IAAF World Championships
LONDON 2017

BIOMECHANICAL REPORT

FOR THE

IAAF World Championships
LONDON 2017

Hammer Throw Women's

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INTRODUCTION

The women's hammer final took place on the night of August 7th in good weather conditions. Coming into the final, Anitia Wlodarczyk from Poland was the favourite as the world leader in 2017, current world record holder and Olympic Champion of 2016. After the first three rounds, Zheng Wang from China led the competition with a 75.98 m throw. Subsequently, Wlodarczyk seized the gold medal by throwing an impressive 77.39 m in the fourth round and then bettering this in the fifth round with a throw of 77.90 m. Wang was already assured of the silver medal going into her final throw, whereby she produced her best throw of the night measured at 75.98 m. Malwina Kopron from Poland secured the bronze medal with her first throw of the evening measured at 74.76 m, however she was unable to better this in the subsequent five rounds of the competition.

IAAF World Championships

London 4-13 August 2017

RESULTS

Hammer Throw Women - Final

RECORDS	RESULT	NAME	COUNTRY	AGE	VENUE	DATE
World Record WR	82.98	Anita WLODARCZYK	POL	31	Warszawa (Stadion Narodowy)	28 Aug 2016
Championships Record CR	80.85	Anita WLODARCZYK	POL	30	Beijing (National Stadium)	27 Aug 2015
World Leading WL	82.87	Anita WLODARCZYK	POL	32	Cetniewo (OPO)	29 Jul 2017

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

7 August 2017 — 18:59 START TIME — 20:13 END TIME — TEMPERATURE 19° C / 19° C — HUMIDITY 56 % / 56 %

PLACE	NAME	COUNTRY	DATE of BIRTH	ORDER	RESULT		1	2	3	ORDER	4	5	6
1	Anita WLODARCZYK	POL	8 Aug 85	3	**77.90**		70.45	X	71.94	3	77.39	77.90	73.91
2	Zheng WANG	CHN	14 Dec 87	8	**75.98**		74.31	75.94	75.00	8	74.86	74.52	75.98
3	Malwina KOPRON	POL	16 Nov 94	10	**74.76**		74.76	X	X	7	X	69.90	71.66
4	Wenxiu ZHANG	CHN	22 Mar 86	6	**74.53**	SB	69.70	X	73.19	5	70.62	74.53	72.21
5	Hanna SKYDAN	AZE	14 May 92	9	**73.38**		72.45	72.38	73.38	6	71.70	X	71.77
6	Joanna FIODOROW	POL	4 Mar 89	5	**73.04**		X	73.02	72.41	4	73.04	71.69	72.67
7	Sophie HITCHON	GBR	11 Jul 91	4	**72.32**		71.47	71.62	71.80	2	X	70.81	72.32
8	Katerina ŠAFRÁNKOVÁ	CZE	8 Jun 89	12	**71.34**	SB	71.34	X	X	1	X	X	66.26
9	DeAnna PRICE	USA	8 Jun 93	2	**70.04**		65.20	67.46	70.04				
10	Hanna MALYSHIK	BLR	4 Feb 94	1	**69.43**		69.43	X	69.00				
11	Kathrin KLAAS	GER	6 Feb 84	7	**68.91**		67.83	68.91	X				
12	Alexandra TAVERNIER	FRA	13 Dec 93	11	**66.31**		X	66.31	66.01				

Timing and Measurement by SEIKO — AT-HT-W-f--A--.RS1..v1 — Issued at 20:15 on Monday, 07 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: 1/1750; 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 hammer throw.

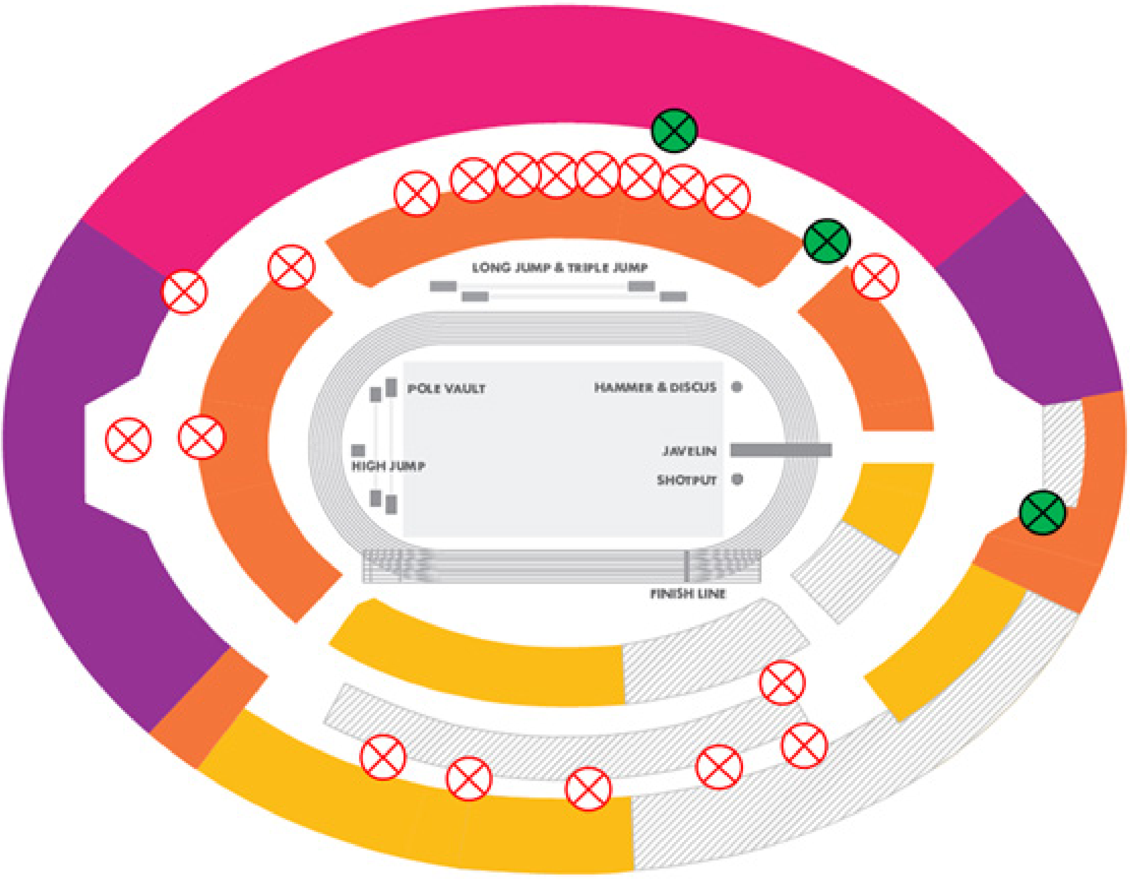


Figure 1. Stadium layout with camera locations for the women's hammer final (shown in green).

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.

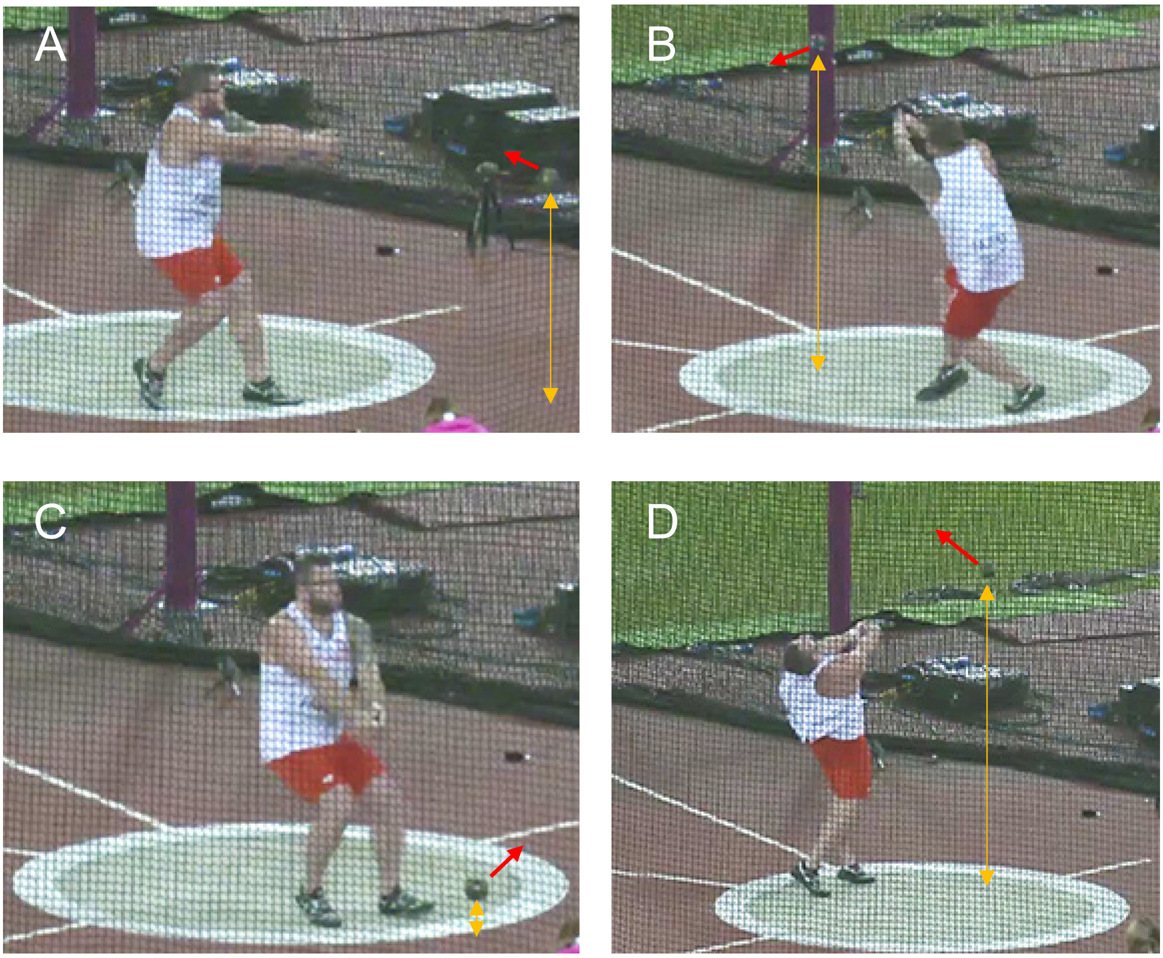
All video files were imported into SIMI Motion (SIMI Motion version 9.2.2, Simi Reality Motion Systems GmbH, Germany) and manually digitised by a single experienced operator to obtain kinematic data. Each video file was synchronised at critical instants to synchronise the two-dimensional coordinates from each camera involved in the recording. The hammer was digitised 15 frames before the lowest point of the final preliminary swing 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. 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. 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 hammer throw.

Variable	Definition
Release velocity	The resultant velocity of the hammer at release.
Angle of release	The angle between the hammer direction of travel and the horizontal at release.
Height of release	The vertical distance from the hammer centre to the ground at release.
Starting velocity of hammer	The resultant velocity of the hammer entering the first turn, which was defined as the first toe off after the preliminary swings (see Figure 3).
Peak velocity of hammer in each turn	The maximum resultant velocity of the hammer in each turn.
Duration of turns	The time taken to perform each turn.
Duration of support phases	The time taken for each single-support and double-support phase (see Figure 3).
The cumulative time spent in each phase	The total time spent in single-support and double-support phases.
Path of the hammer during turns	The cumulative distance travelled by the hammer during each turn.
Path of the hammer in single and double-support phases	The distance of the hammer travelled within each phase.
Sum of hammer path in single and double-support phases	The cumulative distance of the hammer's path in both phases.
Azimuthal angle in the single-support and double-support phases	A 2D angle that defines the horizontal position of a vector representing the hammer-thrower system with respect to a fixed reference line on the same horizontal plane. The horizontal plane is considered as a circular area situated around the hammer-thrower system. To align this convention with the hammer circle, the reference vector points the central position at the back of the circle, measured as 0°, with 180° representing the central position

	at the front of the circle. The angle is measured anticlockwise from 0°.
Angle of twisting in the single-support and double-support phases	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.
Angle of trailing in the single-support and double-support phases	The angle between the line of the athlete's shoulders and the position of the hammer (see Figure 4), whereby 90° represents the hammer is at right angles to the line of the shoulders. An angle less than 90° identifies that the hammer moving towards the lead shoulder, whereas an angle greater than 90° identifies that the hammer is moving away from the lead shoulder.
Velocity of the hammer at the high and low point of each turn	The resultant velocity of the hammer at the low and high points within each turn.
Vertical distance of the hammer at the high and low point of each turn	The vertical distance from the hammer centre to the ground at the low and high points within each turn.
Relative upswing path angle	The angle to the horizontal between the low and high point within each turn.



Key: → *= direction of hammer and* ↔ *= height of hammer.*

Figure 3. Visual depiction of A) entry, B) single support, C) double support and D) release phases of the throw.

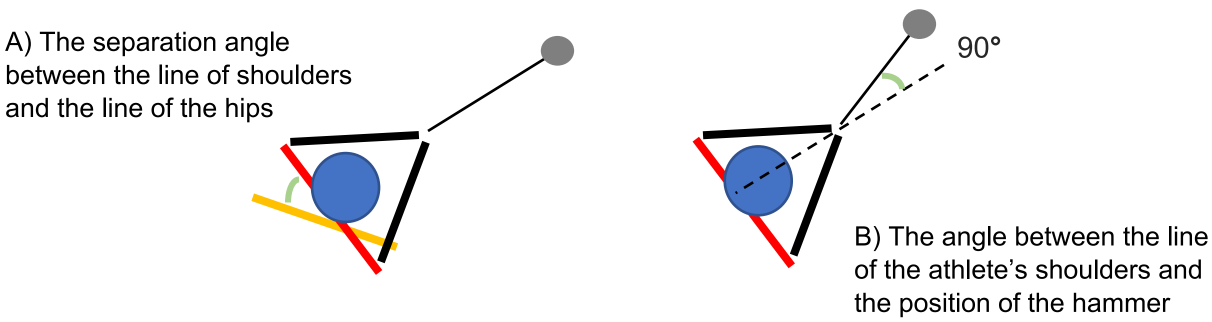


Figure 4. Visual representation of A) angle of twisting and B) angle of trailing variables.

RESULTS

Performance

Table 2 details the twelve finalist's 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, three of the finalists threw season's best over the course of the championships, although 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)
WLODARCZYK	82.87	82.98	74.61	−8.26	77.90	−4.97	−5.08
WANG	76.25	77.68	71.89	−4.36	75.98	−0.27	−1.70
KOPRON	75.11	75.11	74.97	−0.14	74.76	−0.35	−0.35
ZHANG	72.12	77.33	71.39	−0.73	74.53	2.41	−2.80
SKYDAN	75.29	75.29	71.78	−3.51	73.38	−1.91	−1.91
FIODOROW	75.09	75.09	71.72	−3.37	73.04	−2.05	−2.05
HITCHON	73.97	74.54	73.05	−0.92	72.32	−1.65	−2.22
ŠAFRÁNKOVÁ	71.31	72.47	70.67	−0.64	71.34	0.03	−1.13
PRICE	74.40	74.40	72.78	−1.62	70.04	−4.36	−4.36
MALYSHIK	74.94	74.94	72.79	−2.15	69.43	−5.51	−5.51
KLAAS	71.06	76.05	70.33	−0.73	68.91	−2.15	−7.14
TAVERNIER	71.71	74.39	72.69	0.98	66.31	−6.38	8.08

Release parameters

Table 3 shows that both gold and silver medallists achieved the highest release velocities (≥28 m/s), whilst attaining the highest release height (≥1.80 m). The table also shows that the release velocity clearly dictates the position of the athletes with almost a perfect match between the place and the release velocity ranked fastest to slowest.

Table 3. 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)
WLODARCZYK	5	77.90	28.26	41.8	1.80
WANG	6	75.98	28.05	38.5	1.85
KOPRON	1	74.76	27.78	39.7	1.40
ZHANG	5	74.53	27.63	41.6	1.24
SKYDAN	3	73.38	27.85	36.9	1.64
FIODOROW	4	73.04	27.78	39.2	1.41
HITCHON	6	72.32	26.96	40.3	1.54
ŠAFRÁNKOVÁ	1	71.34	26.88	44.4	1.69
PRICE	3	70.04	26.95	38.5	1.27
MALYSHIK	1	69.43	26.78	42.9	1.48
KLAAS	2	68.91	26.33	42.8	1.47
TAVERNIER	2	66.31	26.00	41.2	1.64

Velocity of the hammer

Table 4, Figures 5 and 6 on the next pages show that the entry velocity developed by the preparatory swings provides between 54% – 65% of the total release velocity. Subsequently, every athlete produced their highest velocity gains within the first turn (finalists mean: 4.87 ± 0.65 m/s), whereas the third (finalists mean: 1.79 ± 0.38 m/s) and fourth turn on the whole provided the lowest velocity gain (finalists mean: 1.93 ± 1.01 m/s). However, the gold medallist (Wlodarczyk) and fifth placed athlete (Skydan) gained more (≥3.5 m/s) velocity than any other athlete in the fourth turn.

Table 4. The velocity gain of the hammer from each turn for the twelve finalists.

Athlete	Starting (m/s)	Turn 1 (m/s)	Turn 2 (m/s)	Turn 3 (m/s)	Turn 4 (m/s)
WLODARCZYK	16.19	4.35	2.58	1.64	3.50
WANG	17.55	4.35	2.45	1.50	2.20
KOPRON	15.66	5.49	2.90	2.41	1.32
ZHANG	15.65	4.97	3.06	2.28	1.68
SKYDAN	15.16	5.04	2.97	1.34	3.79
FIODOROW	16.71	4.55	2.01	1.63	2.88
HITCHON	15.60	5.55	2.94	1.89	0.99
ŠAFRÁNKOVÁ	15.56	5.87	2.60	1.54	1.31
PRICE	15.19	3.68	2.92	2.24	2.93
MALYSHIK	15.29	5.53	3.03	1.65	1.29
KLAAS	16.69	4.80	3.00	1.18	0.66
TAVERNIER	16.99	4.32	2.28	1.87	0.55

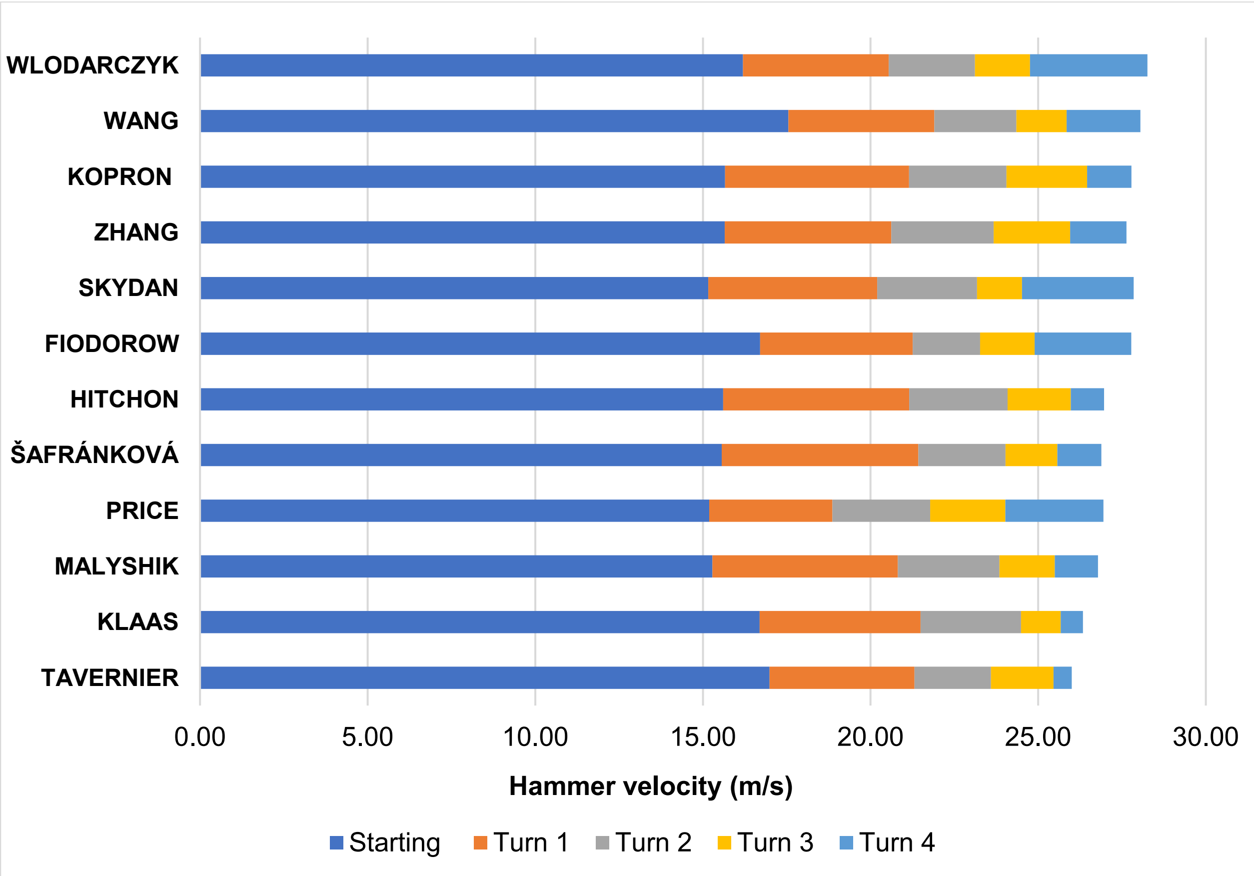


Figure 5. The velocity gain of the hammer throughout the turns.

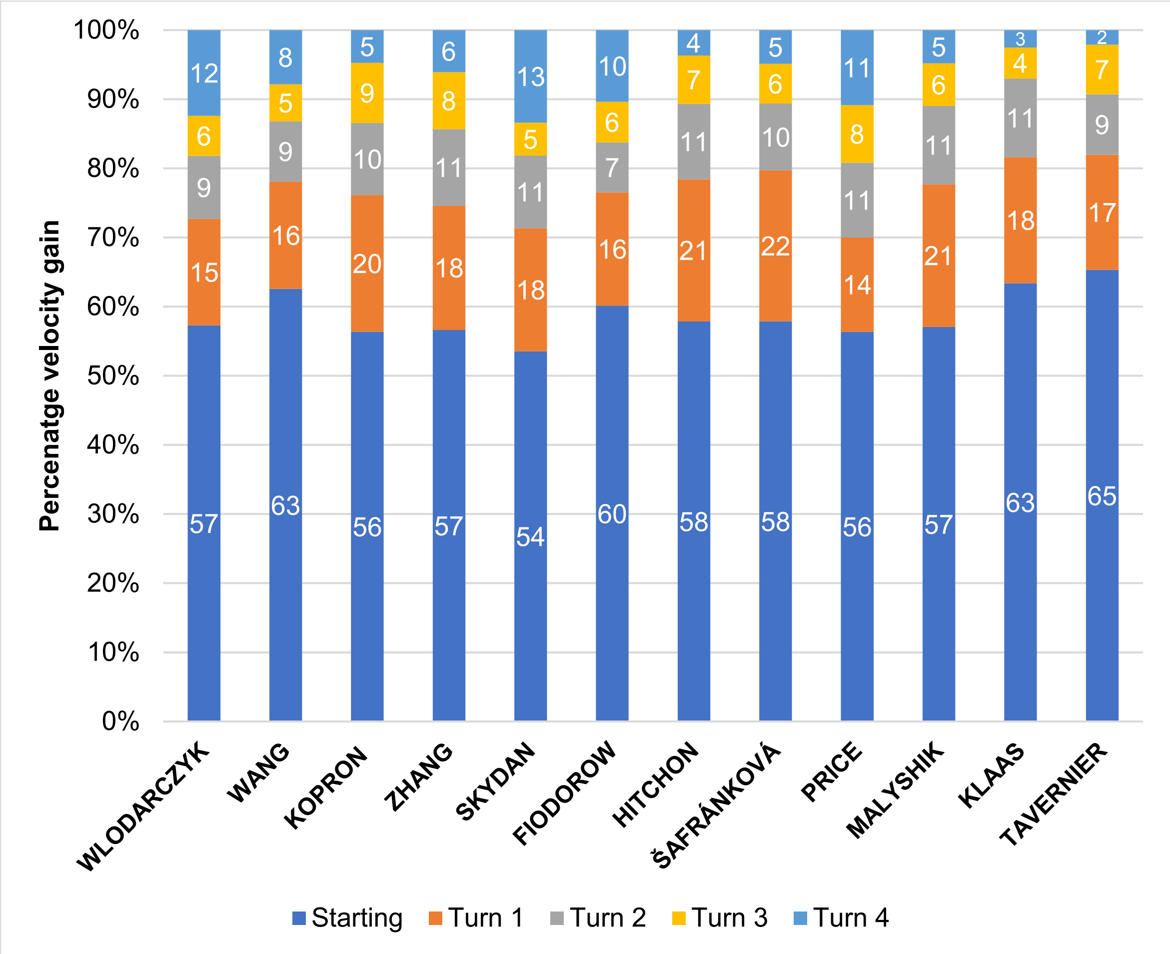


Figure 6. The velocity gain expressed as a percentage of release velocity.

Duration of turns

Figure 7. Visual description of A) toe off at the end of the double support phase and B) touchdown at the end of the single support phase.

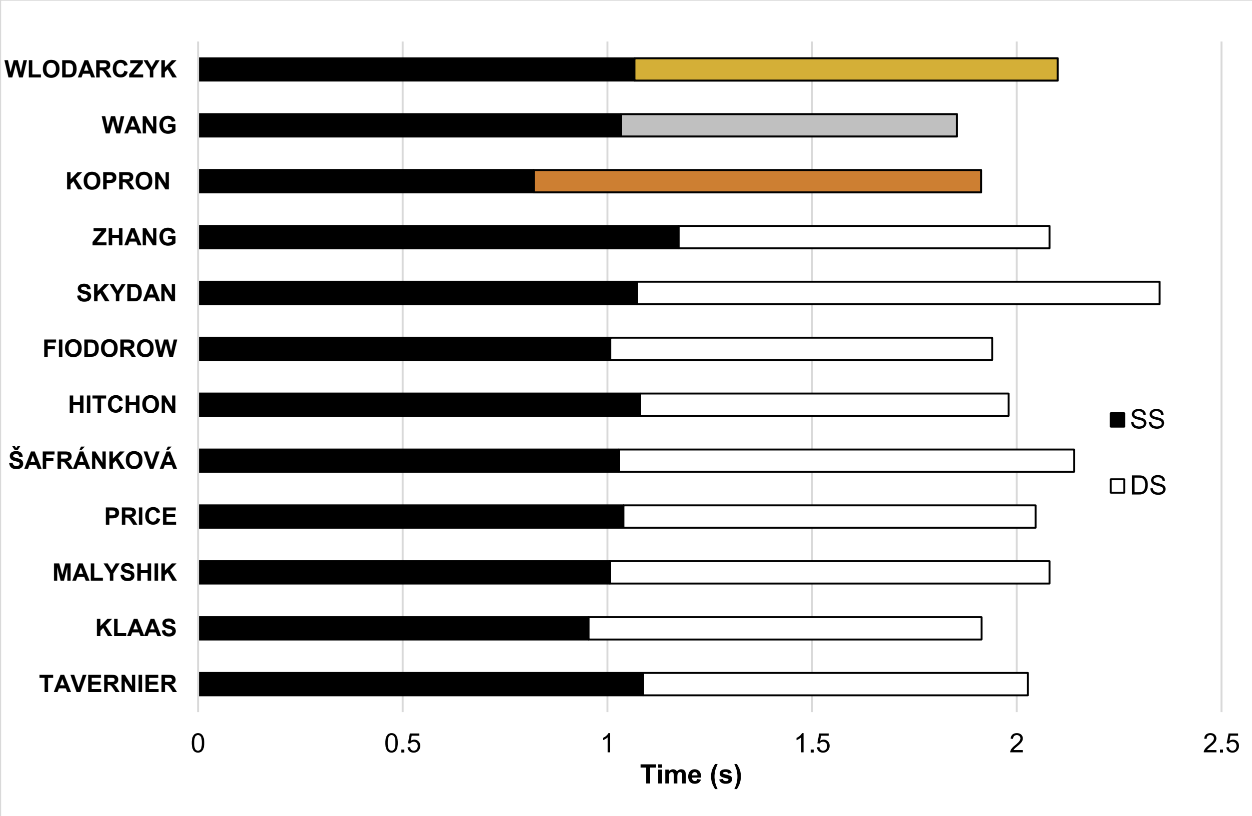


Figure 8. The total duration of turns split into single support (SS) and double support (DS) phases for the twelve finalists.

Figure 8 shows that the total duration of the four turns for the twelve finalists ranged between 1.85 s - 2.35 s. Figure 9 shows that the percentage time spent in the single support phase of the four turns ranged from 42% to 56% for the twelve finalists. Figure 10 shows the duration of the first turn took the longest time (finalists' mean: 0.611 ± 0.045 s), whereas the third turn took the shortest time (finalists' mean: 0.452 ± 0.032 s).

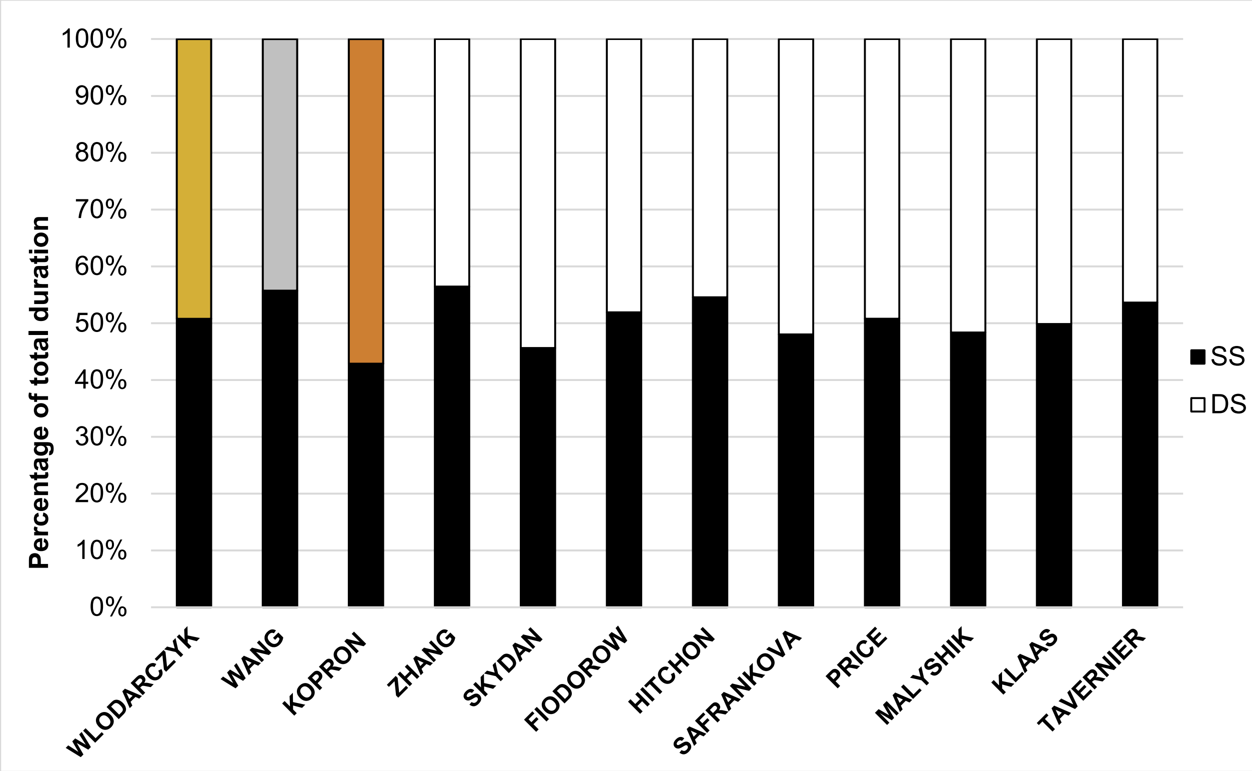


Figure 9. The total duration spent in the single support (SS) and double support (DS) phases expressed as a percentage of the total duration.

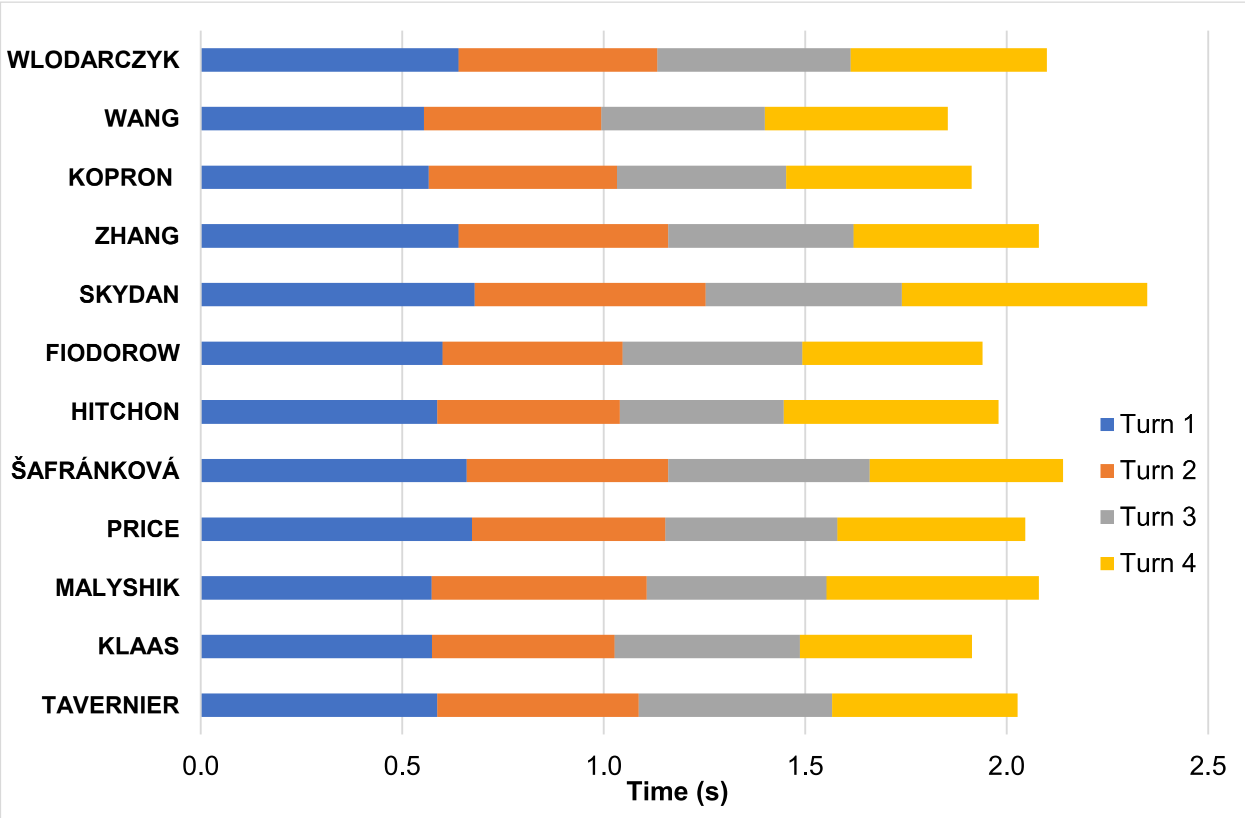


Figure 10. The total duration of each turn.

Table 5. The duration of each single support (SS) and double support (DS) phases for the twelve finalists.

Athlete	Turn 1 SS (s)	Turn 1 DS (s)	Turn 2 SS (s)	Turn 2 DS (s)	Turn 3 SS (s)	Turn 3 DS (s)	Turn 4 SS (s)	Release (s)
WLODARCZYK	0.326	0.314	0.266	0.227	0.227	0.253	0.247	0.240
WANG	0.287	0.267	0.220	0.220	0.286	0.120	0.240	0.214
KOPRON	0.226	0.340	0.194	0.273	0.200	0.220	0.200	0.260
ZHANG	0.360	0.280	0.300	0.220	0.267	0.193	0.247	0.213
SKYDAN	0.326	0.354	0.253	0.320	0.253	0.234	0.240	0.369
FIODOROW	0.293	0.307	0.220	0.227	0.240	0.206	0.254	0.193
HITCHON	0.300	0.287	0.260	0.193	0.247	0.160	0.273	0.260
ŠAFRÁNKOVÁ	0.280	0.380	0.240	0.260	0.254	0.246	0.254	0.226
PRICE	0.293	0.380	0.233	0.247	0.233	0.194	0.280	0.186
MALYSHIK	0.293	0.280	0.267	0.267	0.226	0.220	0.220	0.307
KLAAS	0.274	0.300	0.220	0.233	0.240	0.220	0.220	0.207
TAVERNIER	0.327	0.260	0.267	0.233	0.260	0.220	0.233	0.227

Table 5 details the time spent in each single (SS) and double support (DS) phase and as previously highlighted in Figure 11, the third turn took the shortest time to perform (finalists' mean: 0.452 ± 0.032 s). The fourth turn took a similar total time (finalists mean: 0.484 ± 0.05 s) as the second turn (finalists mean: 0.488 ± 0.04 s). The key difference between the duration of the third and fourth turns exists within the DS phase, whereby the act of delivery in the fourth turn increases the time taken in the DS phase (finalists' mean: 0.242 ± 0.052 s) in comparison to the time taken in the third turn's DS phase (finalists' mean: 0.207 ± 0.037 s).

Path of hammer

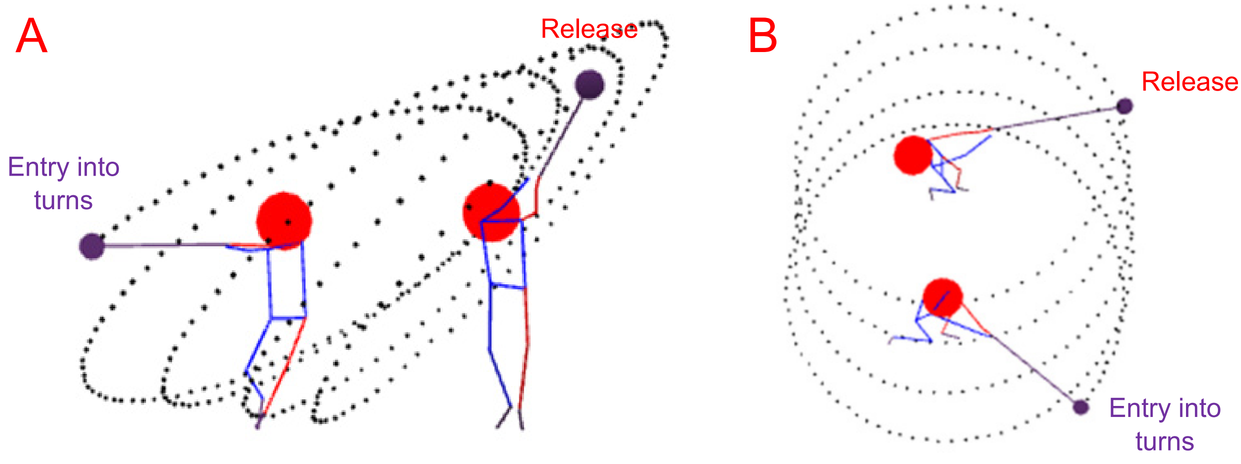


Figure 11. Wlodarczyk's path of the hammer from entry to release, A) side on view and B) superior view.

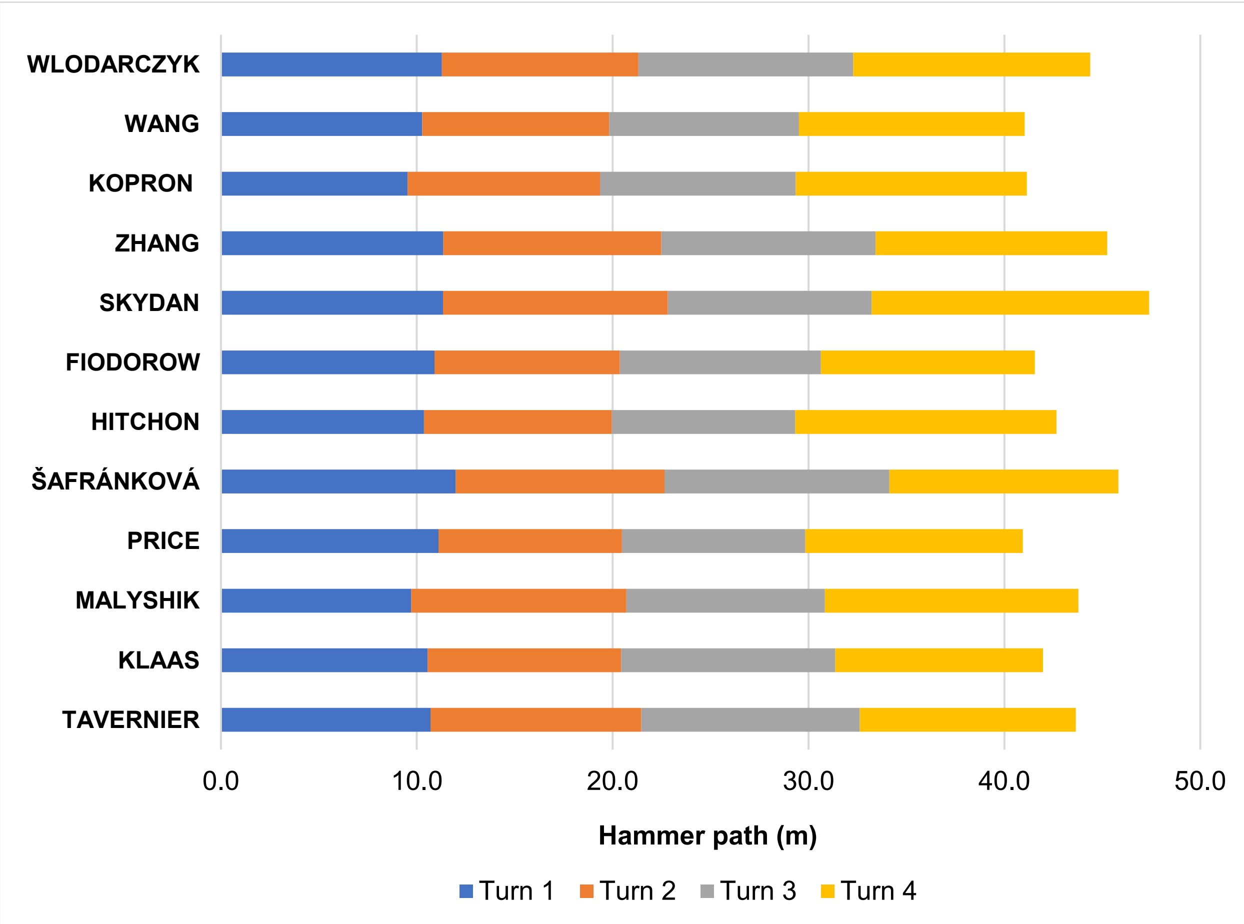


Figure 12. The total path of hammer for each turn.

Figure 12 and Table 6 show that the length of the hammer's path is similar in the first turn (finalists' mean: 10.76 ± 0.72 m), second turn (finalists' mean: 10.23 ± 0.73 m) and third turn (finalists' mean: 10.29 ± 0.71 m). In contrast, the fourth turn exhibited a larger path length (finalists' mean: 11.92 ± 1.07 m), which can be attributed to the effort of release.

Table 6. The path of the hammer during each single (SS) and double (DS) support phase for the twelve finalists.

Athlete	Turn 1 end of SS (m)	Turn 1 end of DS (m)	Turn 2 end of SS (m)	Turn 2 end of DS (m)	Turn 3 end of SS (m)	Turn 3 end of DS (m)	Turn 4 end of SS (m)	Release (m)
WLODARCZYK	5.24	6.04	5.17	4.87	4.99	5.97	5.83	6.28
WANG	4.92	5.35	4.56	4.99	5.21	4.48	5.80	5.72
KOPRON	3.54	5.98	3.89	5.93	4.59	5.41	4.87	6.93
ZHANG	5.87	5.48	6.11	5.02	6.05	4.89	5.99	5.84
SKYDAN	4.91	6.43	4.83	6.64	5.18	5.23	5.17	9.00
FIODOROW	4.87	6.03	4.38	5.08	5.30	4.96	5.93	5.00
HITCHON	4.87	5.50	5.25	4.34	5.55	3.82	6.53	6.82
ŠAFRÁNKOVÁ	4.49	7.50	4.75	5.91	5.53	5.95	5.84	5.86
PRICE	4.34	6.77	4.20	5.17	4.84	4.53	6.29	4.81
MALYSHIK	4.53	5.19	5.18	5.80	4.93	5.21	5.14	7.81
KLAAS	4.63	5.92	4.56	5.33	5.47	5.46	5.25	5.36
TAVERNIER	5.44	5.26	5.45	5.32	5.86	5.29	5.34	5.69

Azimuthal angle

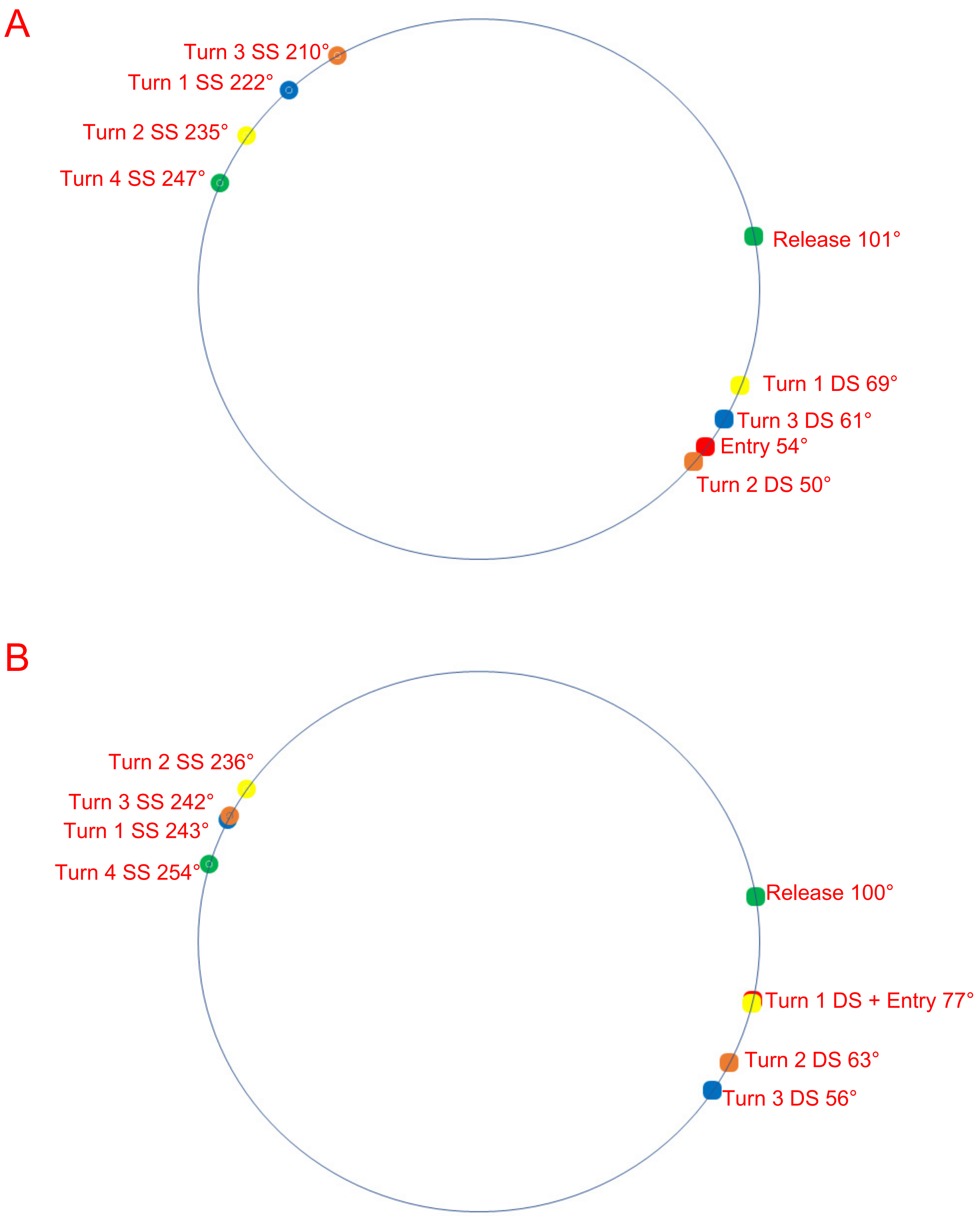


Figure 13. Visual representation of the top four athletes' azimuthal angles at: entry, end of single support (SS) for each turn, end of double support (DS) for each turn and release. A) Wlodarczyk, B) Wang, C) Kopron and D) Zhang.

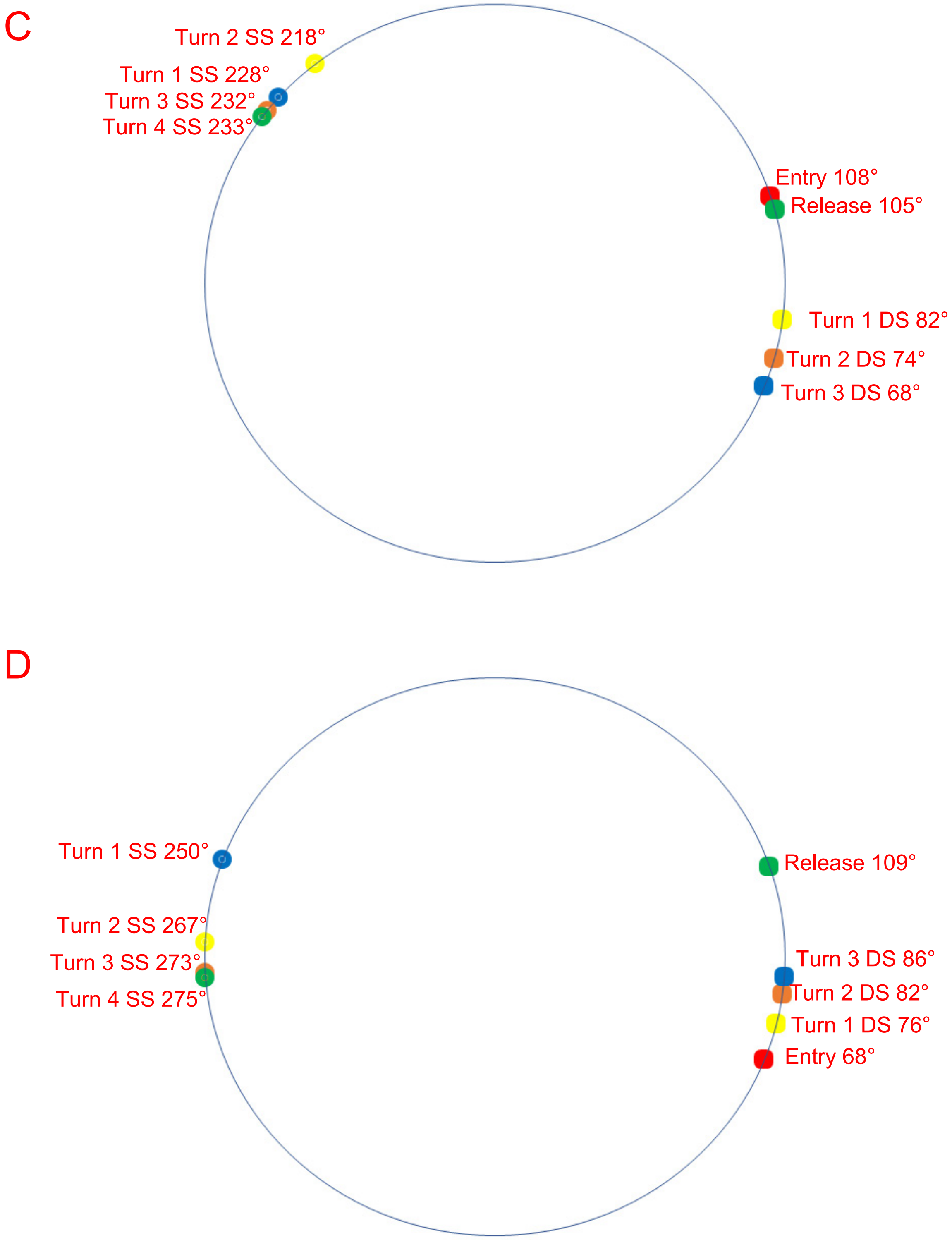


Figure 13 continued. Visual representation of the top four athlete's azimuthal angles at: entry, end of single support (SS) for each turn, end of double support (DS) for each turn and release. A) Wlodarczyk, B) Wang, C) Kopron and D) Zhang.

Figure 13 and Table 7 detail the azimuthal angle which represents the position of the hammer head with respects to a 360° circle. Hence, 0° identifies that the hammer is positioned at the central point at the back of the circle and 180° identifies that hammer is positioned at the central point at the front of the circle. The twelve finalists' azimuthal angle at release ranged between 97° to 109°, whereas a much larger variation of angles was observed at entry which ranged between 50° to 122°.

Table 7. The azimuthal angle for the twelve finalists at: entry, end of single support (SS) for each turn, end of double support (DS) for each turn and release.

Athlete	Entry (°)	Turn 1 end of SS (°)	Turn 1 end of DS (°)	Turn 2 end of SS (°)	Turn 2 end of DS (°)	Turn 3 end of SS (°)	Turn 3 end of DS (°)	Turn 4 end of SS (°)	Release (°)
WLODARCZYK	54	222	69	235	50	210	61	247	101
WANG	77	243	77	236	63	242	56	254	100
KOPRON	108	228	82	218	74	232	68	233	105
ZHANG	68	250	76	267	82	273	86	275	109
SKYDAN	50	199	47	194	50	209	19	176	108
FIODOROW	85	249	98	249	72	252	75	276	101
HITCHON	51	214	52	232	35	224	3	233	104
ŠAFRÁNKOVÁ	57	195	78	231	69	245	84	265	103
PRICE	122	265	132	275	96	262	68	281	97
MALYSHIK	78	229	50	220	61	222	42	208	107
KLAAS	62	218	72	231	66	256	92	272	103
TAVERNIER	58	239	65	246	74	265	91	266	101

Angle of twisting

Table 8 specifies the angle of twisting for all finalists. On the whole, during each of the phases the athletes kept their shoulders behind their hips, whereas during the act of delivery most of the athletes twisted their torsos so their shoulders were positioned in front of the line of their hips.

Table 8. The angle of twisting for each single (SS) and double (DS) support phases for the twelve finalists.

Athlete	Turn 1 end of SS (°)	Turn 1 end of DS (°)	Turn 2 end of SS (°)	Turn 2 end of DS (°)	Turn 3 end of SS (°)	Turn 3 end of DS(°)	Turn 4 end of SS (°)	Release (°)
WLODARCZYK	24	25	27	16	36	14	15	−14
WANG	18	25	12	7	5	6	27	−13
KOPRON	49	24	36	−4	16	10	14	−19
ZHANG	47	17	47	16	53	9	35	−50
SKYDAN	47	14	47	12	51	36	54	−50
FIODOROW	8	0	18	5	13	5	29	−17
HITCHON	43	25	47	34	35	32	55	−44
ŠAFRÁNKOVÁ	61	18	24	33	15	7	30	−5
PRICE	24	3	30	6	1	9	48	−20
MALYSHIK	34	19	26	26	43	23	58	−30
KLAAS	17	16	25	10	32	7	36	−33
TAVERNIER	16	10	27	1	30	4	21	−9

Angle of trailing

Table 9 specifies the angle of trailing for all finalists. Figures 15 and 16 highlight the relationship between the angle of trailing and the angle of twisting at release and the end of the fourth turn's single support (SS) phase, respectively. Both gold medallist and bronze medallist exhibit similar patterns within these two variables, whereby the difference between the end of the SS and release angle of twisting was relatively small (finalists' mean 61 ± 28°) with 29° and 33°, respectively. However, the difference between the end of the SS and release angle of trailing was relatively large (finalists' mean 5 ± 13°) at 23° and 29°, respectively.

Table 9. The angle of trailing for each single (SS) and double (DS) support phases for the twelve finalists.

Athlete	Turn 1 end of SS (°)	Turn 1 end of DS (°)	Turn 2 end of SS (°)	Turn 2 end of DS (°)	Turn 3 end of SS (°)	Turn 3 end of DS (°)	Turn 4 end of SS (°)	Release (°)
WLODARCZYK	128	105	122	110	110	94	112	89
WANG	106	96	114	106	120	111	103	93
KOPRON	104	106	112	116	129	102	121	92
ZHANG	109	94	105	95	98	102	96	99
SKYDAN	116	120	115	116	110	97	111	111
FIODOROW	104	93	106	87	102	92	105	93
HITCHON	113	86	99	84	108	83	88	93
ŠAFRÁNKOVÁ	89	66	101	79	105	97	100	85
PRICE	105	101	100	99	102	91	91	98
MALYSHIK	108	90	113	95	102	97	89	101
KLAAS	116	94	115	99	106	102	108	117
TAVERNIER	110	102	101	114	103	104	98	92

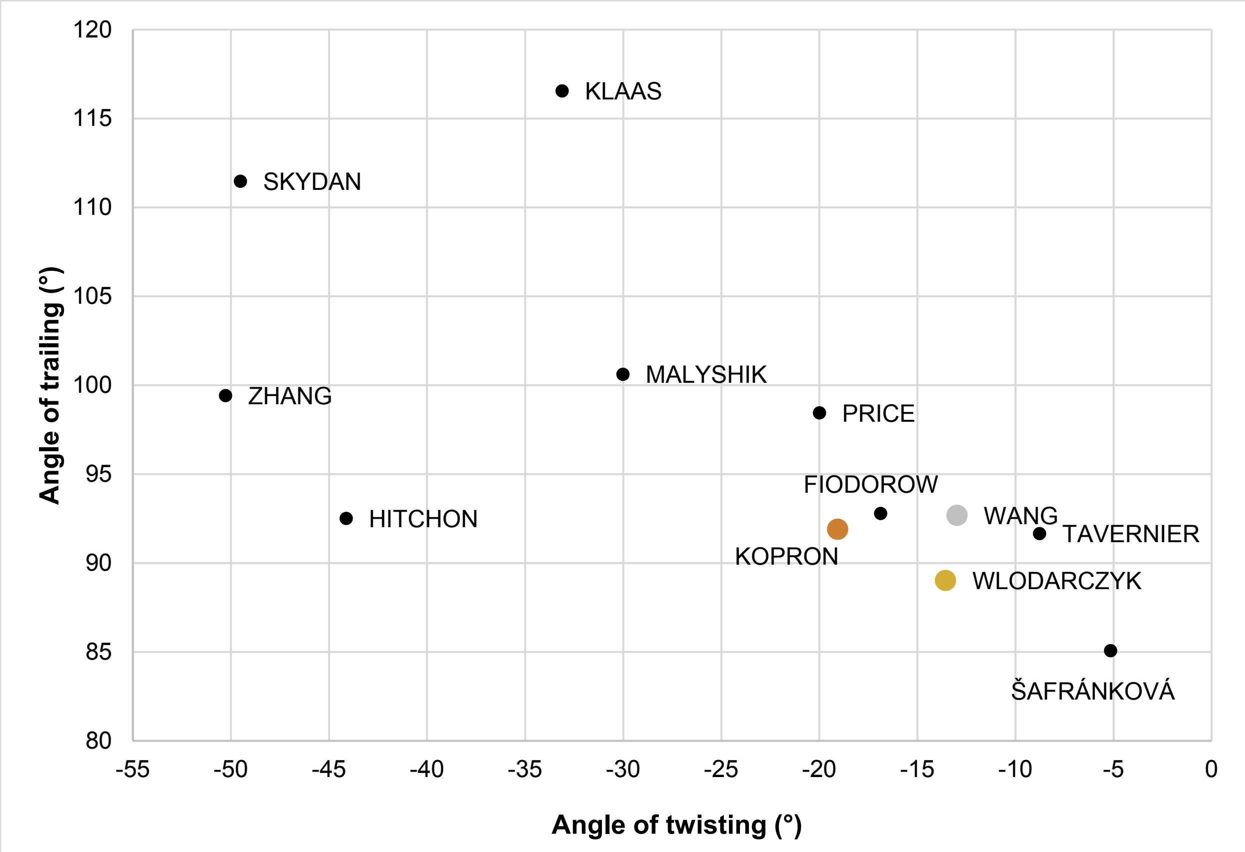


Figure 14. The relationship between the angle of twisting and the angle of trailing at release.

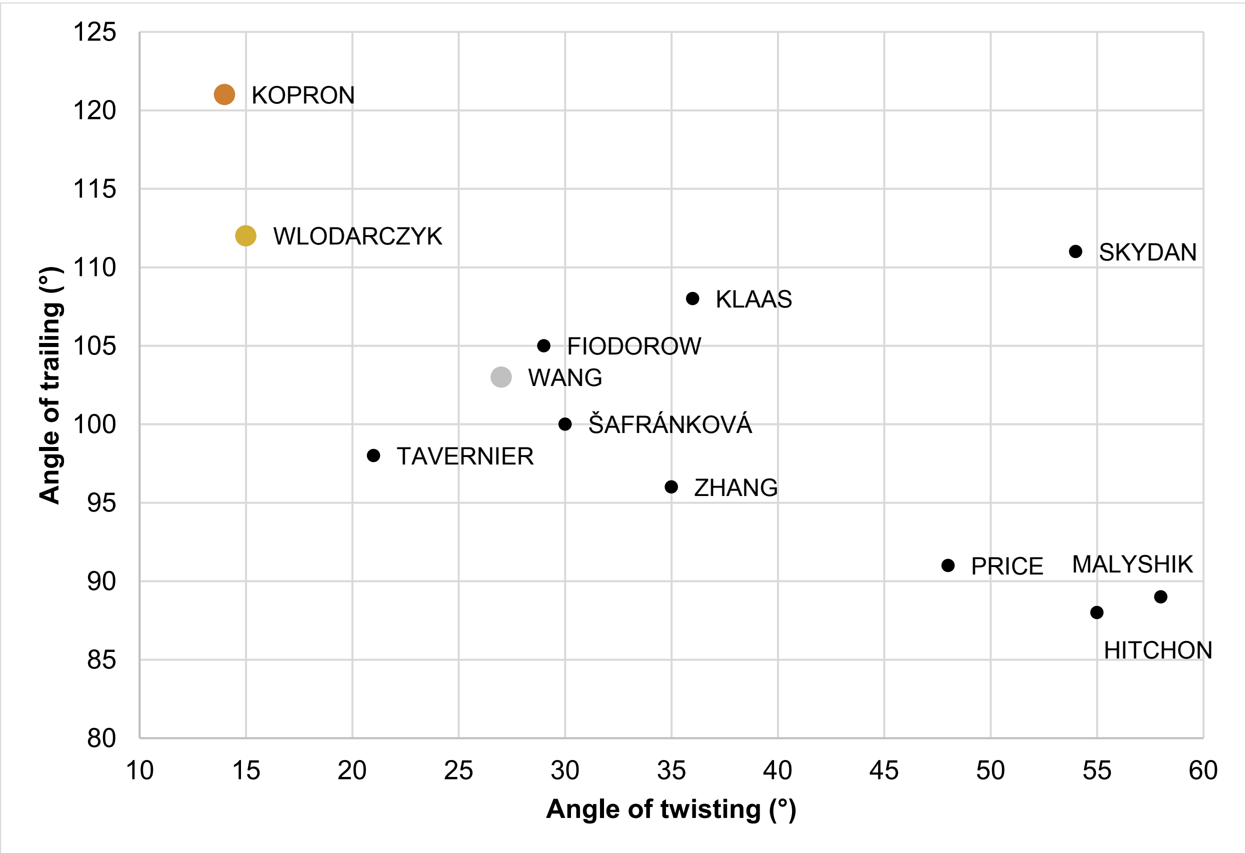


Figure 15. The relationship between the angle of twisting and the angle of trailing at the end of the single support phase in the fourth turn.

Analysis of low and high point of the hammer

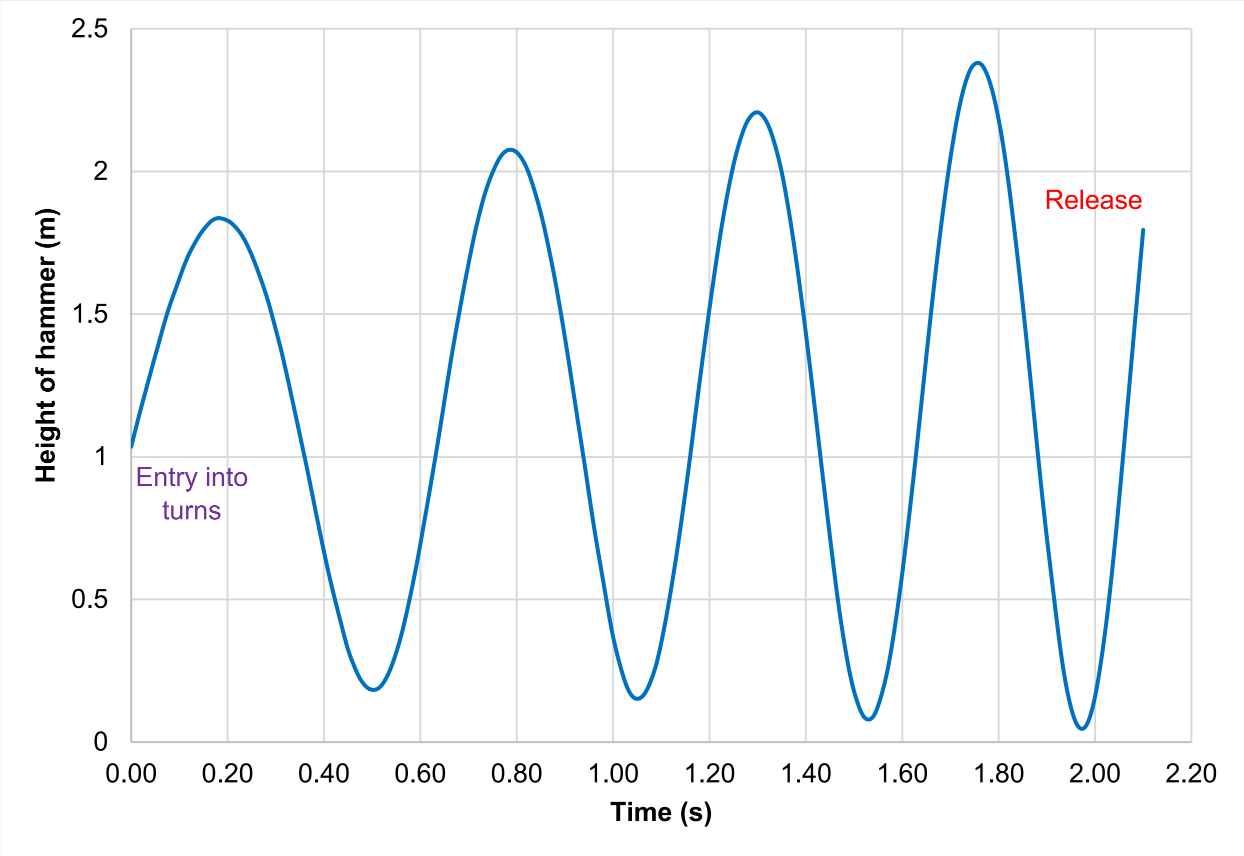


Figure 16. The height of Wlodarczyk's hammer throughout her four turns.

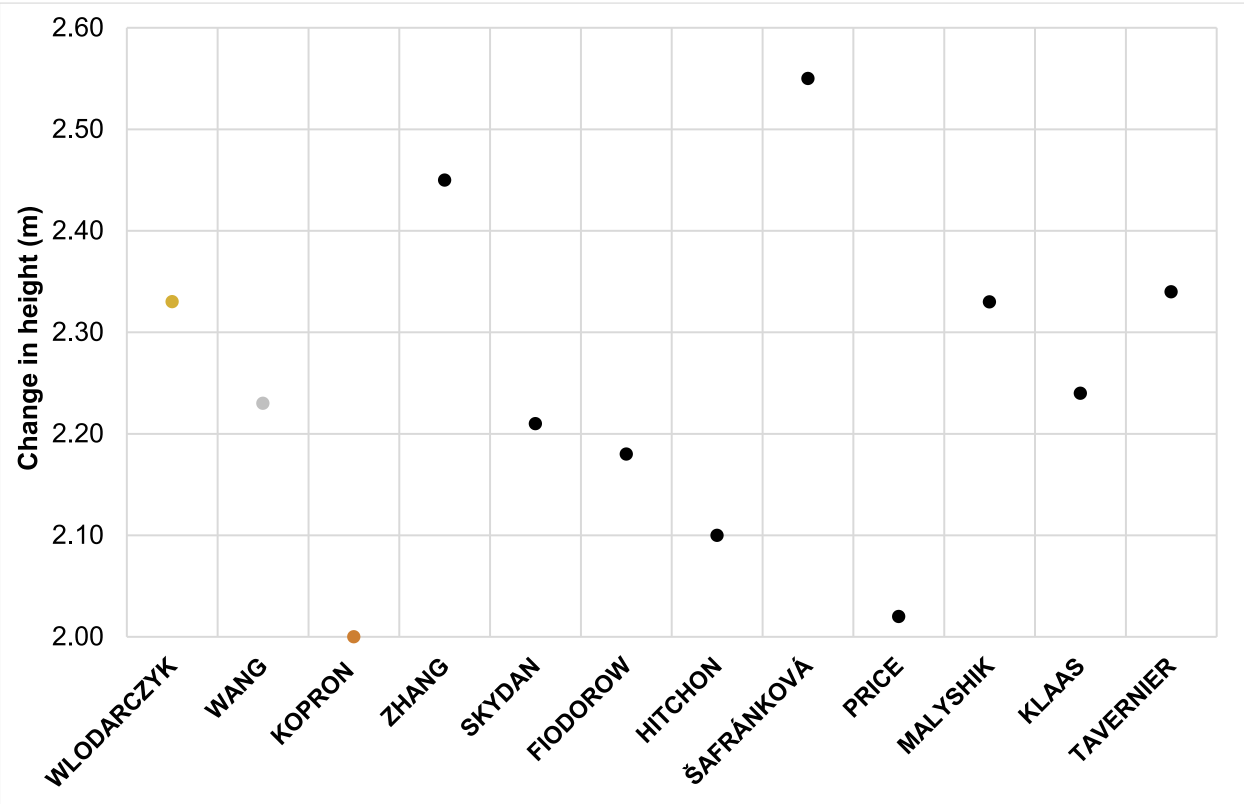


Figure 17. The height difference of the hammer between the low and high points within the fourth turn.

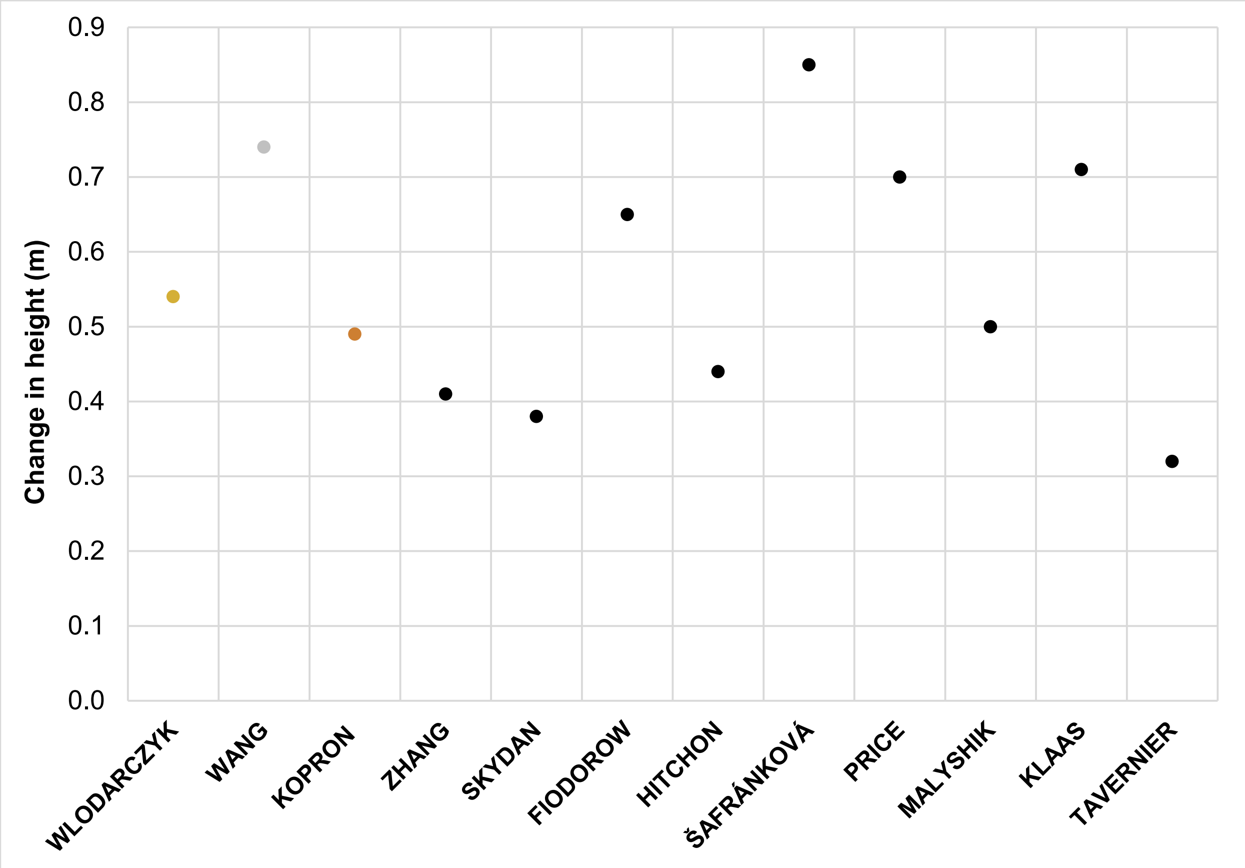


Figure 18. The height gained from the high point in the first turn to the high point in the last turn.

Figure 17, 18 and Table 10 all detail the height of the hammer at the low and high points for each turn. On the whole, the athletes increase their high point and decrease their low point sequentially throughout the four turns. Table 11 also details the relative upswing path angle which represents the angle to the horizontal between the low and high points within each turn.

Table 10. The height of the hammer at low and high points within each turn for the twelve finalists.

Athlete	High point turn 1 (m)	Low point turn 1 (m)	High point turn 2 (m)	Low point turn 2 (m)	High point turn 3 (m)	Low point turn 3 (m)	High point turn 4 (m)	Low point turn 4 (m)
WLODARCZYK	1.84	0.18	2.08	0.15	2.21	0.08	2.38	0.05
WANG	1.64	0.46	2.00	0.33	2.23	0.22	2.38	0.15
KOPRON	1.61	0.44	1.75	0.26	1.97	0.18	2.10	0.10
ZHANG	2.09	0.23	2.23	0.19	2.38	0.14	2.50	0.05
SKYDAN	1.96	0.25	2.11	0.26	2.27	0.23	2.34	0.13
FIODOROW	1.58	0.24	1.89	0.14	2.09	0.09	2.23	0.05
HITCHON	1.76	0.28	2.01	0.22	2.13	0.15	2.20	0.10
ŠAFRÁNKOVÁ	1.77	0.43	2.23	0.33	2.47	0.19	2.62	0.07
PRICE	1.47	0.41	1.73	0.38	1.96	0.25	2.17	0.15
MALYSHIK	1.91	0.39	2.23	0.19	2.37	0.11	2.41	0.08
KLAAS	1.62	0.20	2.02	0.10	2.20	0.07	2.33	0.09
TAVERNIER	2.05	0.14	2.23	0.07	2.36	0.05	2.37	0.03

Note: *The heights are measured relative to the tartan floor and not the bottom of the circle.*

Table 11. Relative upswing angle within each turn for the twelve finalists.

Athlete	Turn 1 (°)	Turn 2 (°)	Turn 3 (°)	Turn 4 (°)	Release (°)
WLODARCZYK	25.1	30.9	34.0	39.6	41.6
WANG	23.0	26.4	33.8	39.7	38.8
KOPRON	21.7	23.6	31.2	34.6	39.8
ZHANG	32.5	32.8	36.9	40.6	41.7
SKYDAN	29.7	29.5	32.1	34.5	37.5
FIODOROW	20.8	27.3	33.2	37.7	39.2
HITCHON	26.7	30.8	34.5	37.6	40.3
ŠAFRÁNKOVÁ	19.6	28.8	35.2	40.8	45.0
PRICE	17.2	21.2	26.4	33.6	38.5
MALYSHIK	22.0	30.5	36.4	40.2	42.9
KLAAS	23.3	32.6	39.0	42.3	42.8
TAVERNIER	32.7	35.8	40.1	40.6	41.7

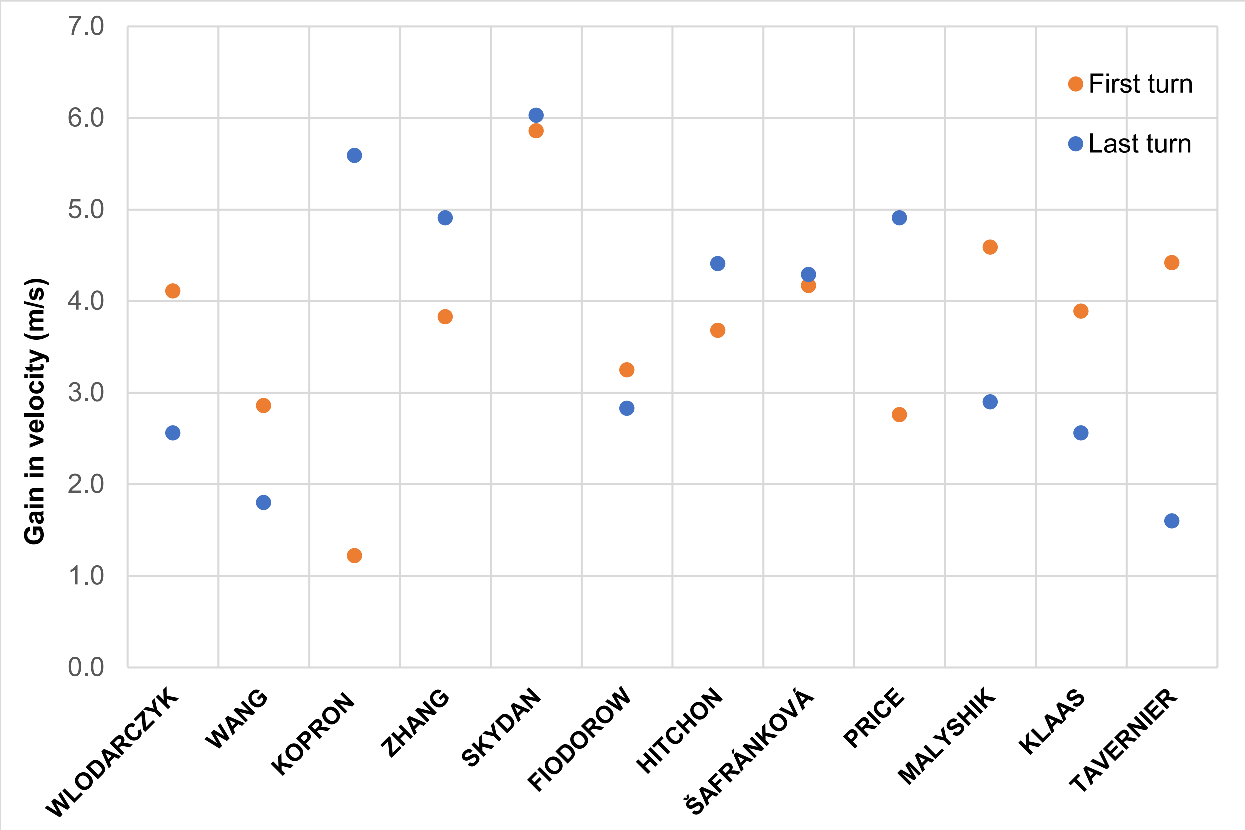


Figure19. The velocity gained from the high point to low point for both the first turn and last turn.

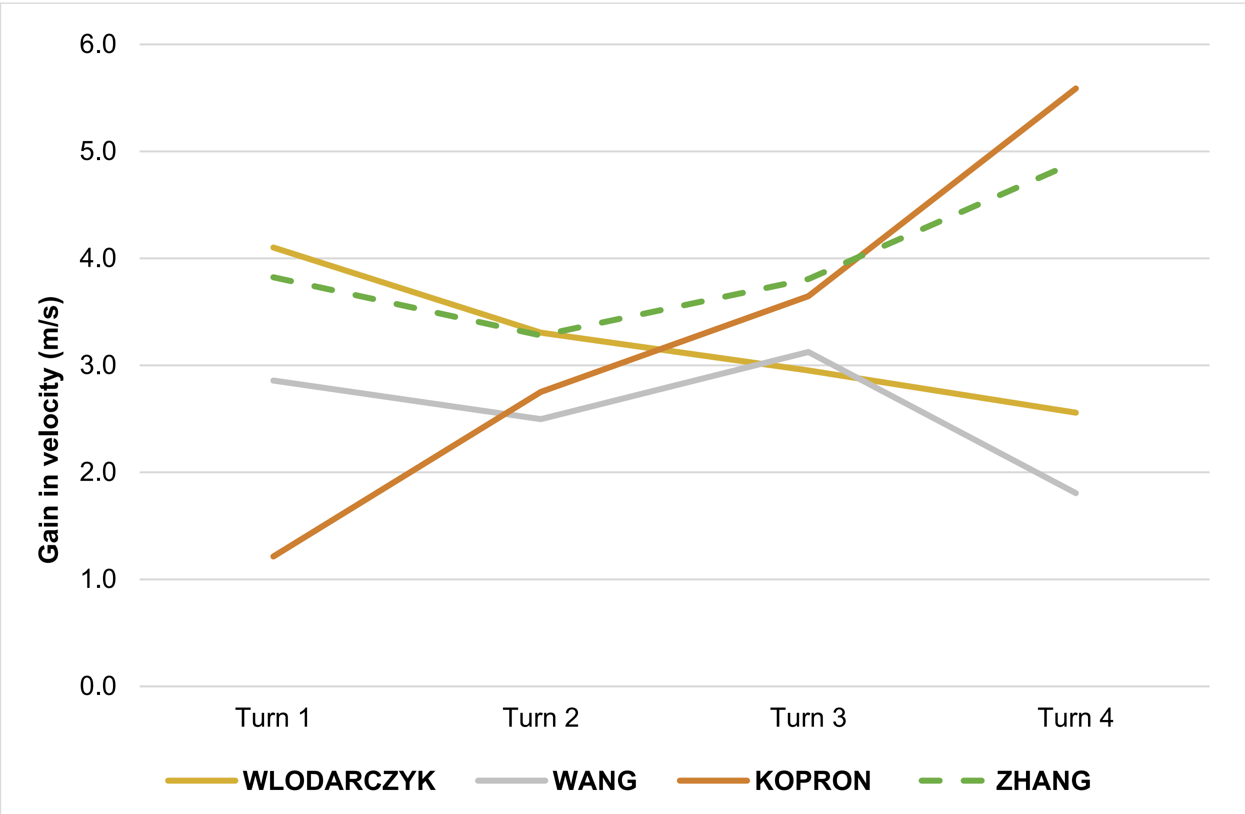


Figure 20. The velocity gained for the top four athletes from the high point to the low point within each turn.

Table 12. The velocity of the hammer at each of the low and high points for the twelve finalists.

Athlete	High point turn 1 (m/s)	Low point turn 1 (m/s)	High point turn 2 (m/s)	Low point turn 2 (m/s)	High point turn 3 (m/s)	Low point turn 3 (m/s)	High point turn 4 (m/s)	Low point turn 4 (m/s)
WLODARCZYK	15.78	19.89	18.97	22.28	21.39	24.34	23.11	25.67
WANG	16.65	19.51	20.93	23.43	22.26	25.38	23.95	25.75
KOPRON	17.11	18.33	20.52	23.27	22.79	26.44	23.93	29.52
ZHANG	16.49	20.32	20.23	23.51	21.99	25.79	23.42	28.33
SKYDAN	13.88	19.74	18.60	22.68	19.59	23.63	20.53	26.56
FIODOROW	16.14	19.39	18.71	22.93	20.84	23.66	21.85	24.68
HITCHON	16.40	20.08	20.72	23.72	22.43	25.97	23.27	27.68
ŠAFRÁNKOVÁ	15.83	20.00	19.66	24.03	21.19	24.35	22.14	26.43
PRICE	14.71	17.47	17.63	20.67	19.80	23.46	20.92	25.83
MALYSHIK	15.11	19.70	18.27	23.07	19.71	25.49	21.84	24.74
KLAAS	17.17	21.06	20.97	24.01	24.28	25.70	23.84	26.40
TAVERNIER	16.49	20.91	20.16	23.38	22.28	23.18	22.74	24.34

Figures 19, 20 and Table 12 all detail the velocity of the hammer at the low and high points throughout the four turns. On the whole, the velocity gained from high to low positions increase throughout the turns, whereas the velocity lost from low to high positions is minimised by the athletes.

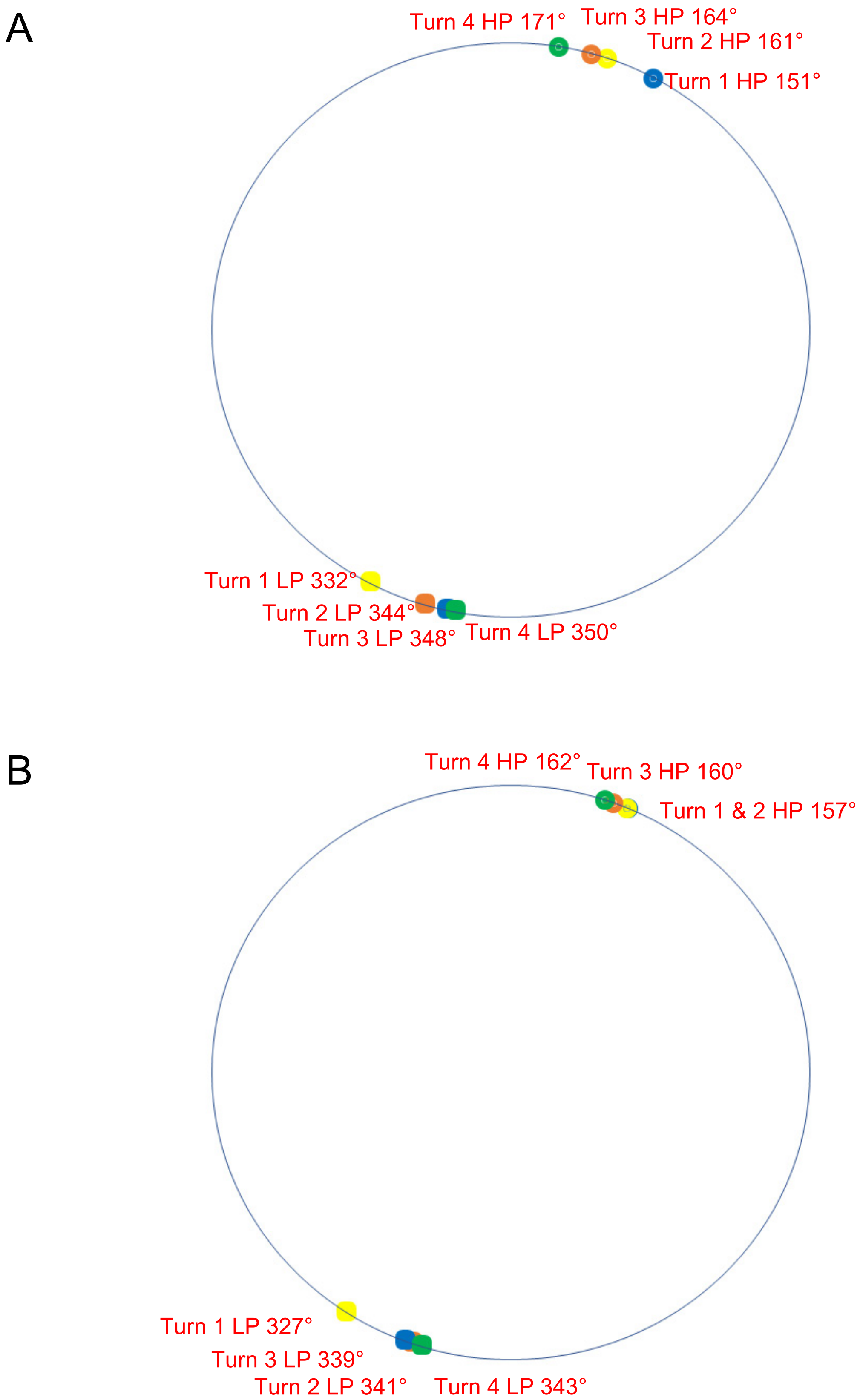


Figure 21. The representation of each of the top four athlete's azimuthal angles for the high point (HP) and low point (LP) for each turn. A) Wlodarczyk, B) Wang, C) Kopron and D) Zhang.

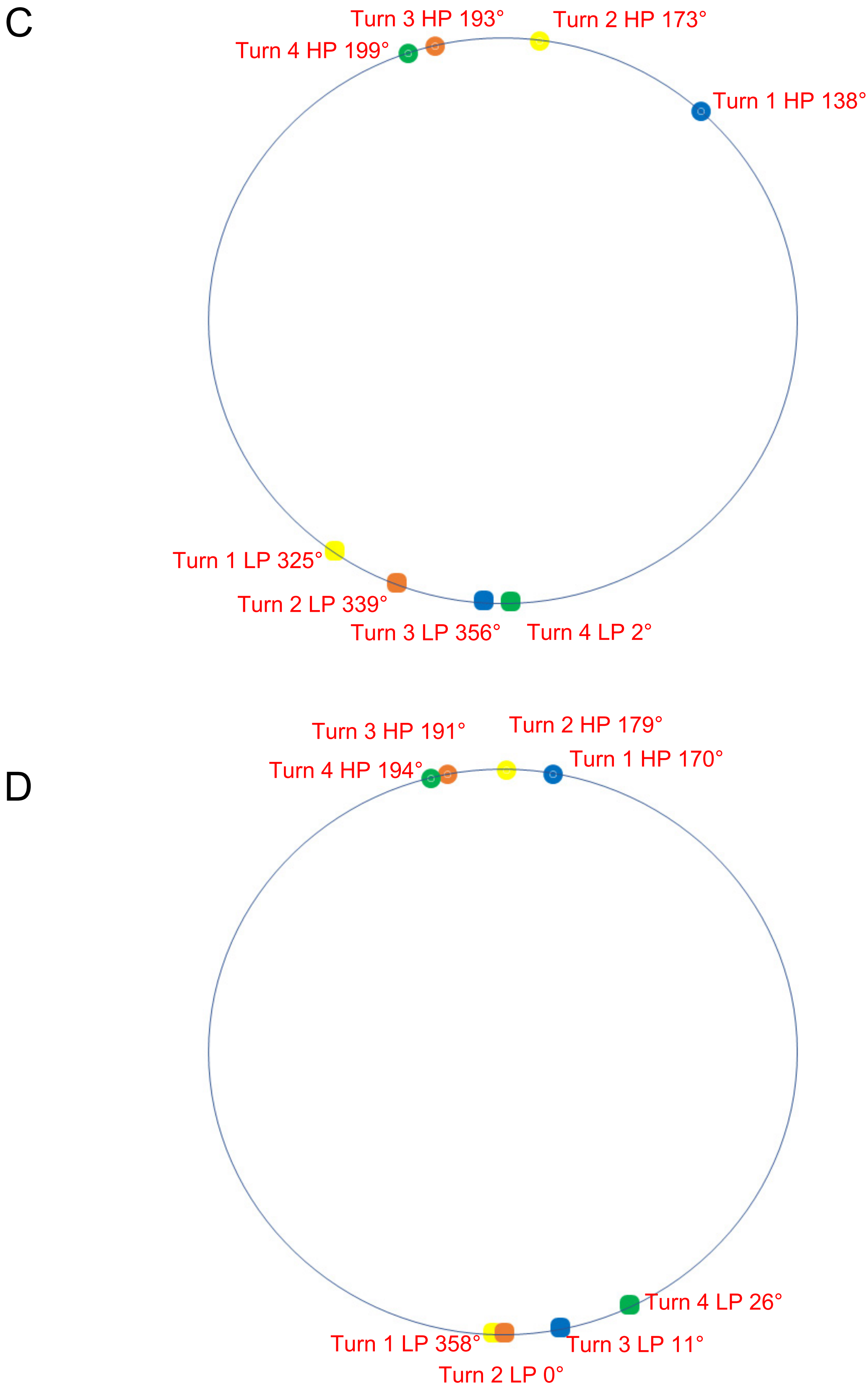


Figure 21 continued. The visual representation of the top four athlete's azimuthal angles for the high point (HP) and low point (LP) for each turn. A) Wlodarczyk, B) Wang, C) Kopron and D) Zhang.

Figure 21 and Table 13 detail the azimuthal angle for all athletes. On the whole, most athletes progressively move their high point position towards or slightly past 180°, as well as their low point position towards or slightly past 0°.

Table 13. The azimuthal angle for each of the low and high points for twelve finalists.

Athlete	High point turn 1 (°)	Low point turn 1 (°)	High point turn 2 (°)	Low point turn 2 (°)	High point turn 3 (°)	Low point turn 3 (°)	High point turn 4 (°)	Low point turn 4 (°)
WLODARCZYK	151	332	161	344	164	348	171	350
WANG	157	327	157	341	160	339	162	343
KOPRON	138	325	173	339	193	356	199	2
ZHANG	170	358	179	0	191	11	194	26
SKYDAN	161	340	174	355	177	6	176	0
FIODOROW	153	340	162	346	166	346	172	355
HITCHON	143	326	164	348	166	3	185	4
ŠAFRÁNKOVÁ	129	312	155	342	165	352	179	10
PRICE	165	354	178	352	183	358	181	5
MALYSHIK	161	358	178	1	183	14	183	358
KLAAS	149	339	161	351	178	354	179	13
TAVERNIER	139	320	154	339	168	345	171	354

Type of turn in the first single support (SS) phase

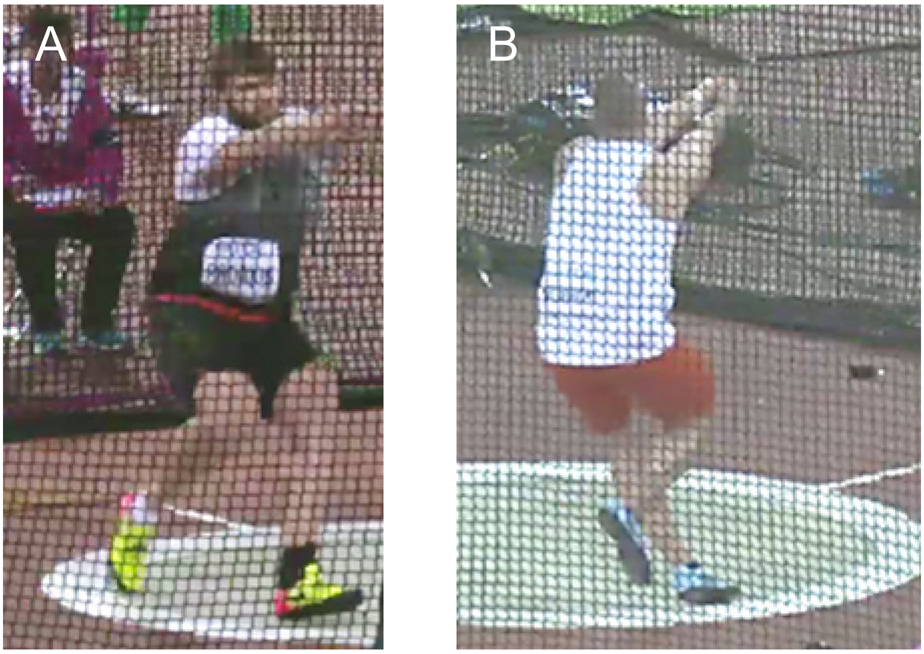


Figure 22. A visual representation of A) heel turn and B) toe turn.

Table 14. The type of turn that the twelve finalists utilised within the first single support (SS) phase.

Athlete	Type of turn in the first SS phase
WLODARCZYK	Heel
WANG	Toe
KOPRON	Heel
ZHANG	Heel
SKYDAN	Toe
FIODOROW	Heel
HITCHON	Heel
ŠAFRÁNKOVÁ	Toe
PRICE	Heel
MALYSHIK	Toe
KLAAS	Heel
TAVERNIER	Heel

COACH'S COMMENTARY

The women's finalists (all of which were four turners) began their single support phases at an mean of 72.5°, and ended them around 240-250° (see Figure 13). This was noticeably different from what was observed with the men's four turners who would begin their single support phase much earlier (56.7°) and completed single support around 230°. The later right foot pickup at entry for the women's finalists caused a repetitive cycle of entering SS later throughout the throw when compared with the men's four turners (72.5/74.8/66/62° for women vs. 56.7/54.7/49.5/50.3° for men) The later right foot pickup on the first turn also allowed the women's throwers to gain more hammer head velocity as a percentage of final release velocity than the men upon entry (59% to 55%). The most likely reason for this technical difference is the greater strength to implement ratio exhibited by the female throwers.

The medallists in the women's hammer throw by and large the highest release velocities between 28.26 m/s and 27.78 m/s. The release angles were all in the neighbourhood of 40° (41.8 to 38.5°). Skydan, the fifth-place finisher, had recorded a release velocity of 27.85 m/s but at a lower angle of release at 36.9°.

With regard to the angle of trailing, the women's hammer medallists were in a position where they "led" the hammer more with their shoulders throughout the throw than the rest of the field. However, in comparison with the men's hammer finalists, the women exhibited a steadier, or more constant rate of trailing by having lower rates of trailing at the end of single support, while also having higher rates of trailing at the end of the double support phases.

Figures 14 and 15 showed that the medallists had a combination of some of the highest rates of trailing combined with the lowest rates of twisting at the end of the single support phase in turn four. This was all done while also having the highest hammer head velocities in this point of the throw for the group.

Skydan showed the largest velocity gain in the final turn by adding 3.8 m/s to her final release velocity in turn four. She did this by having the longest ball path of any of the throwers in the release (9.0 m), while also maintaining the largest angle of trailing throughout the delivery (−50°). During delivery she also moved through from a 50 degree angle of twisting all the way to -50 degree angle of twisting at release for quite a dynamic finish.

The women's hammer event can still be considered as a developing event in some ways, having been contested internationally for less than 20 years. It first appeared in the IAAF World Championships in 1999, and one of the key factors that came out of these 2017 World Championships, is that there is certainly not one typical way in which women throw the hammer.

There is so much variation in technique, much less consistency as a whole than the men's competition. Certainly, there were no real trends emerging between countries. For example, with 3 Polish and 2 Chinese Athletes among the finalists, you could not see patterns of consistency between the nationalities as you may see in the men's competition with a much longer tradition in the event. In the women's event there are many ways to throw the hammer far, perhaps because of the relative lighter weight of the implement compared to strength levels. You also have a great variety in the sizes of the athletes in the final, from Kathrin Klaas at 168 cm and 72 kg, to Šafránková at 193 cm and 103 kg. There are also shorter, heavy athletes, that can utilise their extra bodyweight to good effect to counterbalance the hammer in the turns without a great deal of movement.

Anita Wlodarczyk lies very much in the middle of the size range at 178 cm and 95 kg, but for a number of years has clearly been the best female hammer thrower in the world. She came into the competition as overwhelming favourite, unbeaten in many competitions, and a seasonal best some 6.5 m better than the rest of the field. Her victory here with a throw of 77.90 m, 4.97 m down on her seasonal best, and a margin of victory of less than 2.0 m, leads us to believe that this day was not some of her best technical throwing and she was well within her physical capabilities on the day. This biomechanical analysis of only one of her below par throws, demonstrates the difficulty in applying this data from a coaching perspective.

In looking for trends or discrepancies across the data from all finalists, one interesting issue jumped out and demanded some further investigation, and was regarding the maximal and release velocities of some throws. On her best throw of 77.90 m, Wlodarczyk clearly displays the highest release velocity in Table 3 of 28.26 m/s at a release angle of 41.8° and a release height of 1.80 m, which we know are the three main determinants of overall distance thrown. If we compare this data to her countrywoman Kopron, who took the bronze medal with a throw of 74.76 m, with a release velocity of 27.78 m/s at a release angle of 39.7° and release height of only 1.40 m, all figures just slightly below that of Wlodarczyk- which would explain the difference of 3.14 m in the results.

Kopron, however, recorded the highest recorded hammer velocity of the whole study (Table 12), with 29.52 m/s at the low point of her 4th turn, however she was unable to maintain this velocity through to release, by which time her hammer velocity had dropped to the aforementioned 27.78 m/s, a loss of 1.74 m/s over a relatively short distance. This can be seen in Figures 13 and 21 which show the azimuthal angle as viewed from above, for the low point in turn 4 at 2° through to the release point at 105°, a total of 103°, so a little over ¼ of a turn! Over this same period of low point T4 to delivery, Wlodarczyk was able to increase her velocity from 25.67 m/s to 28.26 m/s at release, an addition of 1.74 m/s from the low point T4 (350°) to delivery (101°) for a total of 111°, an increase of only 8° over Kopron.

We can look at these two athletes to try and see if we can find anything worthy of further investigation in another study with more data points, and why Kopron may have lost so much velocity, which certainly affected the distance thrown. We can use the data in Table 10 to show the high and low points of the hammer head through the throw as is shown graphically for Wlodarczyk in Figure 16. If we were to superimpose the similar path of the throw of Kopron, she would have a much smaller amplitude as her low points are not as low and Wlodarczyk, and her high points not as high!

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.

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.

Dr Athanassios Bissas is the Head of the Biomechanics Department in the Carnegie School of Sport at Leeds Beckett University. His research includes a range of topics but his main expertise is in the areas of biomechanics of sprint running, neuromuscular adaptations to resistance training, and measurement and evaluation of strength and power. Dr Bissas has supervised a vast range of research projects whilst having a number of successful completions at PhD level. Together with his team he has produced over 100 research outputs and he is actively involved in research projects with institutions across Europe.

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.