IAAF World Championships
LONDON 2017

BIOMECHANICAL REPORT

FOR THE

IAAF World Championships
LONDON 2017

Hammer Throw Men's

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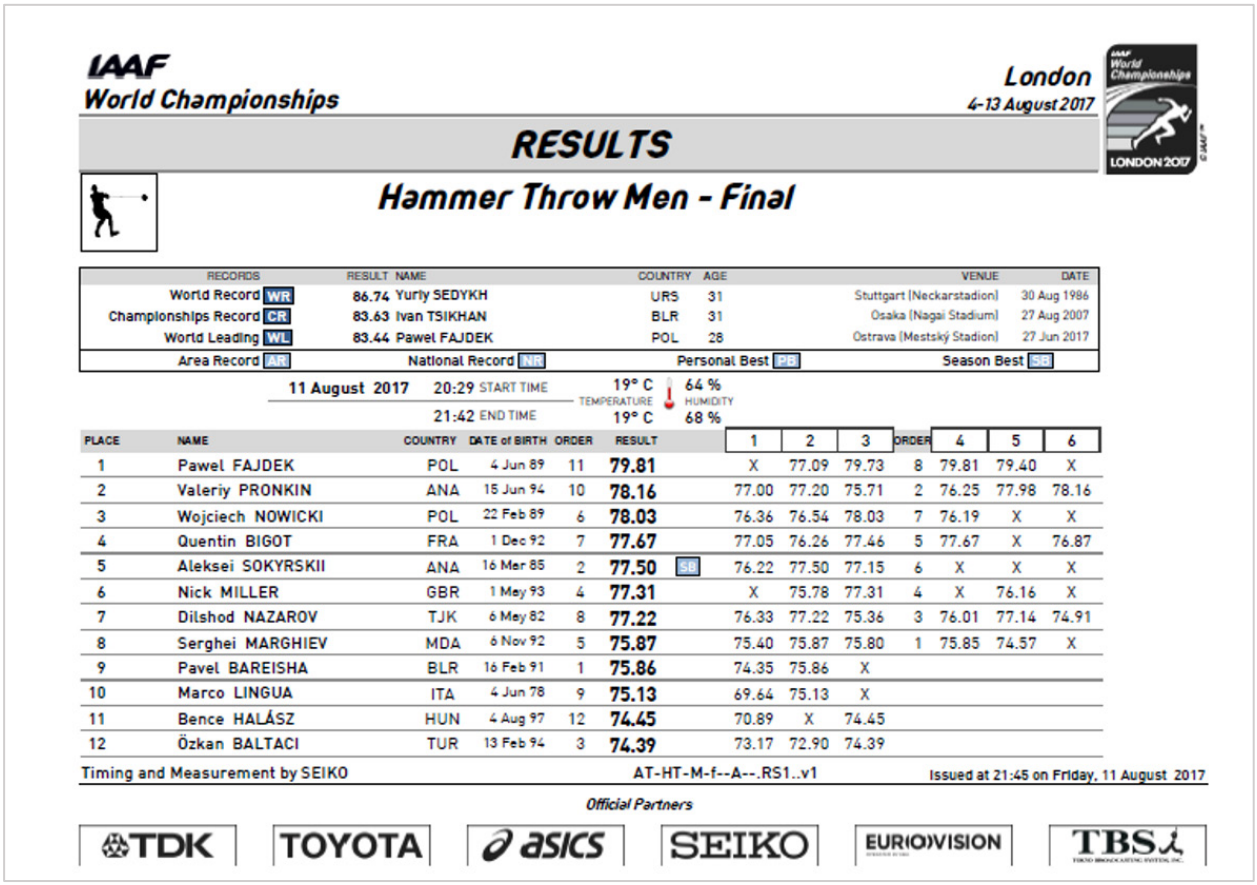
INTRODUCTION

The men's hammer final took place on the night of August 11th in good weather conditions. Coming into the final, Pawel Fajdeck of Poland was the favourite as the world leader in 2017. After the first two rounds, Aleksei Sokyrsii clinched an early lead with a season's best throw of 77.50 m. Subsequently, Pawel Fajdeck then took control of the competition with an imposing sequence of throws, in which his best throw came in the fourth round which was measured at 79.81 m. Wojciech Nowicki was in the silver medal position going into the final round after throwing 78.03 m in the third round. In an enthralling finish, Valeriy Pronkin seized the silver medal with a throw of 78.16 m. However, Nowicki was unable to respond to this late surge from Pronkin which meant Nowicki had to settle for the bronze medal.



IAAF World Championships — London 4-13 August 2017

RESULTS

Hammer Throw Men - Final

RECORDS	RESULT	NAME	COUNTRY	AGE	VENUE	DATE
World Record WR	86.74	Yuriy SEDYKH	URS	31	Stuttgart (Neckarstadion)	30 Aug 1986
Championships Record CR	83.63	Ivan TSIKHAN	BLR	31	Osaka (Nagai Stadium)	27 Aug 2007
World Leading WL	83.44	Pawel FAJDEK	POL	28	Ostrava (Mestský Stadion)	27 Jun 2017

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

11 August 2017 — 20:29 START TIME — 19° C TEMPERATURE — 64 % HUMIDITY

21:42 END TIME — 19° C — 68 %

PLACE	NAME	COUNTRY	DATE of BIRTH	ORDER	RESULT		1	2	3	ORDER	4	5	6
1	Pawel FAJDEK	POL	4 Jun 89	11	**79.81**		X	77.09	79.73	8	79.81	79.40	X
2	Valeriy PRONKIN	ANA	15 Jun 94	10	**78.16**		77.00	77.20	75.71	2	76.25	77.98	78.16
3	Wojciech NOWICKI	POL	22 Feb 89	6	**78.03**		76.36	76.54	78.03	7	76.19	X	X
4	Quentin BIGOT	FRA	1 Dec 92	7	**77.67**		77.05	76.26	77.46	5	77.67	X	76.87
5	Aleksei SOKYRSKII	ANA	16 Mar 85	2	**77.50**	SB	76.22	77.50	77.15	6	X	X	X
6	Nick MILLER	GBR	1 May 93	4	**77.31**		X	75.78	77.31	4	X	76.16	X
7	Dilshod NAZAROV	TJK	6 May 82	8	**77.22**		76.33	77.22	75.36	3	76.01	77.14	74.91
8	Serghei MARGHIEV	MDA	6 Nov 92	5	**75.87**		75.40	75.87	75.80	1	75.85	74.57	X
9	Pavel BAREISHA	BLR	16 Feb 91	1	**75.86**		74.35	75.86	X				
10	Marco LINGUA	ITA	4 Jun 78	9	**75.13**		69.64	75.13	X				
11	Bence HALÁSZ	HUN	4 Aug 97	12	**74.45**		70.89	X	74.45				
12	Özkan BALTACI	TUR	13 Feb 94	3	**74.39**		73.17	72.90	74.39				

Timing and Measurement by SEIKO — AT-HT-M-f--A--.RS1..v1 — Issued at 21:45 on Friday, 11 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.

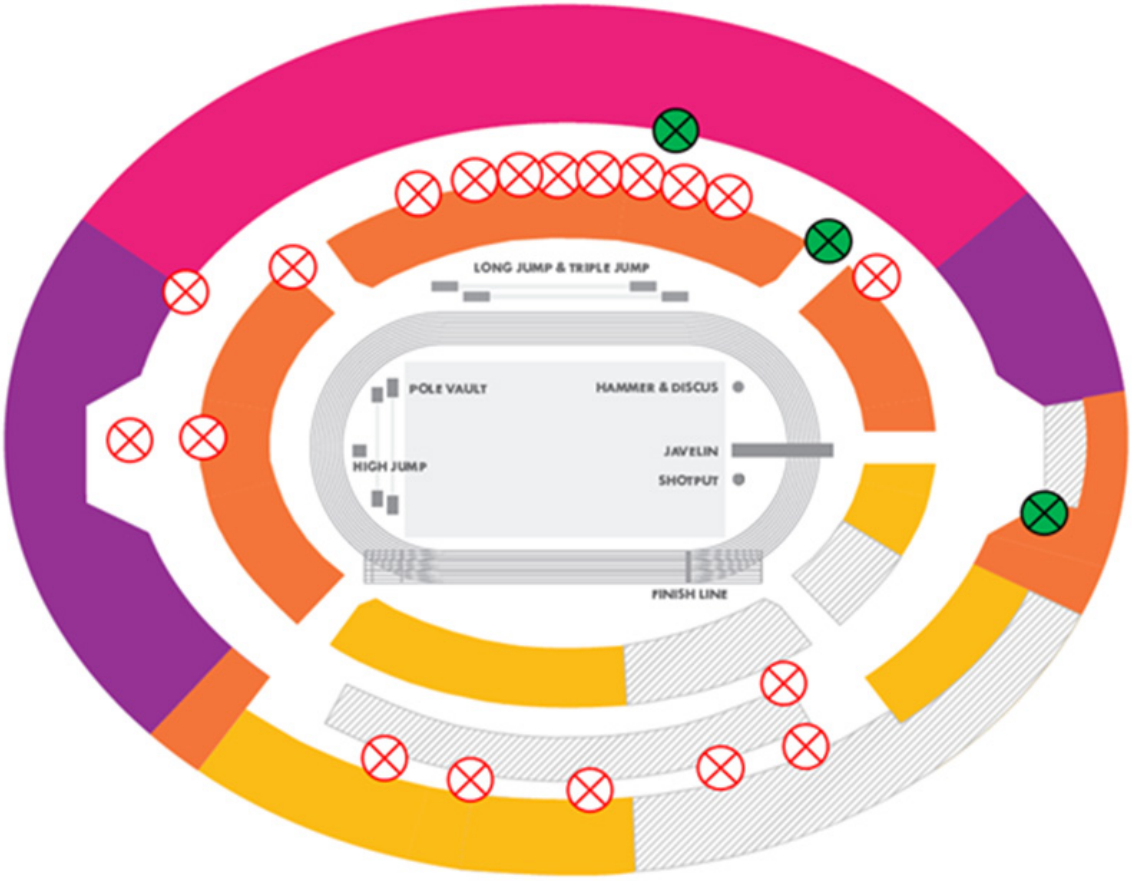


Figure 1. Stadium layout with camera locations for the men's hammer final (shown in green).

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.

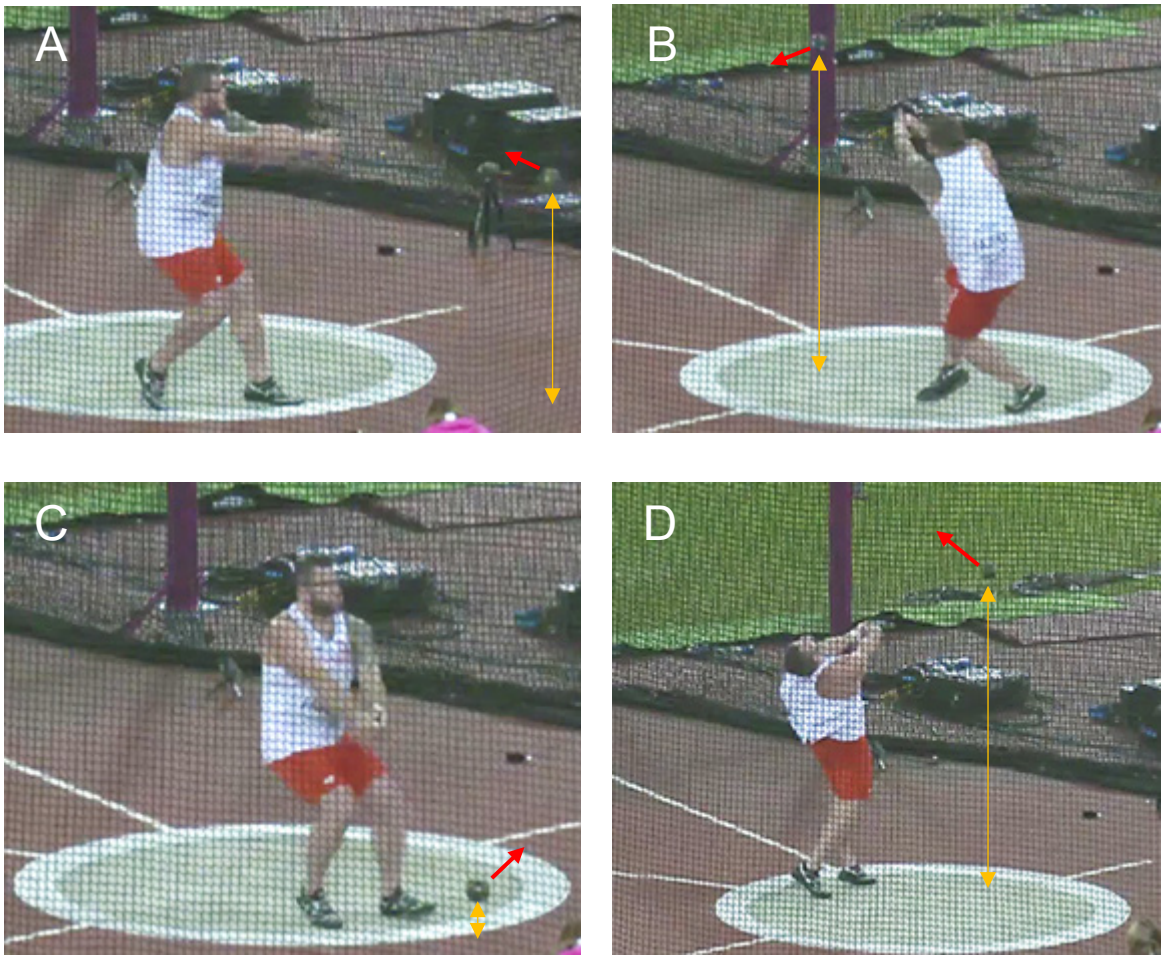
All video files were imported into SIMI Motion (SIMI Motion version 9.2.2, Simi Reality Motion Systems GmbH, Germany) and manually digitised by a single experienced operator to obtain kinematic data. Each video file was synchronised at critical instants to synchronise the two-dimensional coordinates 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 where the hammer was tracked at each point through the full movement. 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 located 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.

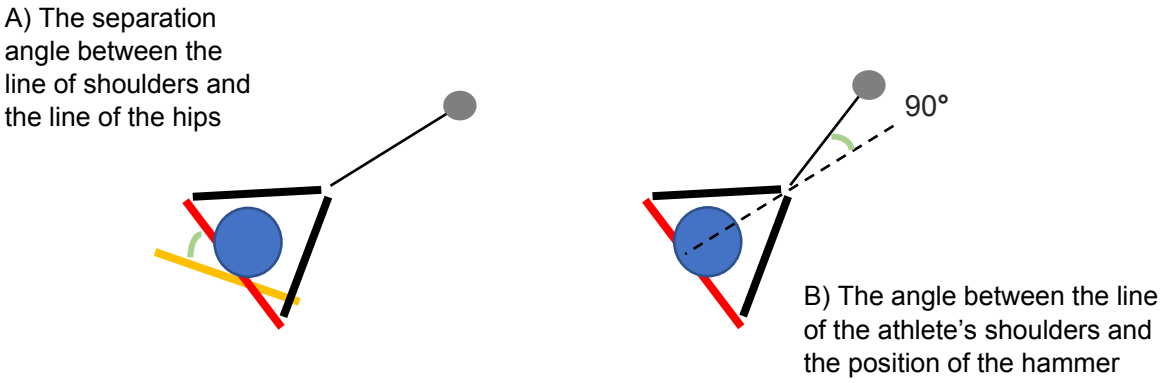


Figure 4. Visual representation of A) angle of twisting and B) angle of trailing variables.

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, only one of the finalists threw a season's best over the course of the championship and none of the finalists threw personal bests.

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

Athlete	SB (m)	PB (m)	QP (m)	SB vs. QP (m)	SB vs. QP (m)	FP (m)	SB vs. FP (m)	PB vs. FP (m)
FAJDEK	83.44	83.93	76.82	−7.11	−7.11	79.81	−3.63	−4.12
PRONKIN	79.32	79.32	75.09	−4.23	−4.23	78.16	−1.16	−1.16
NOWICKI	80.47	80.47	76.85	−3.62	−3.62	78.03	−2.44	−2.44
BIGOT	77.87	78.58	76.11	−2.47	−2.47	77.67	−0.2	−0.91
SOKYRSKII	76.23	78.91	75.50	−3.41	−3.41	77.50	1.27	−1.41
MILLER	77.51	77.55	75.52	−2.03	−2.03	77.31	−0.2	−0.24
NAZAROV	77.81	80.71	75.54	−5.17	−5.17	77.22	−0.59	−3.49
MARGHIEV	77.70	78.72	75.18	−3.54	−3.54	75.87	−1.83	−2.85
BAREISHA	78.04	78.60	75.98	−2.62	−2.62	75.86	−2.18	−2.74
LINGUA	77.23	79.97	74.41	−5.56	−5.56	75.13	−2.1	−4.84
HALÁSZ	78.85	78.85	75.56	−3.29	−3.29	74.45	−4.4	−4.4
BALTACI	76.61	76.61	74.69	−1.92	−1.92	74.39	−2.22	−2.22

Release parameters

Table 3 shows that all of the medallists achieved the highest velocities (≥27.6 m/s) at release. A key difference between the gold medallists and other medallists was that Fajdek optimised his angle of release (i.e. close to 45°).

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)
FAJDEK	4	79.81	27.68	46.2	1.69
PRONKIN	6	78.16	27.60	41.9	1.82
NOWICKI	3	78.03	28.10	39.1	1.96
BIGOT	4	77.67	27.57	39.7	1.57
SOKYRSKII	2	77.50	27.43	40.9	1.57
MILLER	3	77.31	27.39	42.1	1.76
NAZAROV	2	77.22	27.07	43.0	1.86
MARGHIEV	2	75.87	27.13	42.3	1.83
BAREISHA	2	75.86	27.22	44.7	1.64
LINGUA	2	75.13	27.28	39.5	1.58
HALÁSZ	3	74.45	27.53	36.7	1.78
BALTACI	3	74.39	26.97	39.3	1.77

Velocity of the hammer

Table 4, Figures 5 and 6 show that the entry velocity developed by the preparatory swings provides between 50%–63% of the total release velocity. Subsequently, every athlete produced their highest velocity gain (finalists mean: 5.07 ± 0.55 m/s) within the first turn. Interestingly, ten out of the twelve finalists performed four turns, whereas Pronkin performed three turns and Lingua performed five turns. Pronkin's entry velocity was the highest (17.40 m/s) of all the athletes and he gained the most velocity in his last turn (3.41 m/s). Lingua's entry velocity was the lowest (13.66 m/s) of all the athletes, although he gained the most velocity throughout his turns. Fajdek produced high velocity gains for his first three turns and then produced a very small gain for his last 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)	Turn 5 (m/s)
FAJDEK	14.62	5.22	3.83	3.07	0.94	-
PRONKIN	17.40	4.51	2.28	3.41	-	-
NOWICKI	15.92	4.44	3.20	2.18	2.37	-
BIGOT	16.75	4.72	2.14	1.48	2.48	-
SOKYRSKII	14.75	6.35	3.62	1.81	0.90	-
MILLER	16.72	4.51	2.50	1.85	1.81	-
NAZAROV	15.59	5.77	2.25	1.55	1.91	-
MARGHIEV	15.29	5.00	2.55	1.34	2.96	-
BAREISHA	15.10	5.13	3.64	1.99	1.35	-
LINGUA	13.66	5.07	2.97	2.22	1.58	1.77
HALÁSZ	15.20	5.13	3.46	1.71	2.03	-
BALTACI	14.34	4.97	2.99	2.59	2.09	-

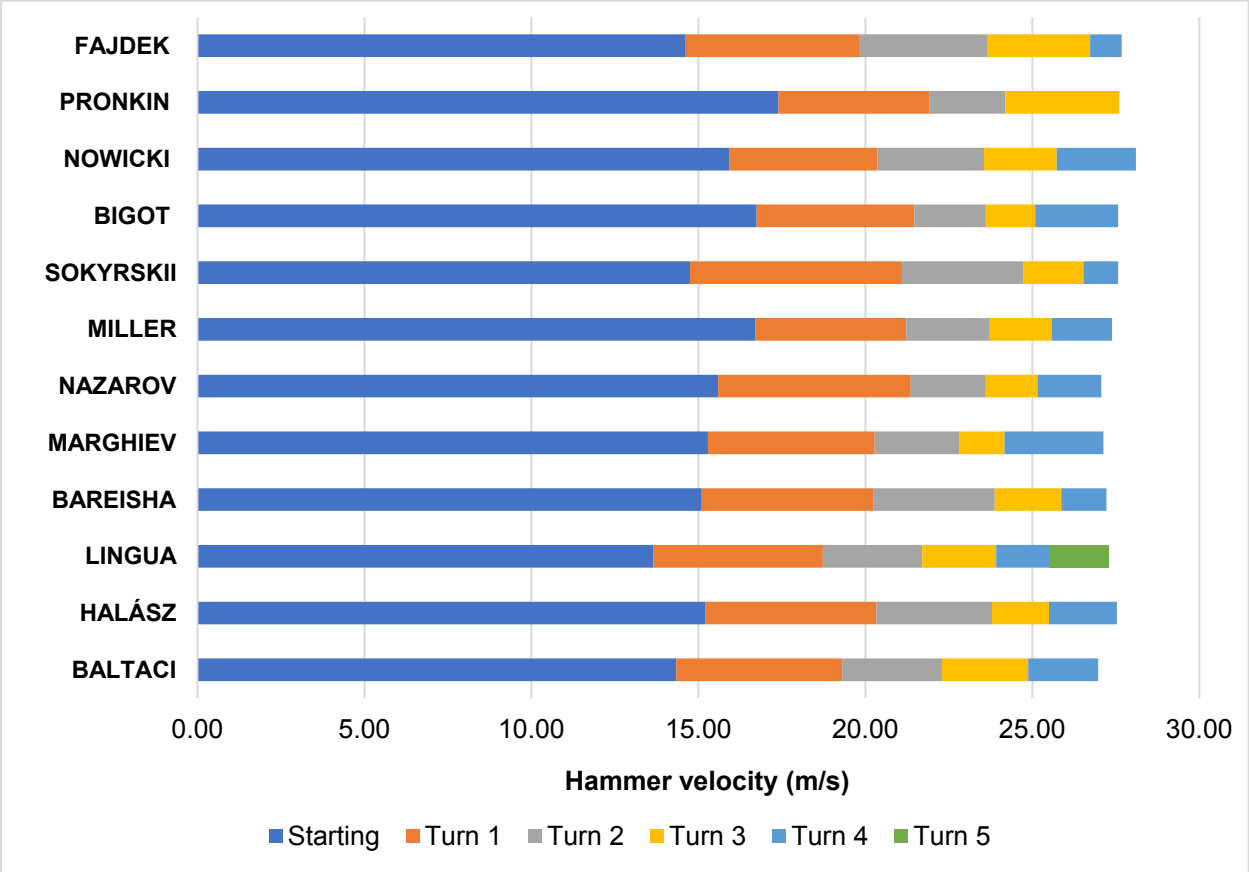


Figure 5. The velocity gain of the hammer throughout the turns.

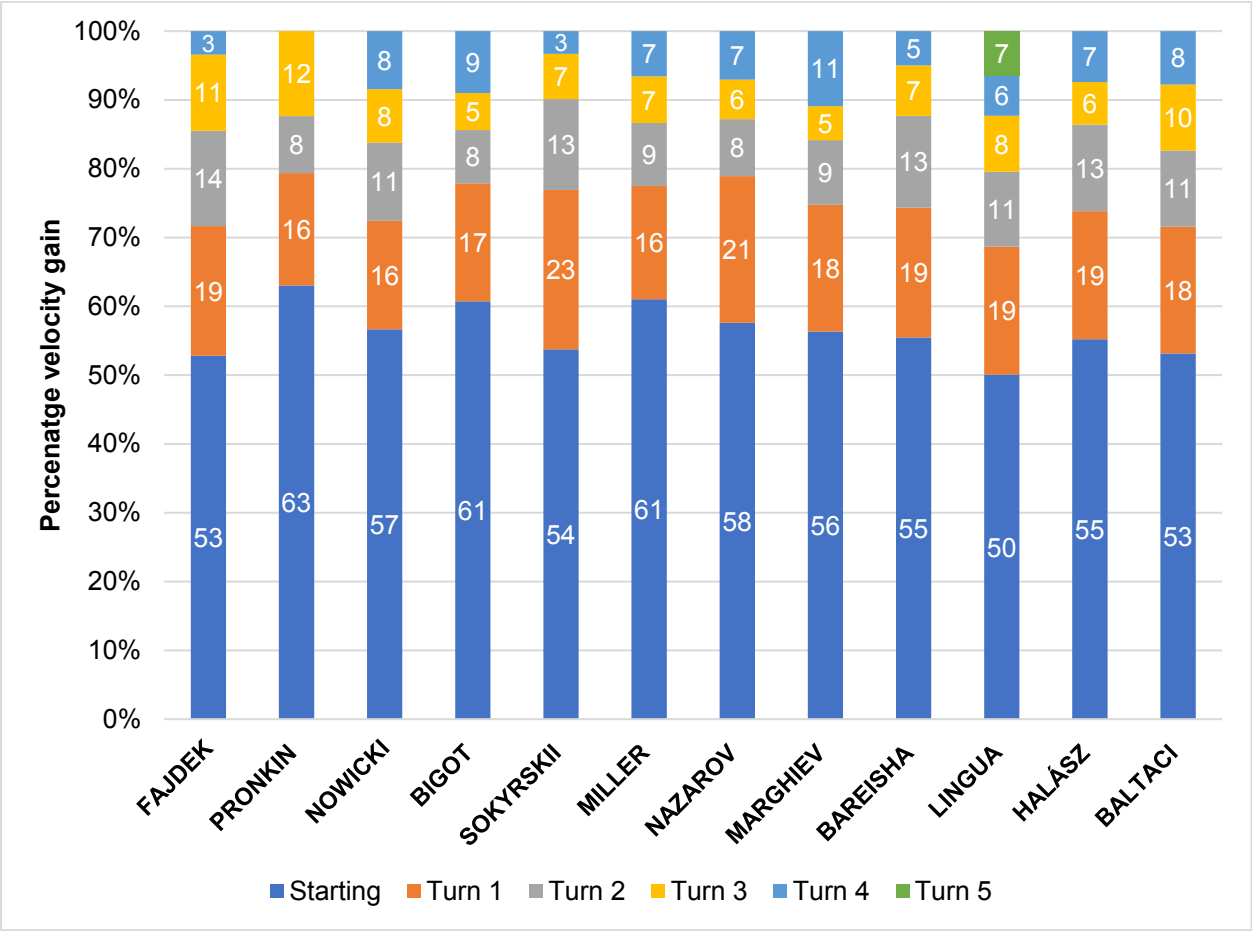


Figure 6. The velocity gain expressed as a percentage of release velocity.

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.

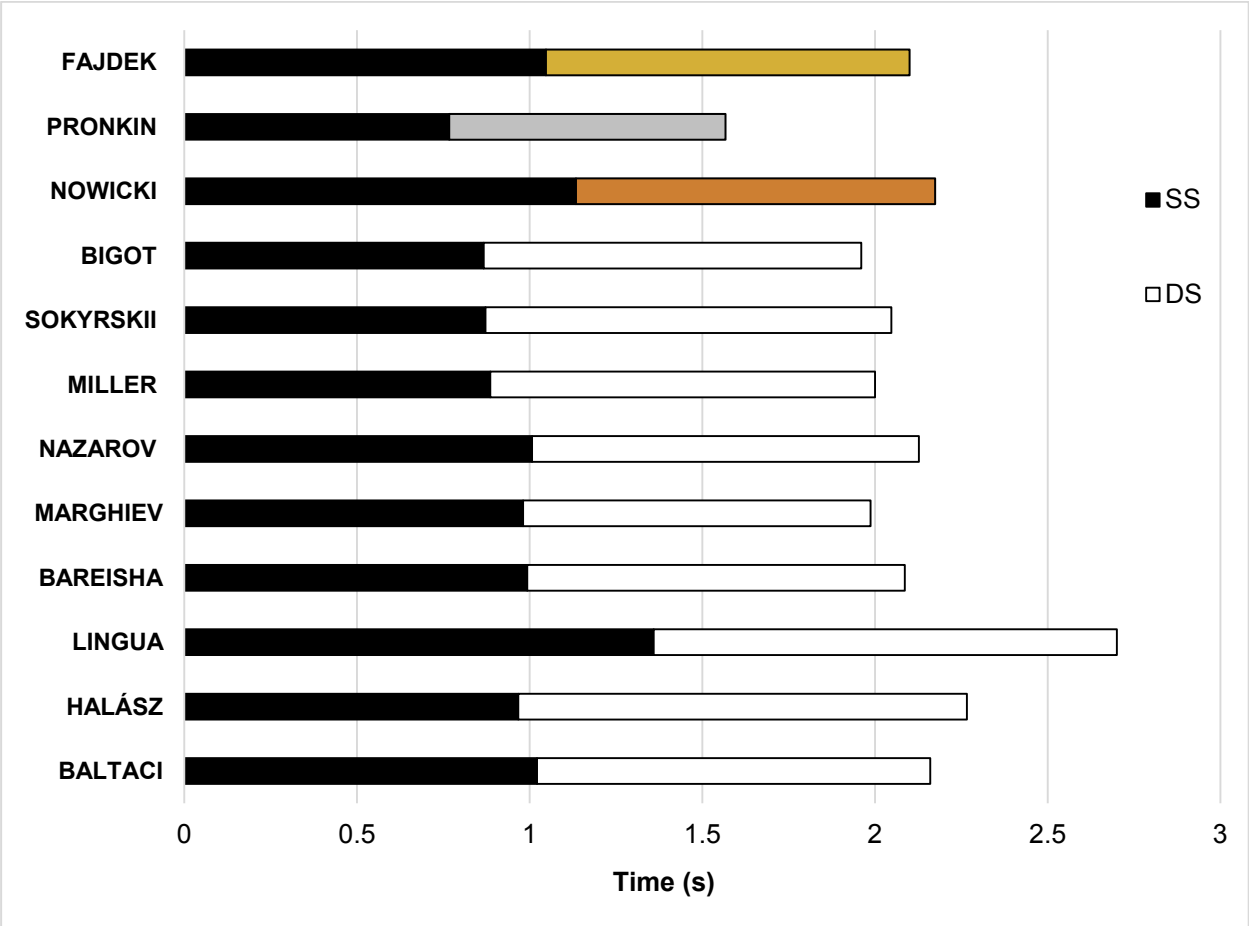


Figure 8. Total duration of turns split into single support (SS) and double support (DS) phases for the twelve finalists.

Figure 8 shows that the total duration of the turns for the twelve finalists ranged between 1.57 s to 2.7 s. Figure 9 shows that the percentage time spent in the single support phase of the turns ranged from 43% to 52% for the twelve finalists. Figure 11 shows the duration of the first turn took the longest time (finalists' mean: 0.636 ± 0.054 s), whereas for the athletes who performed four turns the third turn took the shortest time (finalists' mean: 0.454 ± 0.02 s). The same trend was observed within the penultimate turn for the other two athletes.

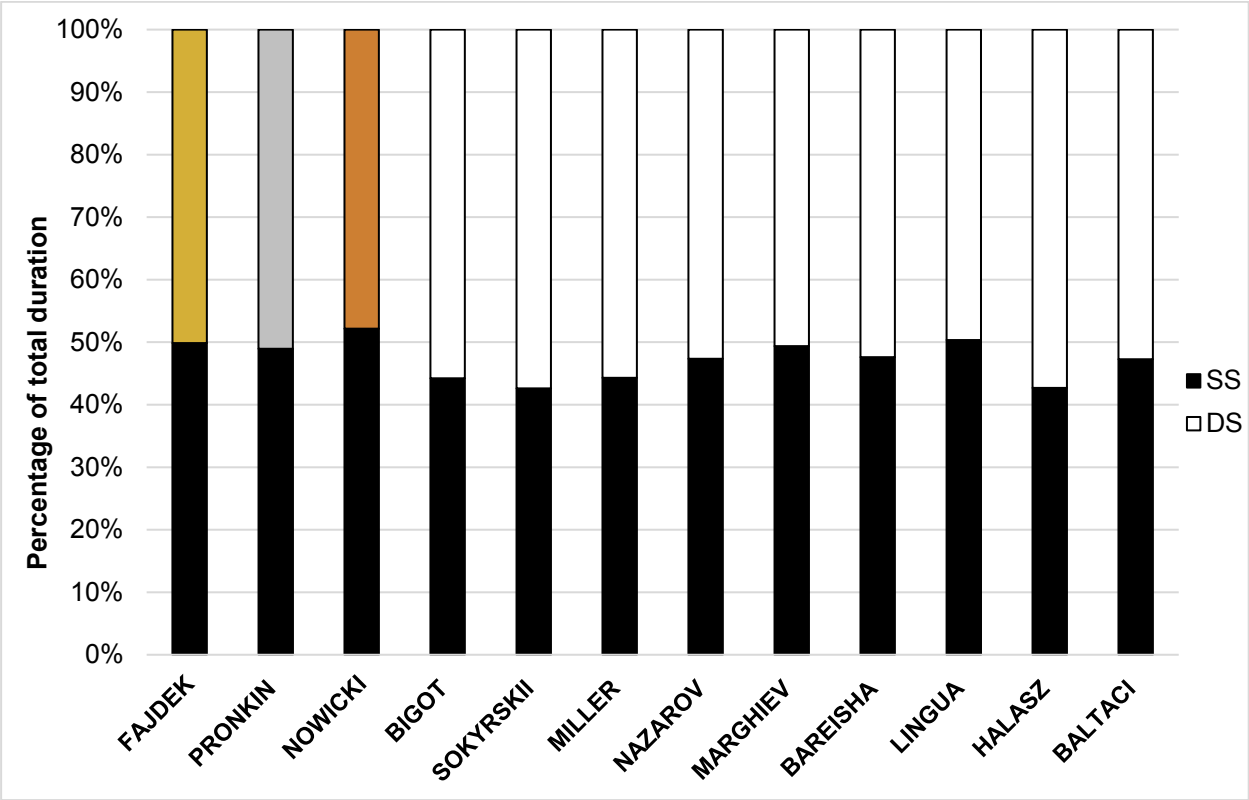


Figure 9. The total duration spent in the single support (SS) and double support (DS) phases expressed as a percentage of the total duration.

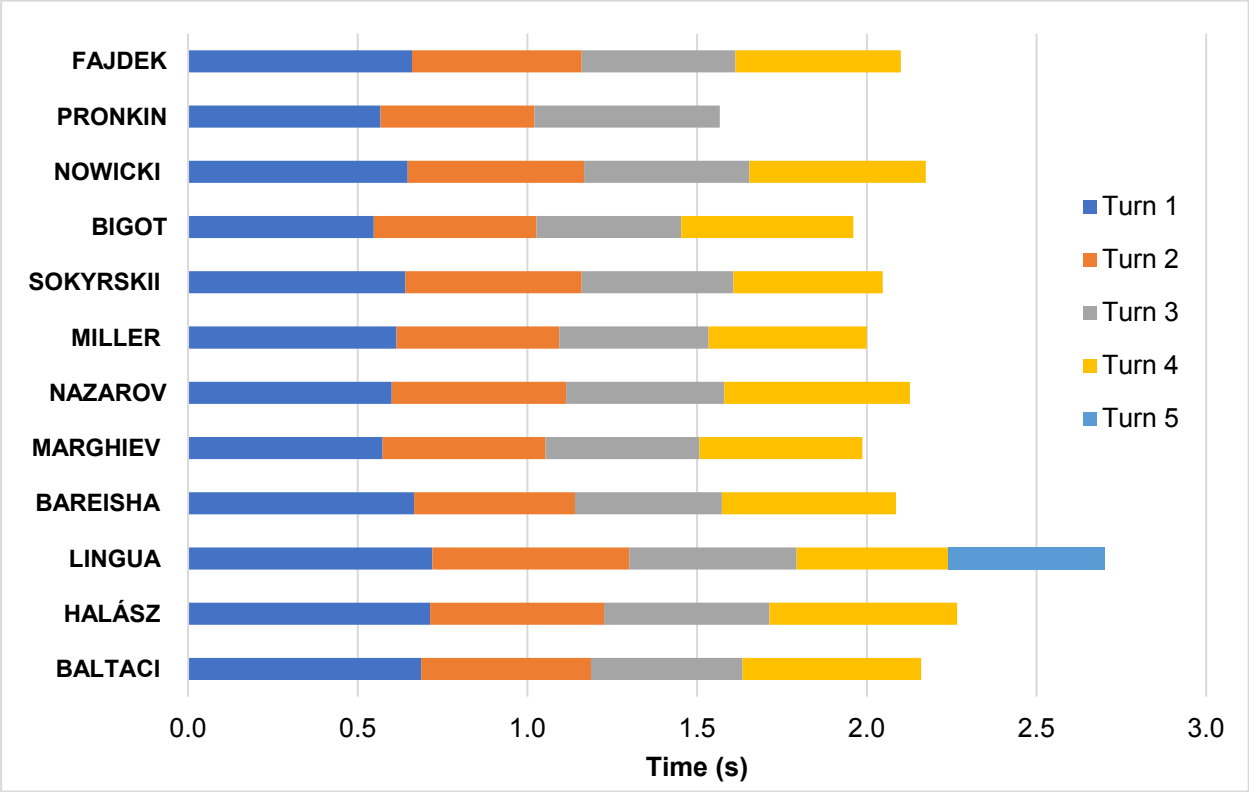


Figure 10. The total duration of each turn.

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)	Turn 4 DS (s)	Turn 5 SS (s)	Turn 5 DS (s)
FAJDEK	0.287	0.373	0.253	0.247	0.253	0.200	0.254	0.233	-	-
PRONKIN	0.267	0.300	0.240	0.213	0.260	0.287	-	-	-	-
NOWICKI	0.320	0.327	0.267	0.253	0.267	0.220	0.280	0.240	-	-
BIGOT	0.247	0.300	0.220	0.260	0.200	0.226	0.200	0.307	-	-
SOKYRSKII	0.273	0.367	0.233	0.287	0.180	0.267	0.186	0.254	-	-
MILLER	0.254	0.360	0.213	0.267	0.206	0.234	0.213	0.253	-	-
NAZAROV	0.287	0.313	0.267	0.247	0.233	0.233	0.220	0.327	-	-
MARGHIEV	0.280	0.293	0.247	0.233	0.234	0.220	0.220	0.260	-	-
BAREISHA	0.293	0.373	0.240	0.234	0.233	0.200	0.227	0.286	-	-
LINGUA	0.360	0.360	0.300	0.280	0.246	0.247	0.227	0.220	0.226	0.234
HALÁSZ	0.273	0.440	0.240	0.273	0.227	0.260	0.227	0.326	-	-
BALTACI	0.334	0.353	0.247	0.253	0.227	0.220	0.213	0.313	-	-

Table 5 details the time spent in each single (SS) and double support (DS) phase and as previously highlighted in Figure 11, the penultimate turn took the shortest time to perform time. The final turn took a similar total time (finalists' mean: 0.503 ± 0.037 s) as the antepenultimate turn (finalists' mean: 0.498 ± 0.017 s – this excludes Pronkin). The key difference between the duration of the penultimate and final turns exists within the DS phase, whereby the act of delivery in the final turn increases the time taken in this phase (finalists' mean: 0.277 ± 0.034 s) in comparison to the time taken in the penultimate turn's DS phase (finalists' mean: 0.226 ± 0.021 s).

Path of hammer

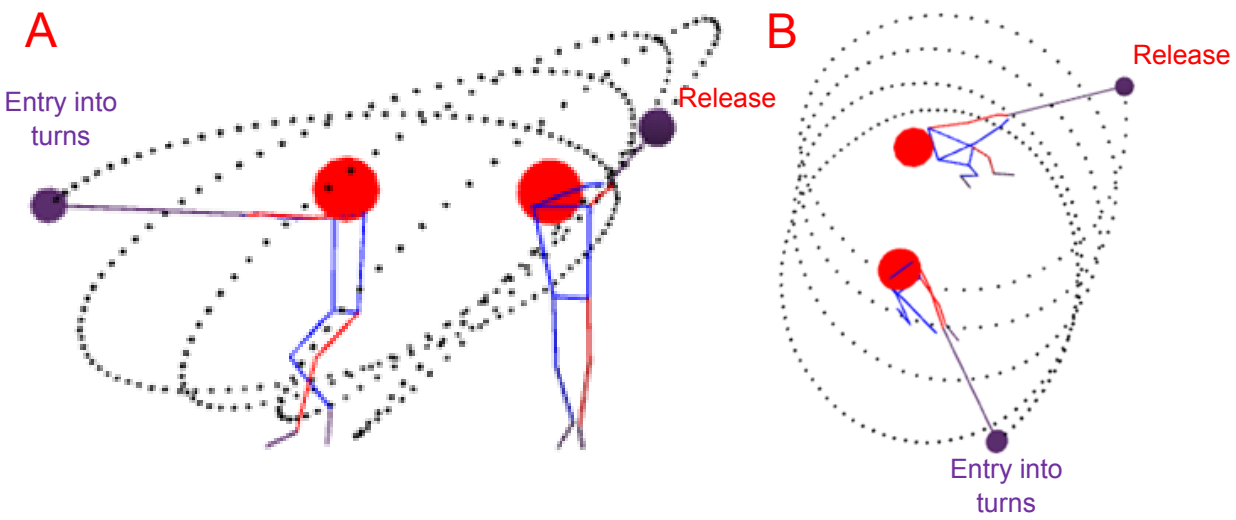


Figure 11. Fajdek's path of the hammer from entry to release, A) side on view and B) superior view.

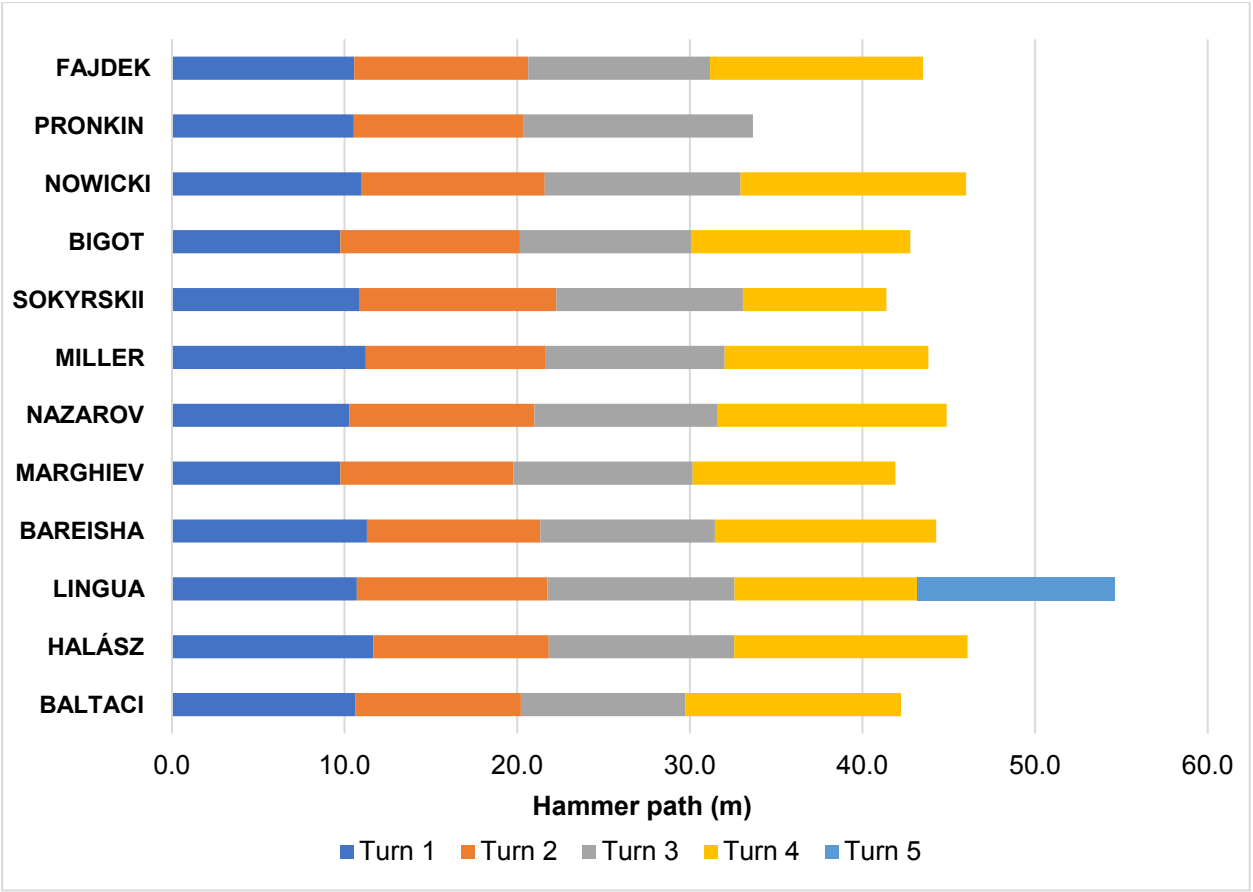


Figure 12. The total path of hammer for each turn.

Figure 12 and Table 6 show that the length of the hammer's path is similar in the first turn (finalists' mean: 10.69 ± 0.55 m), antepenultimate turn (finalists' mean: 10.39 ± 0.47 m) and penultimate turn (finalists' mean: 10.4 ± 0.47 m). In contrast, the final turn exhibited a larger path length (finalists' mean: 12.23 ± 1.34 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)	Turn 4 end of DS (m)	Turn 5 end of SS (m)	Turn 5 end of DS (m)
FAJDEK	4.22	6.34	4.84	5.24	5.65	4.88	6.11	6.22	-	-
PRONKIN	4.64	5.90	5.09	4.72	6.02	7.29	-	-	-	-
NOWICKI	4.98	5.97	5.17	5.48	6.00	5.34	6.72	6.35	-	-
BIGOT	4.10	5.66	4.65	5.75	4.61	5.34	4.87	7.79	-	-
SOKYRSKII	4.04	6.84	4.74	6.64	4.11	6.71	4.52	3.80	-	-
MILLER	4.19	7.04	4.39	6.00	4.71	5.69	5.20	6.61	-	-
NAZAROV	4.43	5.86	5.34	5.37	5.17	5.45	5.08	8.18	-	-
MARGHIEV	4.26	5.50	4.92	5.12	5.19	5.19	5.11	6.63	-	-
BAREISHA	4.44	6.85	4.78	5.26	5.25	4.86	5.44	7.38	-	-
LINGUA	4.85	5.87	5.37	5.65	5.22	5.63	5.18	5.39	5.38	6.04
HALÁSZ	4.12	7.55	4.54	5.62	4.93	5.81	5.34	8.18	-	-
BALTACI	4.73	5.91	4.53	5.05	4.76	4.79	4.83	7.65	-	-

Azimuthal angle

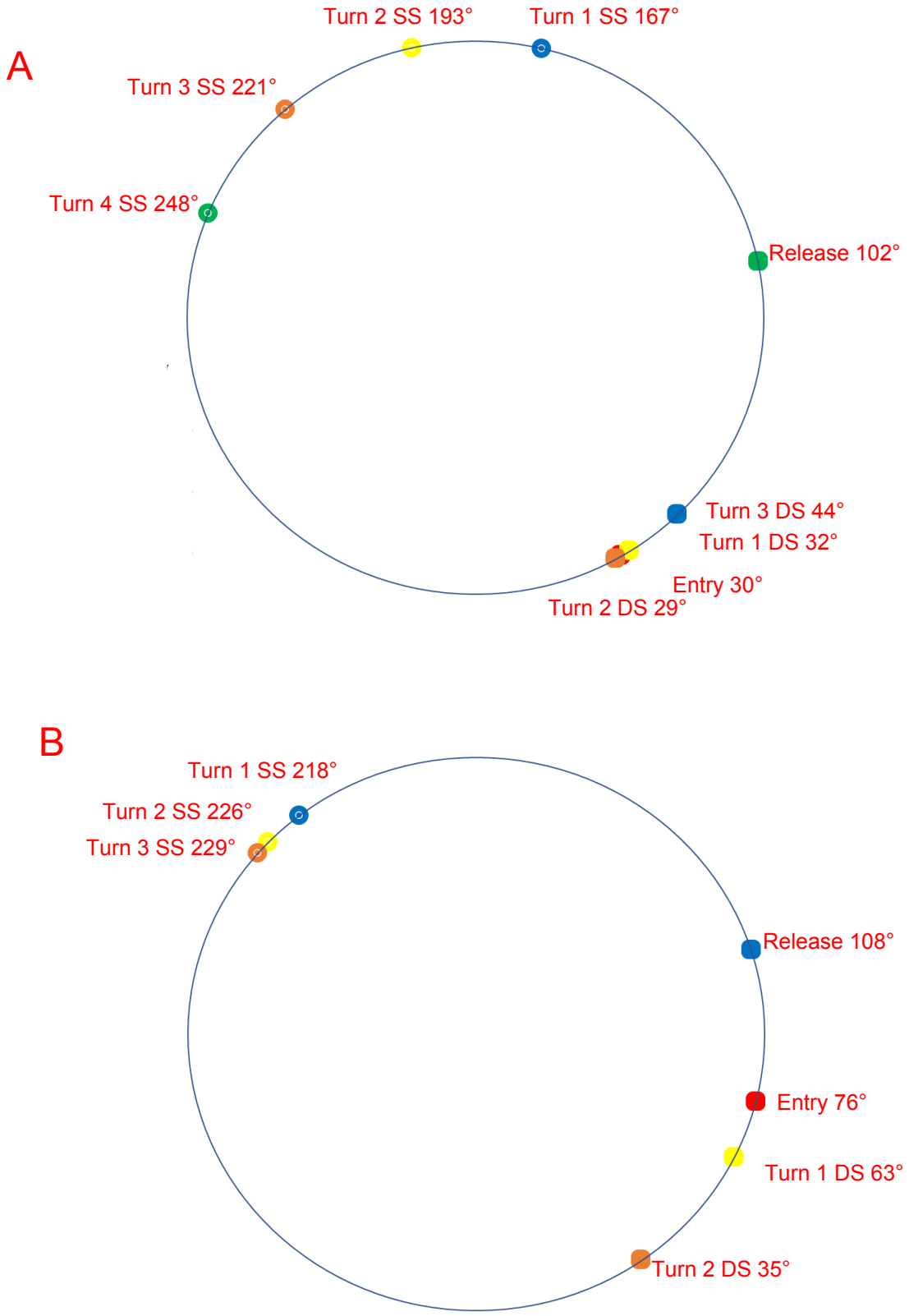


Figure 13. Visual representation of the top four athletes' azimuthal angles at: entry, end of single support (SS) for each turn, end of double support (DS) for each turn and release. A) Fajdek, B) Pronkin, C) Nowicki and D) Bigot.

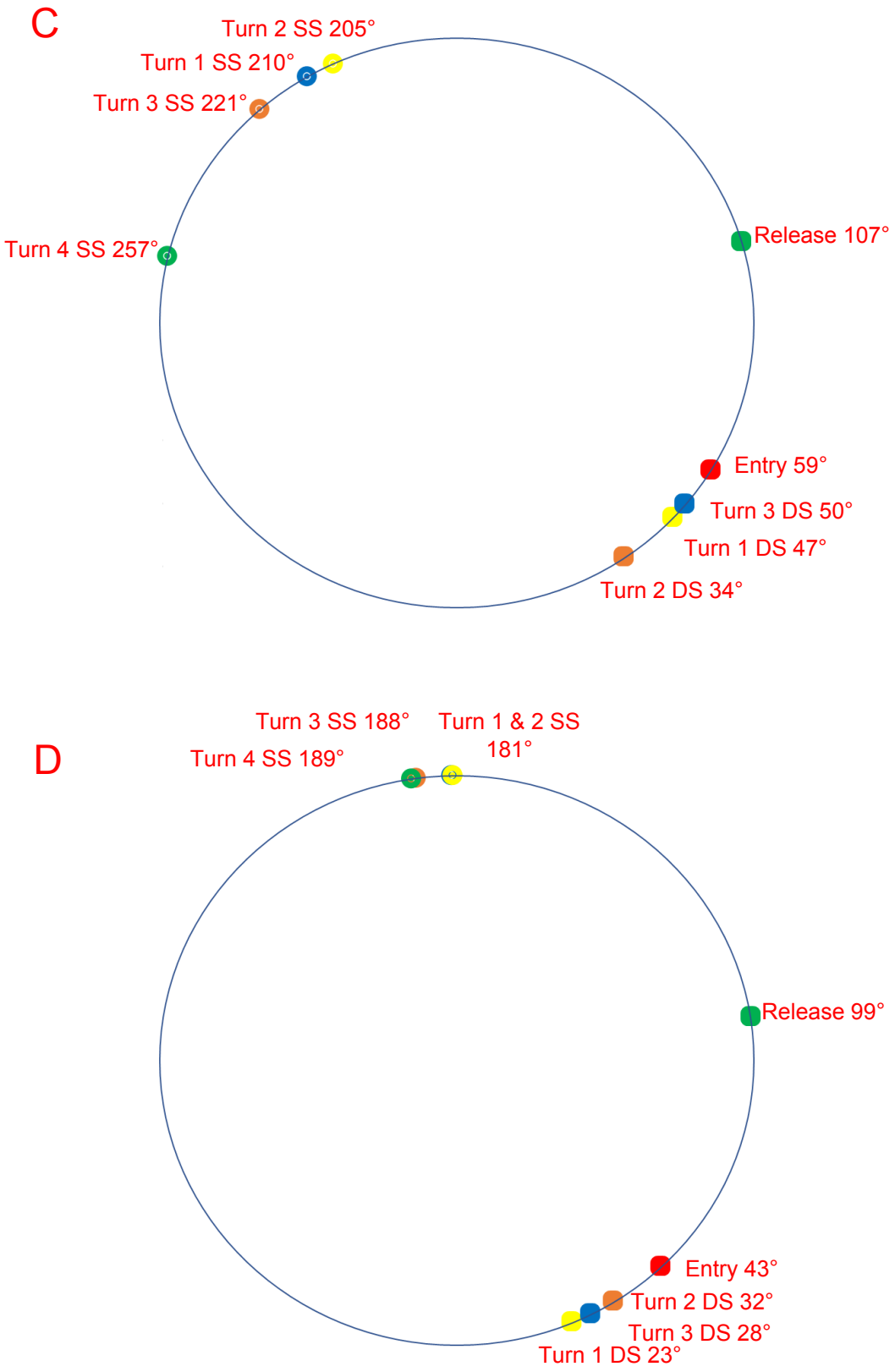


Figure 13 continued. Visual representation of the top four athlete's azimuthal angles at: entry, end of single support (SS) for each turn, end of double support (DS) for each turn and release. A) Fajdek, B) Pronkin, C) Nowicki and D) Bigot.

Figure 13 and Table 7 detail the azimuthal angle. The twelve finalists' azimuthal angle at release ranged between 98° to 118°, whereas a much larger variation of angles was observed at entry which ranged between 30° to 85°.

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 (°)	Turn 4 end of DS (°)	Turn 5 end of SS (°)	Turn 5 end of DS (°)
FAJDEK	30	167	32	193	29	221	44	248	102	-	-
PRONKIN	76	218	63	226	35	229	108	-	-	-	-
NOWICKI	59	210	47	205	34	221	50	257	107	-	-
BIGOT	43	181	23	181	32	188	27	189	99	-	-
SOKYRSKII	84	208	80	233	95	232	95	245	110	-	-
MILLER	35	172	52	202	54	216	59	234	98	-	-
NAZAROV	85	223	62	229	54	214	46	201	111	-	-
MARGHIEV	66	211	48	219	49	230	63	240	104	-	-
BAREISHA	50	191	64	224	52	231	44	225	111	-	-
LINGUA	32	188	33	209	52	226	67	242	76	269	103
HALÁSZ	62	188	75	211	42	191	33	200	107	-	-
BALTACI	54	211	65	222	54	219	43	210	118	-	-

Angle of twisting

Table 8 specifies the angle of twisting for the 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 (°)	Turn 4 end of DS (°)	Turn 5 end of SS (°)	Turn 5 end of DS (°)
FAJDEK	36	12	43	9	40	11	28	−14		
PRONKIN	31	28	38	−3	37	−32				
NOWICKI	20	13	23	11	14	18	25	−15		
BIGOT	48	8	58	12	56	16	51	−24		
SOKYRSKII	34	9	24	18	36	5	24	−47		
MILLER	45	16	36	19	26	16	6	1		
NAZAROV	51	13	36	10	55	13	67	−19		
MARGHIEV	36	11	14	14	7	13	5	−28		
BAREISHA	47	88	25	12	0	9	27	−13		
LINGUA	54	8	36	−5	15	3	18	10	7	−19
HALÁSZ	48	20	27	5	42	14	35	−17		
BALTACI	47	14	58	11	36	22	59	−22		

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 final turn's single support (SS) phase, respectively. Both the gold and bronze medallists exhibit similar patterns within these two variables, whereby the difference between the end of the SS and release angle of twisting was smaller than the finalist mean (52 ± 25°) with 42° and 40°, respectively. The difference between the end of the SS and release angle of trailing was larger than the finalist mean (11 ± 8°) with 19° and 17°, 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 (°)	Turn 4 end of DS (°)	Turn 5 end of SS (°)	Turn 5 end of DS (°)
FAJDEK	105	93	105	95	113	89	107	88		
PRONKIN	117	97	112	96	109	100				
NOWICKI	116	81	116	91	128	86	117	100		
BIGOT	106	103	101	93	99	97	99	103		
SOKYRSKII	113	91	113	93	105	92	100	96		
MILLER	119	96	128	96	120	91	119	95		
NAZAROV	102	92	101	96	101	92	97	91		
MARGHIEV	105	88	114	88	116	90	109	101		
BAREISHA	110	13	104	89	110	87	99	89		
LINGUA	119	95	117	101	122	95	111	89	116	95
HALÁSZ	103	89	104	96	101	96	103	100		
BALTACI	104	106	111	106	117	96	102	93		

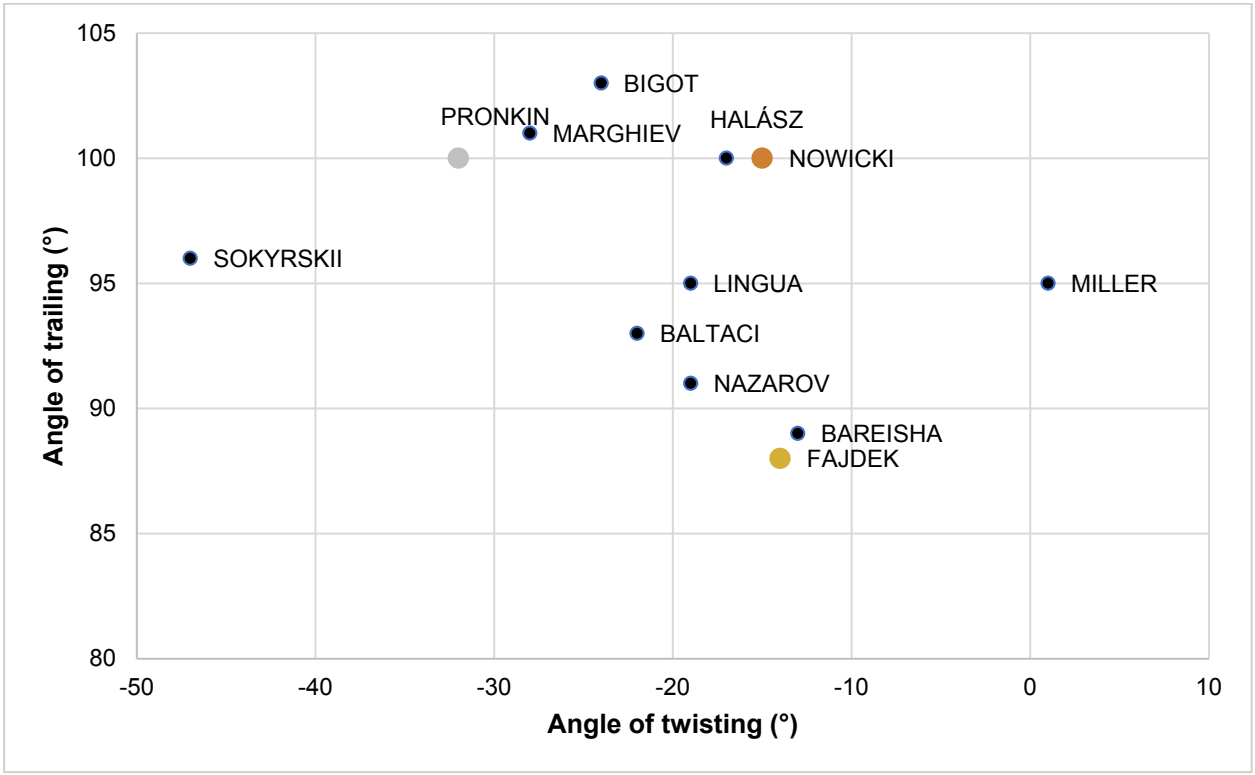


Figure 14. The relationship between the angle of twisting and the angle of trailing at release.

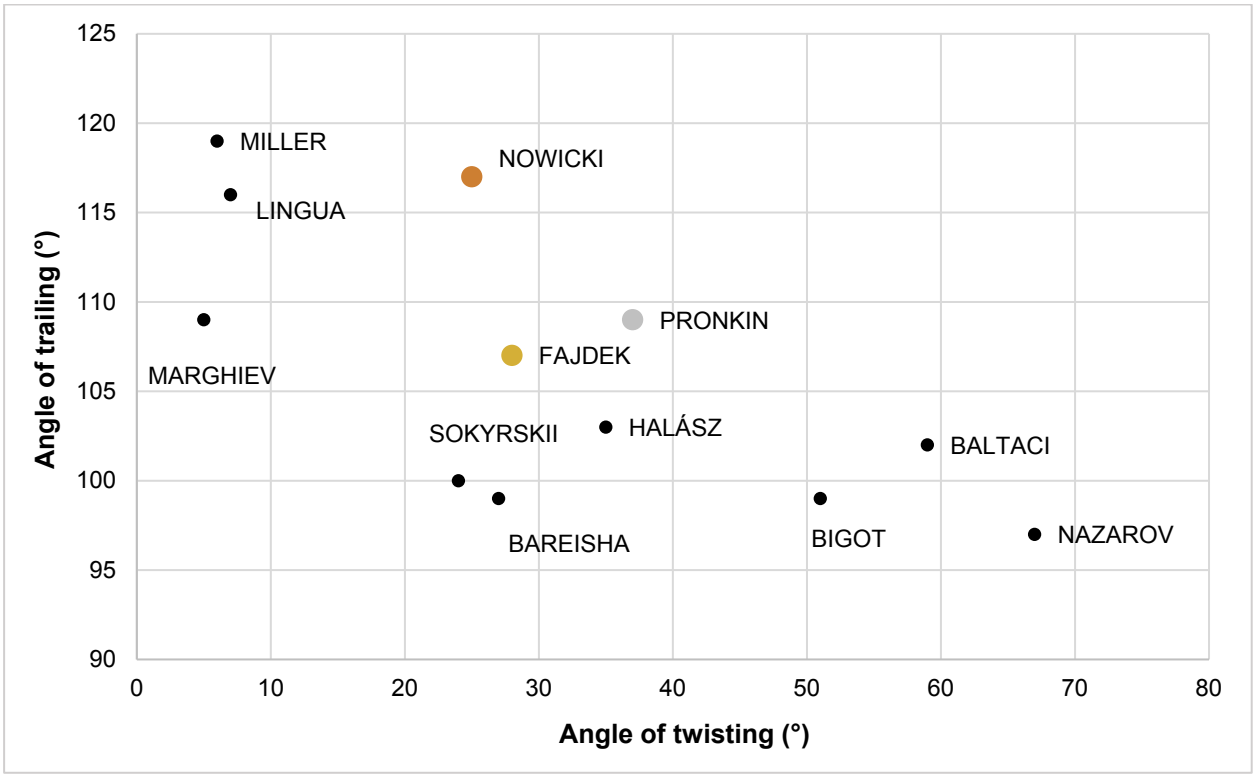


Figure 15. The relationship between the angle of twisting and the angle of trailing at the end of the single support phase in the last turn.

Analysis of low and high point of the hammer

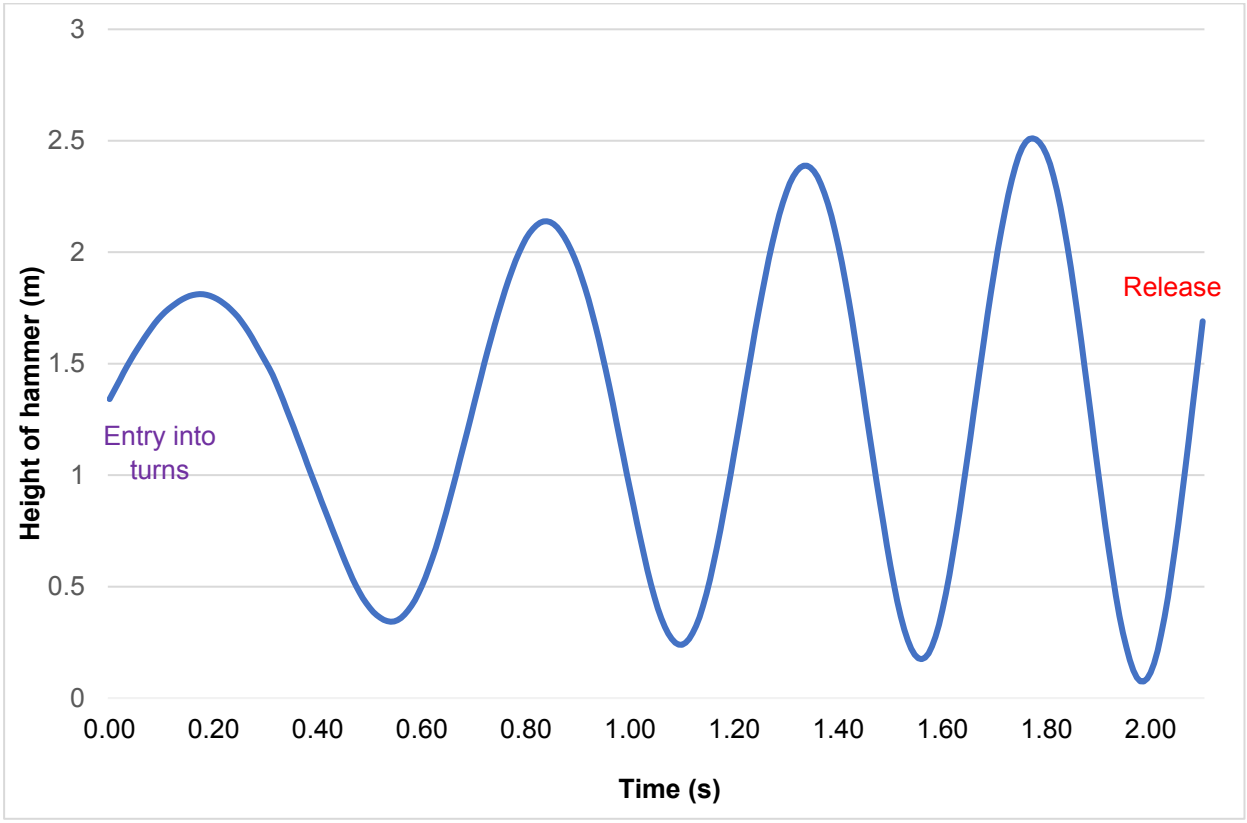


Figure 16. The height of Fajdek's hammer throughout his four turns.

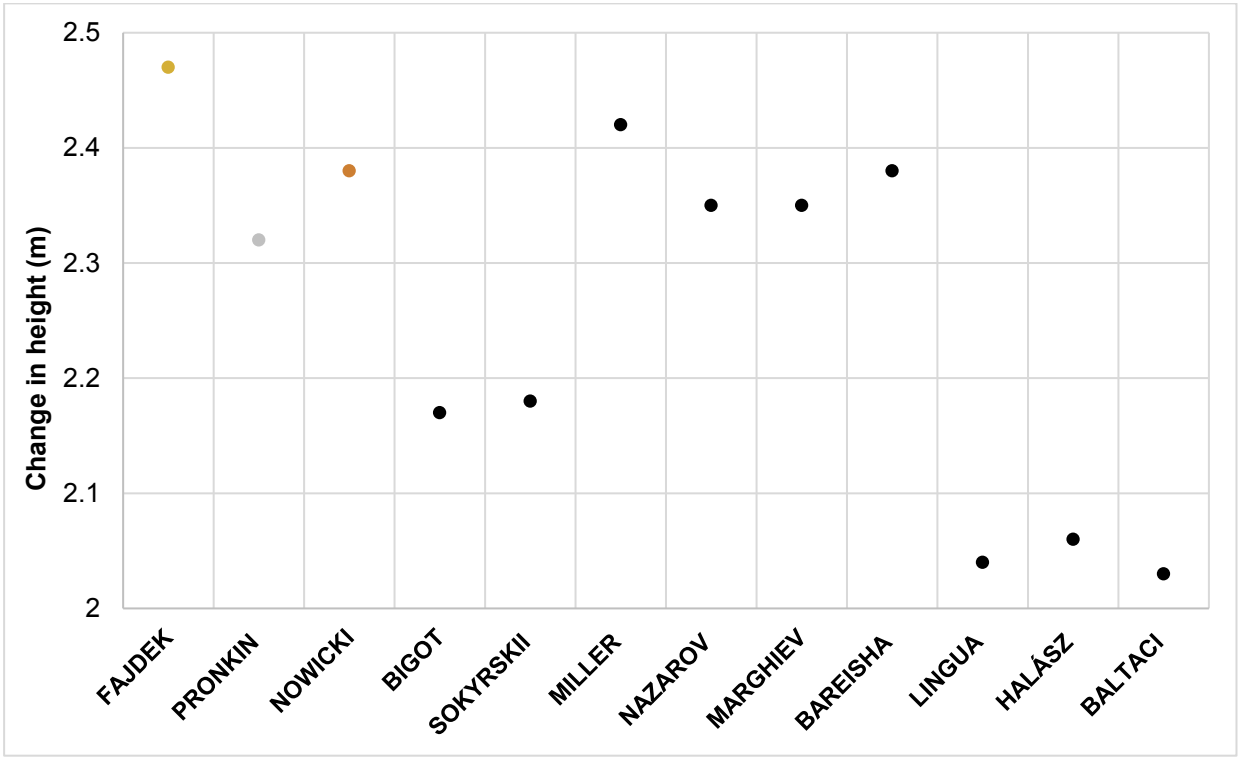


Figure 17. The height difference of the hammer between the low and high points within the last turn.

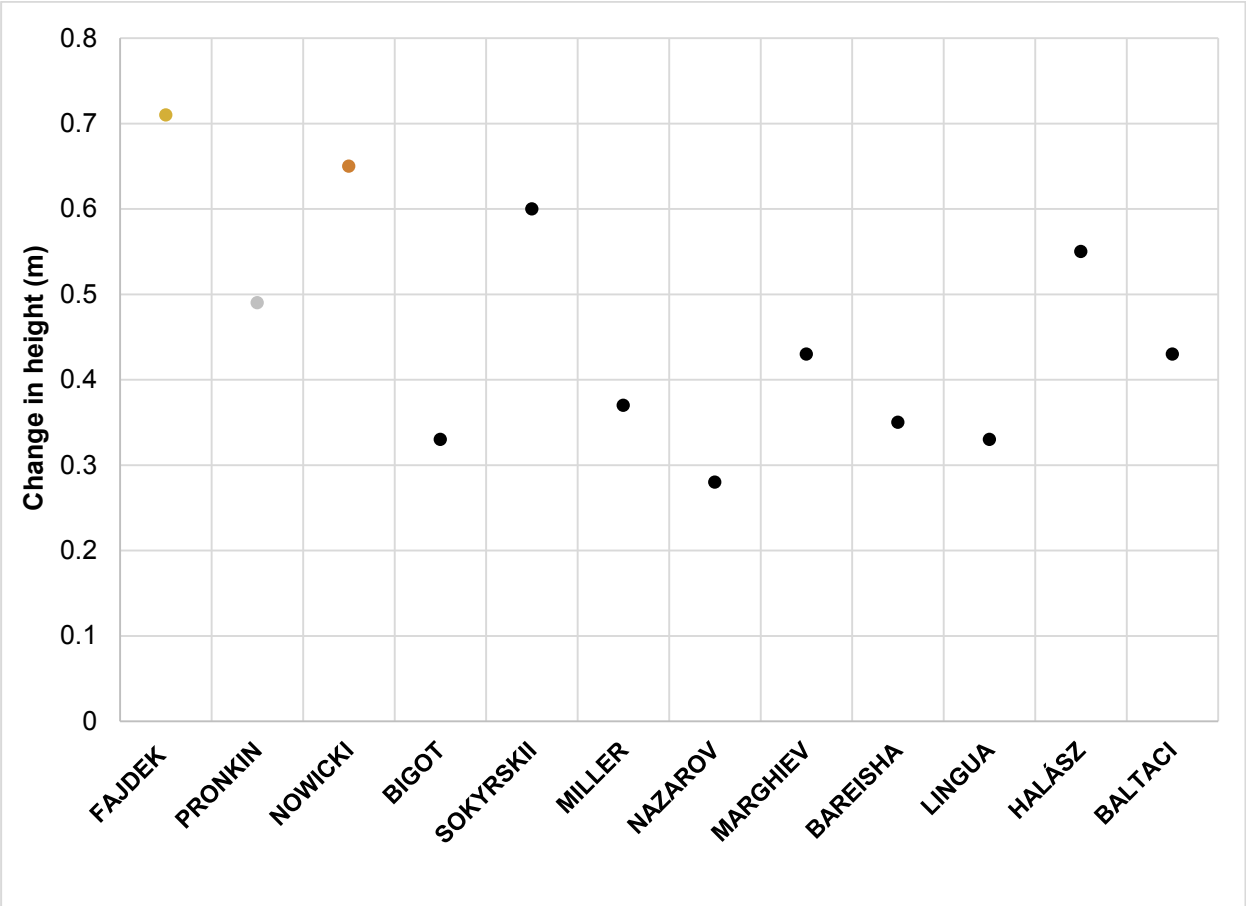


Figure 18. The height gained from the high point in the first turn to the high point in the last turn.

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 turns. Interestingly, Fajdek developed the greatest height throughout his four turns, as well as producing the greatest change in height (2.47 m) between his low point and high point in the fourth turn. Table 11 details the relative upswing path angle which represents the angle to the horizontal between the low and high points within each turn. In accordance with the change in height data, Fajdek's upswing path angle in his fourth turn was the highest (43.2°) in comparison with the other twelve finalists.

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)	High point turn 5 (m)	Low point turn 5 (m)
FAJDEK	1.82	0.33	2.16	0.22	2.4	0.15	2.53	0.06	-	-
PRONKIN	2.08	0.42	2.4	0.38	2.57	0.25	-	-	-	-
NOWICKI	1.86	0.41	2.12	0.26	2.35	0.18	2.51	0.13	-	-
BIGOT	1.94	0.2	2.05	0.15	2.17	0.14	2.27	0.10	-	-
SOKYRSKII	1.66	0.29	2.09	0.13	2.2	0.16	2.26	0.08	-	-
MILLER	2.11	0.14	2.35	0.24	2.42	0.15	2.48	0.06	-	-
NAZAROV	2.12	0.15	2.35	0.11	2.38	0.08	2.4	0.05	-	-
MARGHIEV	2.06	0.29	2.28	0.26	2.4	0.21	2.49	0.14	-	-
BAREISHA	2.15	0.22	2.35	0.17	2.48	0.14	2.5	0.12	-	-
LINGUA	1.80	0.19	1.9	0.18	2.02	0.12	2.13	0.09	2.21	0.09
HALÁSZ	1.68	0.32	1.86	0.21	2.06	0.2	2.23	0.17	-	-
BALTACI	1.76	0.37	1.96	0.29	2.12	0.28	2.19	0.16	-	-

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

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

Athlete	Turn 1 (°)	Turn 2 (°)	Turn 3 (°)	Turn 4 (°)	Turn 5 (°)	Release (°)
FAJDEK	21.0	30.6	38.4	43.2	-	46.2
PRONKIN	28.3	31.9	36.0	-	-	41.9
NOWICKI	21.4	26.4	33.8	39.2	-	40.0
BIGOT	29.5	32.4	35.8	37.4	-	39.7
SOKYRSKII	21.7	29.7	35.0	37.7	-	41.7
MILLER	33.3	37.5	38.0	41.1	-	42.2
NAZAROV	31.0	36.0	37.9	38.2	-	43.1
MARGHIEV	31.2	35.0	38.9	41.2	-	42.4
BAREISHA	29.9	36.1	40.4	42.1	-	44.8
LINGUA	28.2	28.9	31.3	34.4	37.1	39.6
HALÁSZ	21.7	23.3	28.9	33.2	-	36.9
BALTACI	23.1	27.2	32.1	35.9	-	40.3

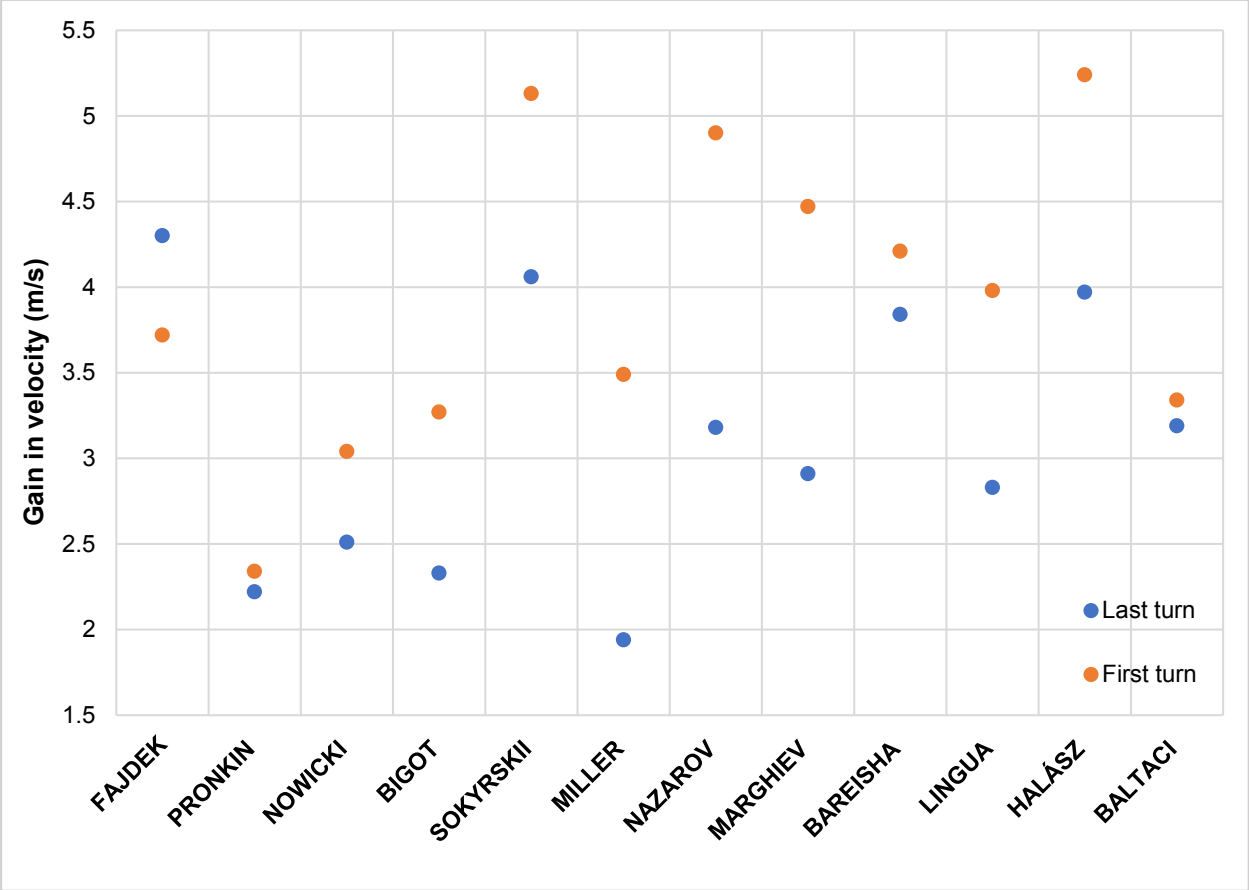


Figure 19. The velocity gained from the high point to low point for both the first turn and last turn.

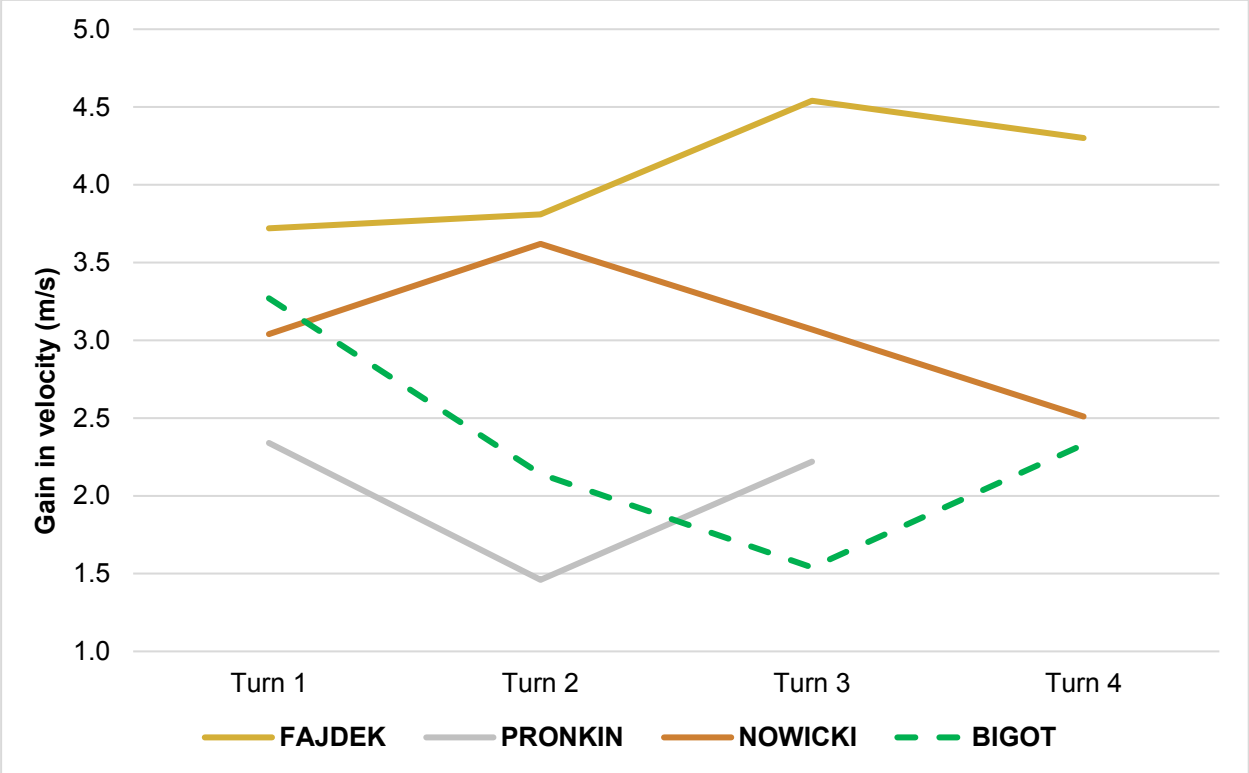


Figure 20. The velocity gained for the top four athletes from the high point to the low point within each turn.

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)	High point turn 5 (m/s)	Low point turn 5 (m/s)
FAJDEK	14.71	18.43	19.15	22.96	21.46	26.00	23.21	27.51	-	-
PRONKIN	16.95	19.29	20.67	22.13	22.34	24.56	-	-	-	-
NOWICKI	15.81	18.85	18.74	22.36	22.15	25.22	23.27	25.78	-	-
BIGOT	16.64	19.91	20.70	22.84	22.53	24.07	23.45	25.78	-	-
SOKYRSKII	14.52	19.65	19.94	24.64	21.80	26.19	23.57	27.63	-	-
MILLER	16.31	19.80	20.14	22.78	21.94	24.28	23.54	25.48	-	-
NAZAROV	15.03	19.93	19.50	22.61	21.25	24.61	22.47	25.65	-	-
MARGHIEV	14.84	19.31	19.46	22.39	21.43	23.95	22.32	25.23	-	-
BAREISHA	15.22	19.43	19.27	23.53	21.71	25.68	22.85	26.69	-	-
LINGUA	13.27	17.25	17.61	20.98	20.36	22.90	22.42	25.25	23.57	25.96
HALÁSZ	14.04	19.28	18.18	22.60	19.44	24.27	22.06	26.03	-	-
BALTACI	14.11	17.45	17.92	20.89	20.45	23.24	22.00	25.19	-	-

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. Fajdek notably developed the highest velocity gain from high to low point, as well as developing the second highest velocity at the low point on his final turn.

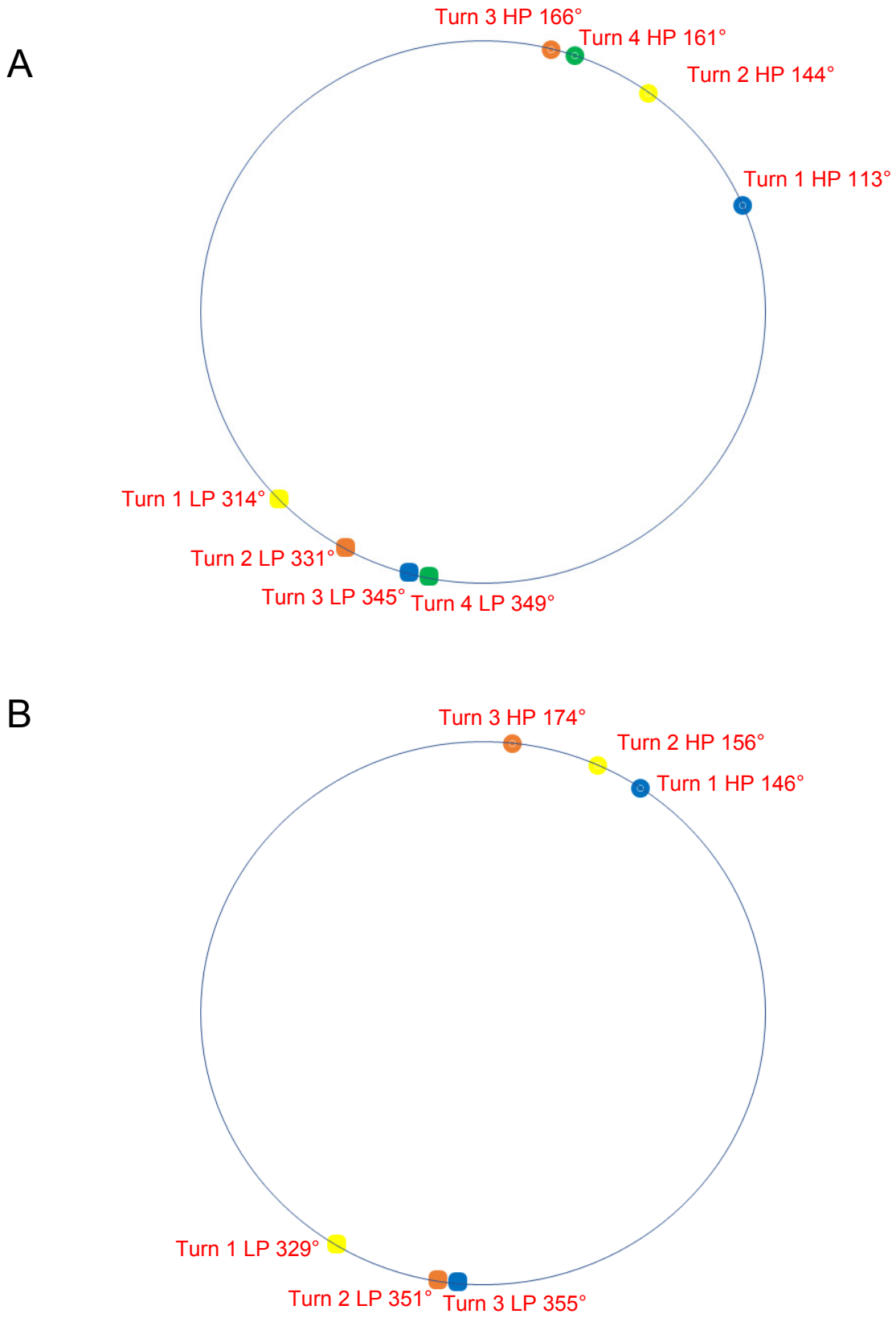


Figure 21. The visual representation of each of the top four athlete's azimuthal angles for the high point (HP) and low point (LP) for each turn. A) Fajdek, B) Pronkin, C) Nowicki and D) Bigot.

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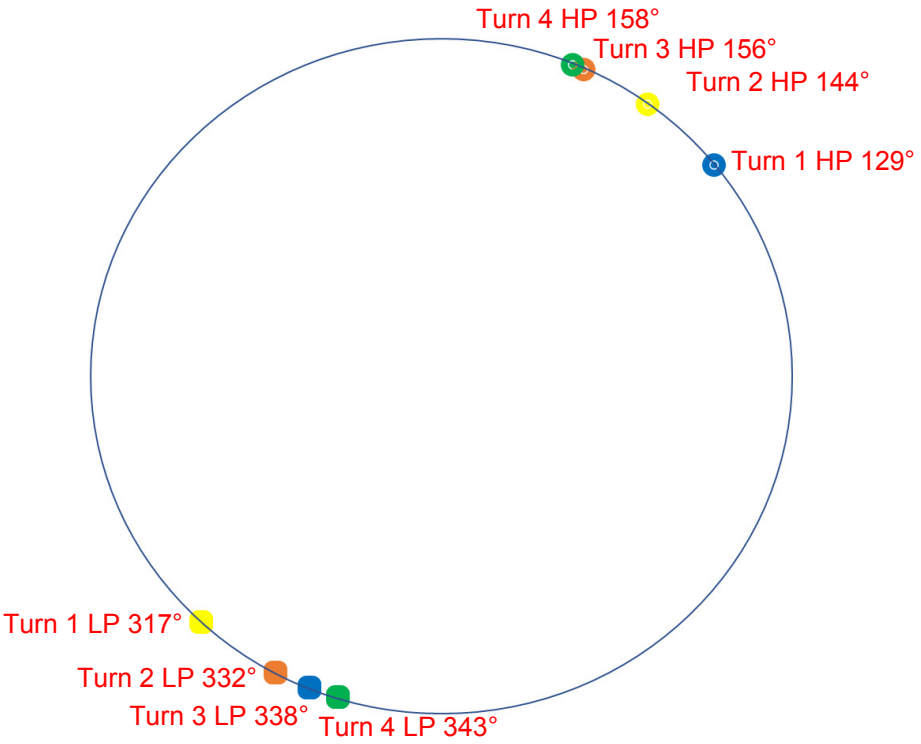

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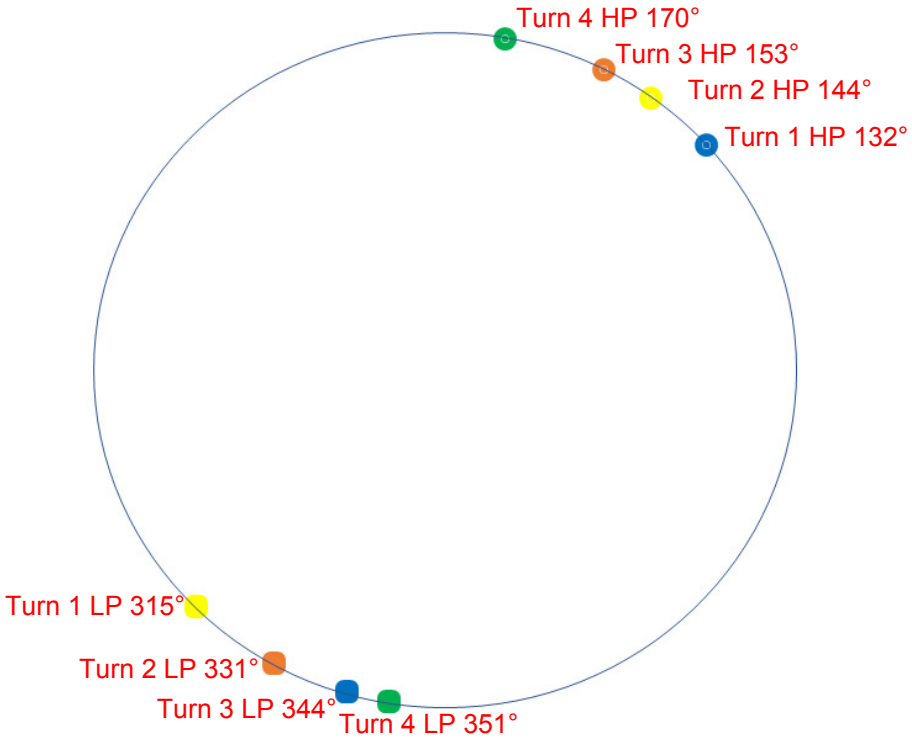

Figure 21 continued. The visual representation of the top four athlete's azimuthal angles for the high point (HP) and low point (LP) for each turn. A) Fajdek, B) Pronkin, C) Nowicki and D) Bigot.

Figures 21 and Table 13 detail the azimuthal angle for all finalists. 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 (°)	High point turn 5 (°)	Low point turn 5 (°)
FAJDEK	113	314	144	331	166	345	161	349	-	-
PRONKIN	146	329	156	351	174	355	-	-	-	-
NOWICKI	129	317	144	332	156	338	158	343	-	-
BIGOT	132	315	144	331	153	344	170	351	-	-
SOKYRSKII	168	342	172	357	178	32	190	351	-	-
MILLER	110	299	135	325	144	339	165	346	-	-
NAZAROV	167	345	169	353	176	356	171	356	-	-
MARGHIEV	137	320	150	337	157	352	174	359	-	-
BAREISHA	147	338	166	357	176	5	185	11	-	-
LINGUA	152	323	151	328	161	340	165	349	171	348
HALÁSZ	161	357	184	355	172	344	173	336	-	-
BALTACI	146	344	175	352	178	7	179	3	-	-

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

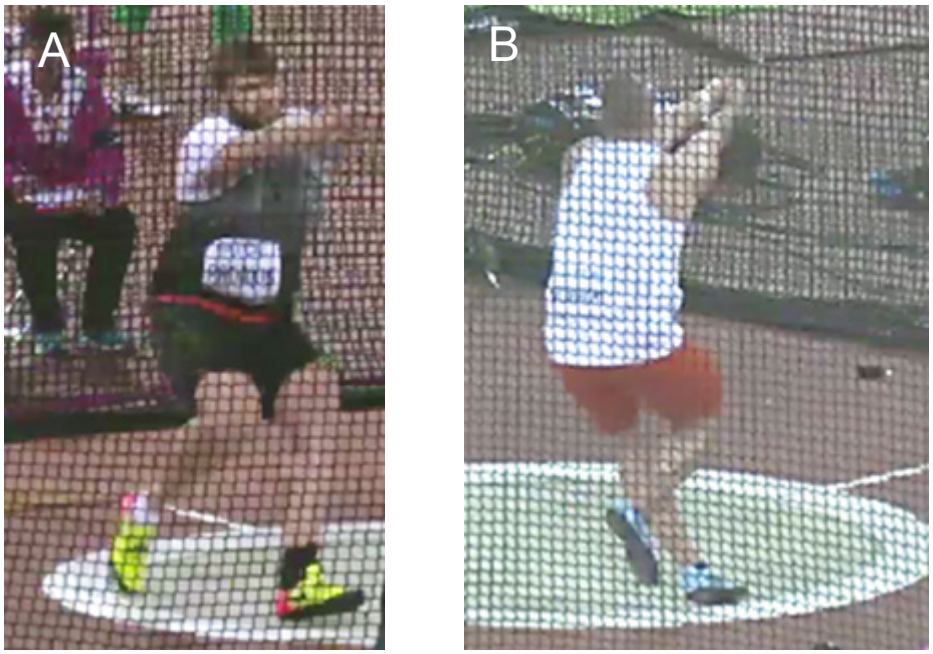

Figure 22. A visual representation of A) heel turn and B) toe turn.

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
FAJDEK	Toe
PRONKIN	Heel
NOWICKI	Toe
BIGOT	Toe
SOKYRSKII	Toe
MILLER	Toe
NAZAROV	Heel
MARGHIEV	Toe
BAREISHA	Heel
LINGUA	Toe
HALÁSZ	Heel
BALTACI	Toe

COACH'S COMMENTARY

The men's hammer competition allowed for some very interesting comparisons, as not only do we have the ongoing debate as to which is a better hammer technique: 3-turns (the long standing world record of 86.74 m by Yuriy Sedykh dating back to 1986, was set using 3-turns) or the now much more common 4-turns utilised by all major championships winners since 1991, but in this competition we also had a 5-turn thrower: Marco Lingua of Italy.

Pawel Fajdek won the men's hammer throw while producing the competitions three best throws (all over 79 m). Fajdek was also among top finalists in terms of release velocity, but was able to couple it with an astounding angle of release at 46.2° (see Table 3). The other two medallists produced similar release velocity readings, however, their release angles were well within the mean of the group at 39.1 and 41.9°.

In terms of starting speed, most of the men's finalists, who utilised four turns, entered the first turn off the winds with a hammer head velocity between 14.50-16.00 m/s. As expected the one finalist who utilised three turns (Pronkin) had a significantly faster starting speed of 17.40 m/s upon entry into the first turn. The men's hammer final did feature one thrower who used a five-turn technique (Marco Lingua of Italy), and as expected he had the slowest hammer head speed at entry at 13.66 m/s. It is interesting to note that Fajdek had the second slowest entry speed of all four turners, which can be used to highlight the notion that there are many possible speeds to start at, and that a high starting speed does not necessarily equate to top throwing distance.

In studying the gain in hammer velocity throughout the turns (see Table 4) over 50% of the final release speed is generated upon entry into the first turn. In addition, another 18% of the final release speed is generated after completion of the first turn, with the second and third turns contributing the same amount to the final release speed as the second turn by itself. This is an expected acceleration pattern for a four-turn hammer thrower. With Pronkin's three turn technique, his entry speed was much higher at over 60% of final release velocity. Pronkin's increases in hammer head speed for turns one and two were very similar to what was seen for the four turn throwers, however, his third, and final turn, added significantly more to the final release speed than the final turn for most four turners.

Fajdek's hammer velocity development stood out from the rest of the field in that he was able to increase the hammer's velocity in turns two and three (24%) more than anyone else. However, he was only able to add a small amount on turn four (3%), which was most likely due to the fact the release angle he was producing was actually steeper (46.2°) than the theoretical optimum of 45°. The five-turner, Lingua, took the longest time to build up hammer head velocity with a ball speed after three turns that was similar to that of a four-turner after two turns.

Figure 14 shows the portion of the hammer orbit where the hammer throwers will enter and exit the double support phase for each turn. Two trends for the men's group emerge from this figure. The first is that the men's finalists all tend to "catch" or "enter double support" further away from 180° with each successive turn. The vast majority of these catches happen on either side of 200°, while the entry point for the hammer into single support is in the range of 30-40° for most of the turns. This is very different from the data presented for the women's hammer finalists who appear to catch the hammer closer to 270° and enter single support when the hammer head was closer to 60-70°.

With regard to the high and low point of the hammers orbit almost all of the finalists started with a low point to the right of 0° (around 330°). As the throwers progressed through the turns the low point would will gradually move to the left finishing at just before 360°. There were a couple of exceptions in Baltaci and Bareisha, who saw their low-point move past 0° after the third turn. Halász of Hungary, was the one exception in the finalist group who did not exhibit "low point drift" to the left, but actually showed a consistent drift to the right throughout the turns.

When looking at trends and potential differences between the finalists, we must always be mindful that we are looking only at a set of data for one throw of each, and while it might have been their best registered performance on the day, this may not have been viewed by the athlete or coach as a "good" throw technically, so we cannot make any strong conclusions from this, but we may have some interesting discussion points for further investigation.

Pawel Fajdek was clearly the favourite coming into the competition, having won the previous 2 World Championships, and the World Leading mark in 2017 at 83.44 m, but had recently been beaten at the Polish Championships by his teammate Nowicki. In the end he was the clear winner with his best throw of 79.81 m beating silver medallist Pronkin by 1.65 m. While around mean height for finalist at 1.86 m Fajdek is listed as the heaviest at 126 kg, although the listed mass for some of the others, such as Pronkin at 1.95 m and 115 kg, seems a little conservative at best!

When looking at the date for Fajdek's throw we can find some interesting discussion points. As already noted, he is among the slowest with regard to velocity of the hammer head on entry at 14.2 m/s but accelerates through the turns to give one of the highest release velocities at 27.68 m/s (Nowicki 28.10 m/s), with the highest angle of release at 46.2°. Fajdek showed among the largest and most consistent velocity gains through the first 3 turns, (5.22 m/s, 3.83 m/s and 3.07 m/s), but very little improvement on the 4th turn with only 0.94 m/s showing that he was not able to keep the same level of acceleration through the final turn and into delivery.

If we look at the data in Table 10, which gives us the relative height of the hammer head at the high point and low point on each turn, and particularly the "relative upswing path angle" that this

gives us, we can see that Fajdek starts with a very flat “orbit” of the hammer on his first turn or 21° relative to the horizontal, but this gets progressively steeper through each turn, at a much higher rate that the other competitors. He goes from 21° in T1 to 30.6° (Δ 9.6°) in T2, to 38.4° (Δ 7.8°) in T3, to 43.2° (Δ 6.8°) in T4 and on to an angle of 46.2° (Δ 3.0°) at delivery. This represents and overall change in the angle of the orbit of 25.2° from turn 1 to delivery. If you compare this with Bigot, who was maintained a flatter orbit throughout his turns of 29.5° in T1 to 32.4° (Δ 2.9°) in T2, to 35.8° (Δ 3.4°) in T3, to 37.4° (Δ 1.6°) in T4 and on to a low angle of 39.7° (Δ 3.0°) at delivery, this change in the orbit through the turns is only 10.2°. The orbit of Fajdek’s throw can be seen graphically in Figure 11, but also in Figure 16 which shows the height of the hammer over time throughout the throw, where the relative steepness (Δ) in the relative upswing path of the curve from low point to high point, represents the angle as it increases with each turn.

Also, much more marked for Fajdek than the others is the variation in the “Catch Point” of each turn, at the end of the single support phase when the right foot lands and the athlete goes into double support and can apply force to the ground in order to accelerate the implement. Figure 14 gives an overhead view of the azimuthal angle (relative position of the hammer head to the front of circle/direction of throw (180°)) of the top 4 athletes. You can see that at the “Catch Point” at the end of turn 1 (turn 1 SS) the hammer is at 167°, but by turn 4 this has moved to 248°, a change of 81°. By comparison, the foot off position where the right foot leaves the ground to go into single support phase (entry or turn 1 DS) remains fairly constant between entry of 30° and turn 3 SS of 44°. The other competitors have a much smaller variation in this “Catch Point” position, with Bigot for example to turn 1 SS of 181° to turn 4 SS of 189°, for a variation of only 8°.

It is difficult to make any conclusion without further information such as trunk angle data, but perhaps Fajdek, whose final release velocity (27.68 m/s) was very average for the top 6 athletes (mean: 27.62 m/s), and even less than countryman Nowicki (28.10 m/s), he seemed to gain a large advantage over them with his greater angle of release of 46.2° compared to the mean of the other top 6 (40.7°). This more favourable release angle was obtained by a more aggressive change in the mean upswing path angle going into the single support phase on each turn. By actively getting increasingly steeper in each turn, Fajdek changed not only the angle of the orbit, but also the axis, moving the catch point further around in the circle each turn. A result of this may have led to him landing with his centre of gravity slightly forwards at the end of the 4th turn and unable to add much speed at delivery (only an additional 0.17 m/s from the low point T4 to delivery) as he could not use his strong legs to drive into the delivery, but rather choosing to “get out of the way” of the hammer so as to maintain the high velocity he had already achieved. By comparison, many of the other finalists were able to add 1.5-3 m/s at this delivery phase.

Quentin Bigot, the smallest and lightest athlete in the field at 1.77 m tall and 90 kg, had the highest velocity on entry to the first turn (16.75 m/s) but remained much flatter throughout the turns, going from 29.5° at entry to 39.7° at delivery, for a change of only 10.2°. He was also very consistent with his take off and catch points on each turn (variation of only 20° and 8°, respectively), which gave him a much more linear orbit around a consistent axis from back to front of the circle, contributing to him to adding 2.32 m/s in the delivery phase, to give a similar release velocity but a lower release angle than Fajdek.

CONTRIBUTORS

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