5	−11.0
ROBERTS-MICHON	37.4	11.8	−1.8	39.5	4.8
PÉREZ	3.9	10.7	62.3	6.5	−16.6
CABALLERO	18.6	6.0	30.7	37.1	−6.3
MÜLLER	38.8	28.8	64.8	73.8	−7.6
SU	24.1	−11.4	16.5	48.0	−16.0
FENG	41.8	27.3	30.9	20.9	−5.5
HARTING	21.5	18.6	49.0	44.6	−21.3
CHEN	38.8	8.8	12.1	33.6	−8.3
DE MORAIS	26.2	32.7	8.3	46.1	−10.4

Note: *Negative separation angles indicate that the arm axis is ahead of the shoulder axis in the angular motion path.*

The following three pages contain graphical representations of the hip-shoulder and shoulder-arm separation angles for the three medallists. Hip-shoulder separation angle is illustrated by the arc shaded in red with blue borders and the shoulder-arm separation angle is illustrated by the arc shaded in black with black borders (Figure 9A).

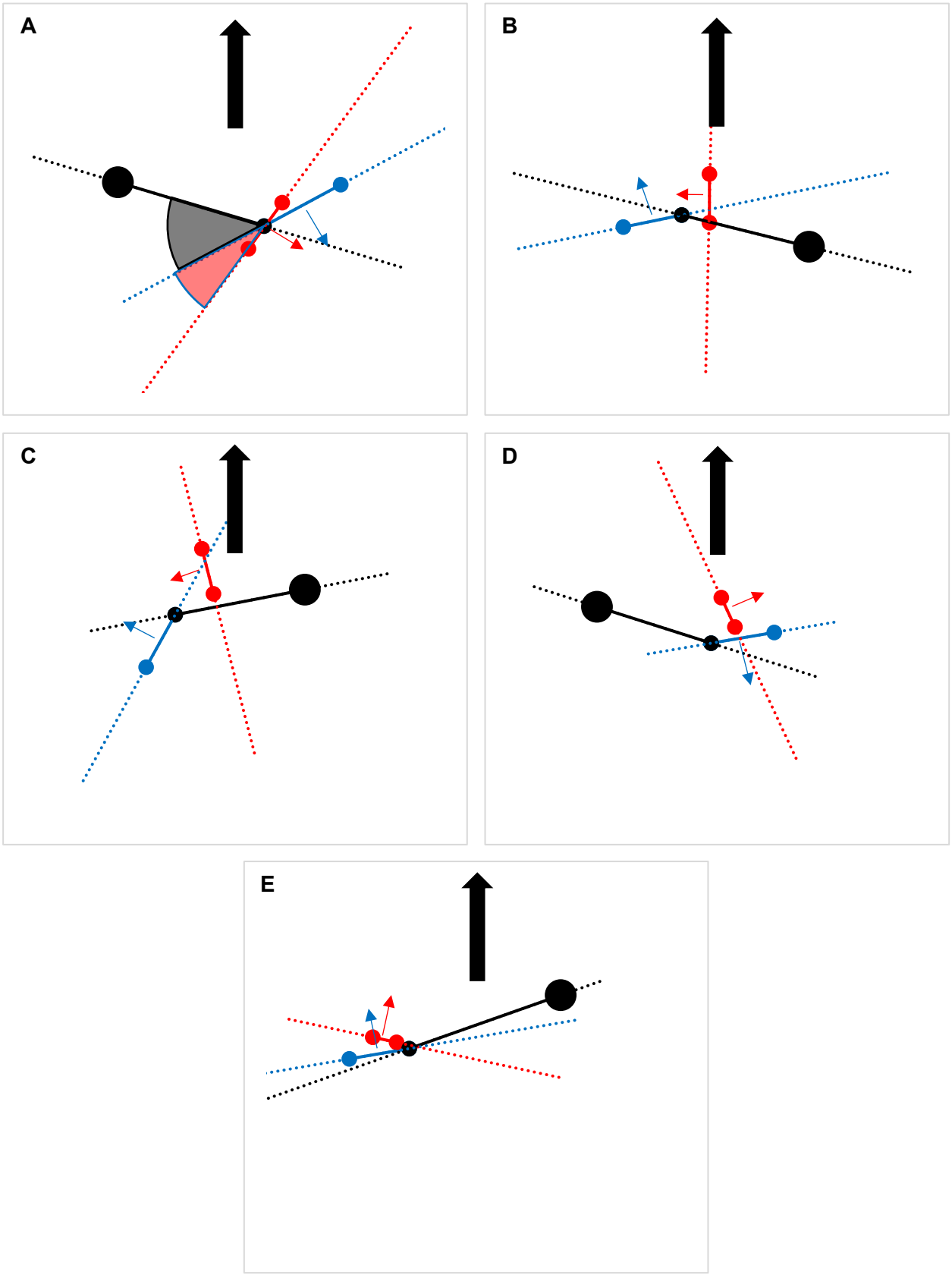


Figure 9. Graphical representation of Sandra Perkovic's hip, shoulder and arm positions at (A) right foot take-off; (B) left foot take-off; (C) right foot touchdown; (D) left foot touchdown; and (E) release. Blue and red arrows represent facing direction of shoulders and hips, respectively. Black arrow indicates throwing direction.

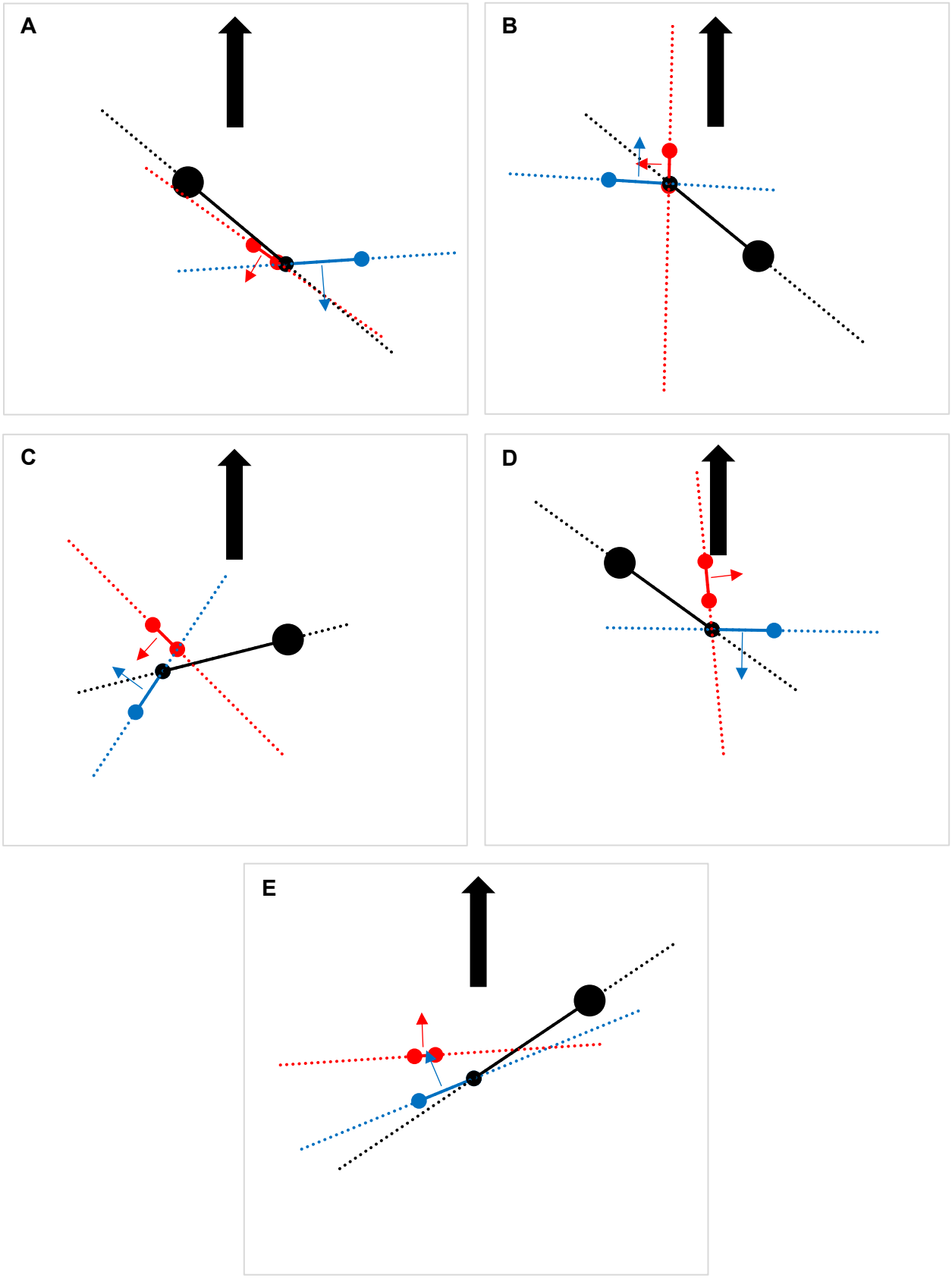


Figure 10. Graphical representation of Dani Stevens' hip, shoulder and arm positions at (A) right foot take-off; (B) left foot take-off; (C) right foot touchdown; (D) left foot touchdown; and (E) release. Blue and red arrows represent facing direction of shoulders and hips, respectively. Black arrow indicates throwing direction.

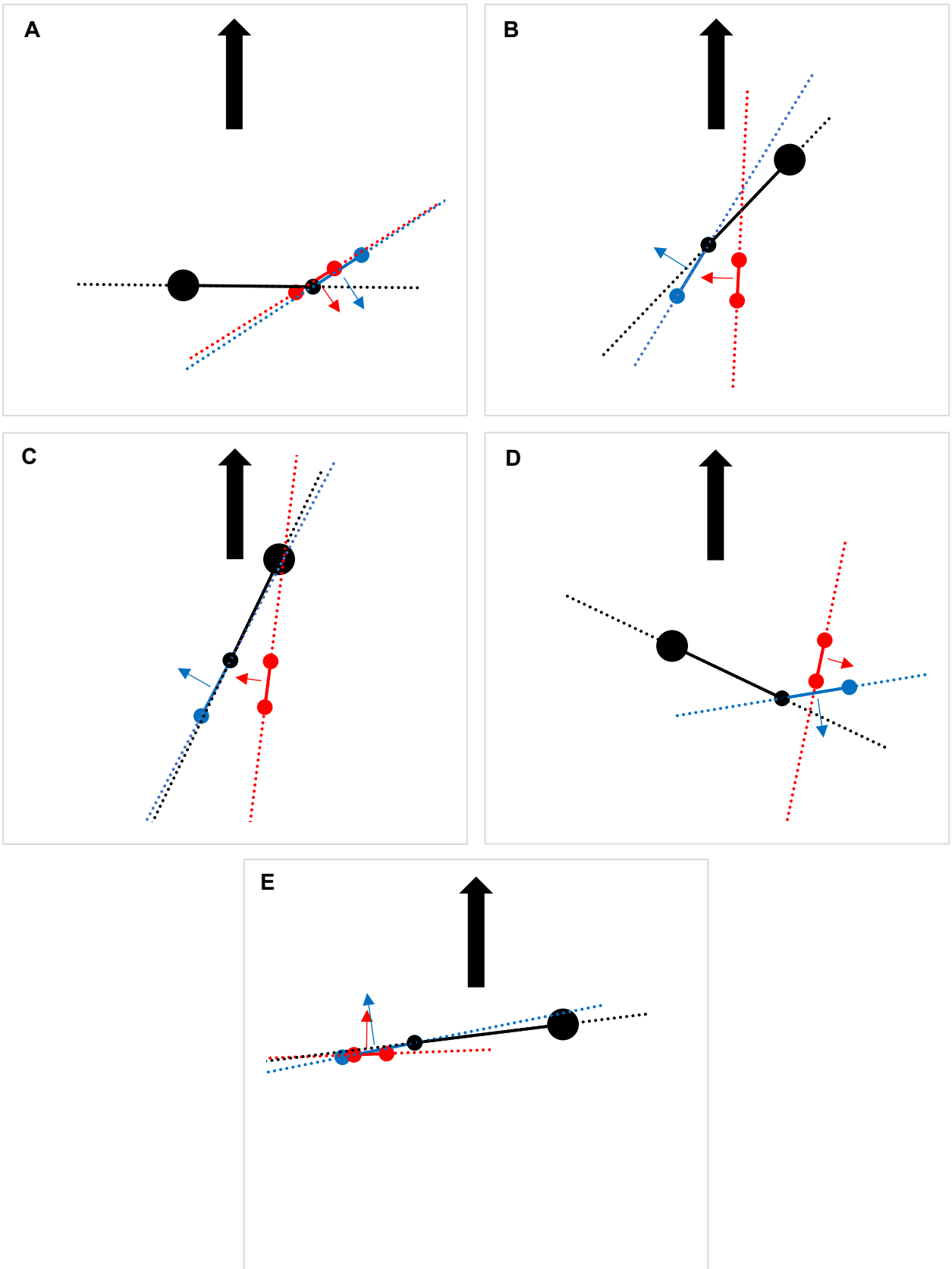


Figure 11. Graphical representation of Melina Robert-Michon's hip, shoulder and arm positions at (A) right foot take-off; (B) left foot take-off; (C) right foot touchdown; (D) left foot touchdown; and (E) release. Blue and red arrows represent facing direction of shoulders and hips, respectively. Black arrow indicates throwing direction.

Table 8. Distance covered during the airborne phase and the base of support at the start of the delivery phase for each athlete.

	Flight distance (m)	Delivery base of support (m)
PERKOVIC	1.20	0.88
STEVENS	1.00	0.90
ROBERTS-MICHON	1.03	0.90
PÉREZ	1.13	0.77
CABALLERO	1.18	0.55
MÜLLER	1.23	0.84
SU	0.80	0.64
FENG	1.01	0.63
HARTING	1.19	0.84
CHEN	0.69	0.43
DE MORAIS	1.05	0.85

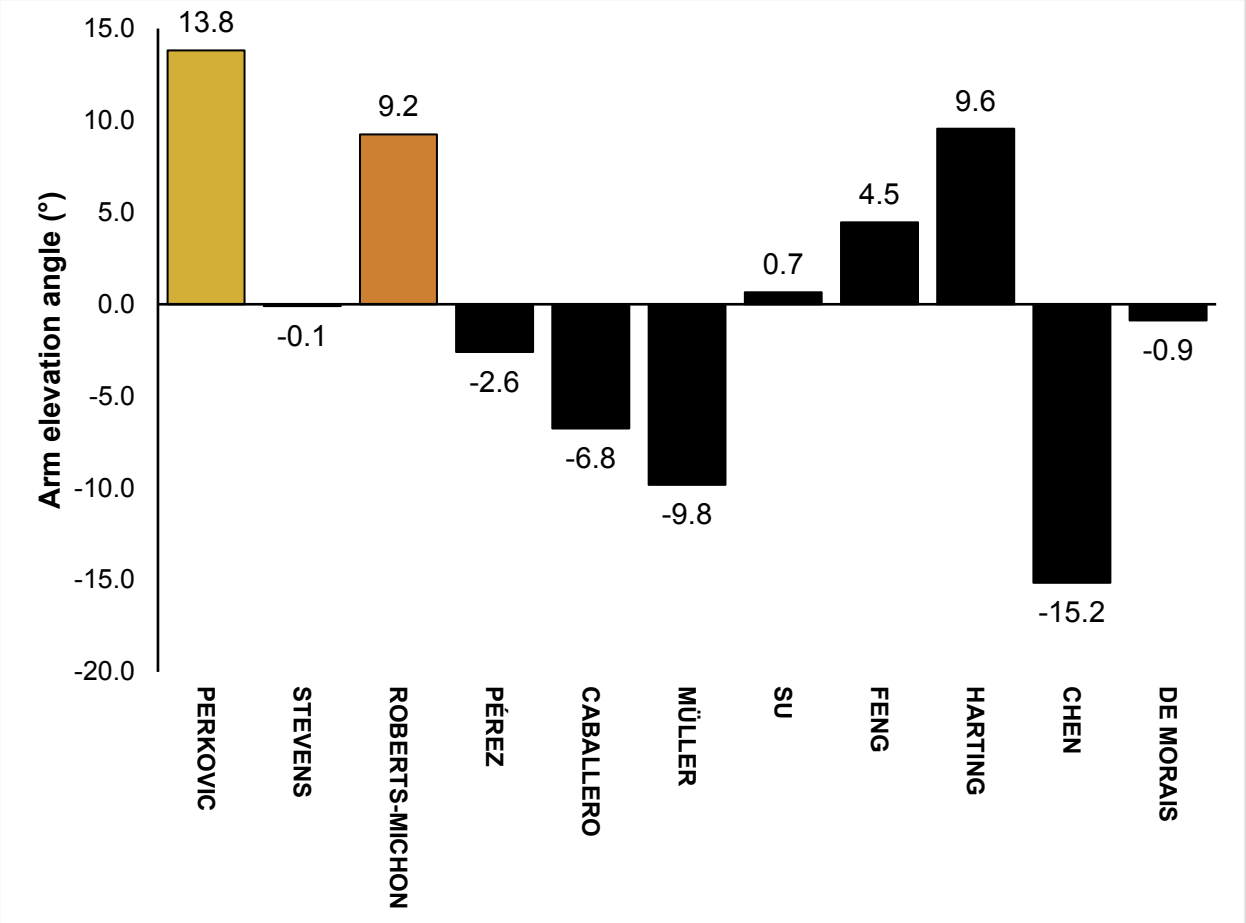


Figure 12. Arm elevation angle for each athlete at release. A positive elevation angle indicates an incline from the shoulder joint to the discus, whereas a negative value indicates a decline.

Table 9. Angles of trunk tilt at key events before and including release.

	RFO (°)	LFO (°)	RFD (°)	LFD (°)	Release (°)
PERKOVIC	9.1	9.8	30.9	17.8	−7.3
STEVENS	3.4	−7.0	30.9	28.1	−18.1
ROBERTS-MICHON	5.5	5.2	2.0	17.2	2.2
PÉREZ	12.5	20.5	41.1	47.8	−8.7
CABALLERO	−6.8	1.3	22.6	23.1	−12.1
MÜLLER	13.5	0.8	37.8	33.3	−0.9
SU	2.3	10.6	26.8	19.7	−12.3
FENG	8.3	0.3	29.9	32.6	−10.3
HARTING	2.6	3.3	21.3	25.3	1.6
CHEN	4.5	18.4	30.8	13.8	−6.3
DE MORAIS	−9.4	27.9	30.7	20.6	−19.9

Note: *Negative trunk tilt angles indicate a backwards lean, whereas positive values indicate a forward lean.*

COACH'S COMMENTARY

With regard to the medallists, the top two finishers, who were more than three metres clear of the rest of the field had much noticeably higher release velocities than the rest of the throwers. This supported a strong correlation which was found between absolute release velocity and throwing performance of 0.70. The fact that both male and female discus finalists showed very strong correlations between absolute release velocity and throwing distance strongly suggests that this is clearly the most important release factor to be considered in generating top performance. Further analysis found there was also a positive correlation between vertical release velocity and throwing performance for women at 0.63. This was interesting in that it differed from the men's results in which there was a correlation between horizontal release velocity and throwing performance of 0.54.

As a group the throwers exhibited a discus acceleration pattern that is associated with that of a fixed foot delivery in which the discus will gain some measure of velocity in each phase on through release. This makes sense in that ten out of the twelve finalists utilised the fixed foot delivery. The women's finalists were able to generate an average of 59% of the final release velocity in the delivery phase. This was close to, but slightly less than what was seen for the men (62.4%). In terms of range, the women's finalists generated between 44-73% of their final release speed in the delivery. This was a broader variance than what was observed for the men's discus finalists, who ranged between 48-71%. This diversity in approaches was also reflected in Figure 5.

The transition phase appeared to hold a lot of importance in the determination of ultimate throwing distance for women. The women's discus throwers all added velocity to the discus during the transition phase. In the case of Chen, she was able to generate 26% of her final release speed in this phase. The average for the women's group as a whole was to add 11.6% of the final release velocity in this phase. There was a positive correlation of 0.53 between the duration of the transition phase and the throwing performance, while the men's finalists had a correlation of -0.16. This large difference in correlation is most likely due to the differences in the fix foot technique, practiced by the vast majority of female throwers, and the reverse technique utilised by over 90% of the male finalists.

There seemed to be more diversity between the elements of horizontal and vertical velocity at release among the female throwers, as exhibited in Figure 5 in both reports. The diversity in the discus motion paths (Figures 6.1-6.11) appeared to be more pronounced for the female throwers, than for the male throwers. This seems to align with the observation that there were more diverse and varied combinations of horizontal/vertical velocities for female throwers at release when compared with their male counterparts. A potential explanation for this could be the greater

strength to implement ratio exhibited by the women toward the 1 kg discus compared to the 2 kg discus for the men.

Lastly, a large majority of the female discus throwers spent less time in the flight/airborne phase of the throw when compared to the male throwers. It was also observed that the female throwers tended to gain implement speed in this phase as well, contrary to the male throwers who tended to lose implement speed. As stated before, this is probably due to the utilisation of the fixed foot delivery technique.

When looking at the medallists and trying to look at some trends or differences from the other competitors, the most important factor, as stated above, is the higher release velocities from Perkovic and Stevens. They are very similar in height and weight at 1.83 m/85 kg and 1.82 m/82 kg respectively. Interestingly, while both had significantly higher release velocities than the other finalists, they gained the least advantage from the aerodynamic qualities of the discus with 9.2% and 6.9% respectively, compared to an average of 15.4% for the others. The discus acts as an aerofoil and when thrown with a good angle of attack will provide favourable lift to the discus and keep it in the air longer, improving distance thrown. These athletes theoretically could have improved on their distances if they have utilised the conditions better, but perhaps there is something in their techniques that give them this great release velocity but perhaps limit angle of attack or pitch angle.

Figure 5 shows that Stevens had the greatest horizontal component of release velocity, while Perkovic had the highest vertical component. Perkovic had one of the higher release angles at 38.9° as you might expect given the vertical component, but Stevens at 35.2° was much closer to the average for the finalists of 35.9°. Perkovic had one of the higher release heights of 1.61 m and the implement was 0.19 m above her shoulder at release, whereas Stevens was lower at 1.40 m around the average of 1.41 m, and she released the discus directly in line with her shoulder, implying a flatter delivery that could use the powerful muscles of the chest in a more effective manner. Stevens does display one of the greatest angles of trunk tilt (Table 9) at 18.1° at release which means she is leaning back slightly in order to give herself a better angle of release using this flatter delivery with the arm and implement.

It is always hard to generalise when we are only looking at the data of a single attempt of each athlete, but perhaps there are some interesting areas of discussion and possible further exploration that we can consider. When looking at the absolute velocity of the implement at key phases (Figure 4), the temporal characteristics (Table 5) and the angular kinematics of the athletes at the same key phases (Table 6 and Table 7) and the graphical representation of these factors (Figures 9 and 10), we see some interesting differences between the two leading athletes.

Compared to Perkovic, Stevens has a much longer preparation (wind-up) phase before entry (687 ms to 353 ms), very nearly double the time of Perkovic, but looking at the discus motion path (Figures 6.1 and 6.2), the relative path of the discus and therefore the distance travelled is approximately the same for both athletes, indicating and intention to “leave the discus behind” as she prepares for entry. This is confirmed by the extremely low velocity of the implement at the entry (right foot take-off) of 2.28 m/s for Stevens compared to 5.35 m/s for Perkovic), but Stevens gains a great deal of velocity of the implement during the following drive phase (airborne) across the circle which increases to 7.29 m/s, while Perkovic maintains at 5.36 m/s.

This is perhaps achieved in Stevens case by delaying the lower body movement as the upper body turns, keeping her right foot on the ground, so that at entry (right foot take-off) her hip-shoulder separation is -33.0°, meaning her shoulders are ahead of her hips at this point, which is not the case for most of the other throwers. However, this all changes by the time that she drives across the circle off the left foot, where the hip-shoulder is now the highest of all competitors at 92.8°, so her hips are well ahead of the shoulders, and adding to it one of the highest shoulder-arm separation values at 39.2°, creating massive separation at this point of drive across the circle. This comes from an active fall/push away of the left hip at the start of the throw, which she and her coach refer to as “The O’Clock Drop”, followed by a very active kick/rotation of the right leg upon entry. Comparing the airborne/flight phase with Perkovic, Stevens is airborne for nearly twice as long, (93 ms to 53 ms) but the distance travelled relatively less (1.00 m to 1.20 m) indication that Stevens delays the right foot touch down by keeping the lower body turning in the air and bringing the right foot back underneath her with a big pre-turn of the hips relative to the shoulders.

You can see clearly from the graphical representation of hip, shoulder and arm positions (Figure 10) that Stevens maintains this big separation with the hips approximately at right angles (90°) ahead of the shoulders, and the arm/implement a further 40° behind this, into the power position when the left foot touches down at the front of the circle. At this point, at the power position ahead of delivery, Perkovic has caught up with Stevens in terms of hip-shoulder and shoulder-arm separation, to a point where they have very similar values (Stevens 95.8° and 38.5°, Perkovic 94.4° and 38.2°), but she seems to have arrived at that through a longer transition phase from right foot landing to left foot (block leg) touchdown at the front (240 ms compared to 167 ms for Stevens). Perkovic was actively working the right foot on the ground, during this Transition Phase increasing the speed of the implement from 6.92 m/s to 11.20 m/s, while Stevens was really only able to maintain the speed of the implement with only a slight increase from 8.54 m/s to 8.99 m/s.

Both athletes have a similar wide base of support at the power position (delivery) at 0.90 m and 0.88 m, respectively. The delivery phase of Perkovic is relatively shorter that Stevens (167 ms to

200 ms), and is able to increase the velocity of the implement from 11.2 m/s up to 24.93 m/s at delivery. Stevens, however, perhaps because of her ability to maintain this strong separation throughout the drive across the circle, and a resulting stretch-reflex, was able to increase the implement velocity from 8.99 m/s up to an amazing 25.60 m/s. If she had been able to improve upon her aerodynamic qualities through a slightly improved angle of attack with the discus, she could have added significantly to her distance on this throw.

CONTRIBUTORS

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