Biomechanical Analysis of the Javelin Throw at the 2009 IAAF World Championships in Athletics

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(Translated from the original German by Matthias Werner)

ABSTRACT

The techniques of the finalists in the men's and women's javelin throw at the 2009 World Championships in Athletics were studied by a team of researchers from the Institute for Applied Training Science in Leipzig, Germany with the aim of obtaining the latest data and insight into the technical condition of the world's current best throwers. The throws in both the preliminary round and finals were recorded with video cameras set up in the seating area of the stadium. The release parameters (release velocity, angle of release, etc) were obtained for all the throws. Spatial and temporal characteristics of the throwing movement and other data were obtained from a three-dimensional photogrammetric analysis of the best throws for which suitable recordings were available. To give guidance for coaches and athletes preparing for future high-level competitions, the mean values and standard deviations were derived and compared with other parameters. Parameters describing the throwing technique were averaged for two groups of the finalists in the two competitions and compared to find those that explained the differences in the final placement.

AUTHOR

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Introduction

In the women's javelin throw at the 2009 IAAF World Championships in Athletics in Berlin, local star Steffi Nerius (GER) was the surprise winner in her last major event before retirement as her season's best throw of 67.30m in the first round stood up against the challenges of the rest of the field. The silver medal went to defending champion and world record holder Barbora Spotakova (CZE), who threw 66.42m, and third place went to Maria Abakumova (RUS), who threw 66.06m. There were season's bests for two other finalists - Monica Stoian (ROU) with 64.51m in fourth place and Olisdeilys Menendez (CUB), with 63.11m in seventh place. Stoian's mark was also a personal best.

There was no surprise at the top in the men's event five days later as Andreas Thorkildsen (NOR) added World Champion to his Olympic (2004 and 2008) and European (2006) titles (plus two World Championship silver medals). The winning 89.59m throw was his season's best and more than three metres better than the 86.44m of second placer Guillermo Martinez (CUB), who also threw a season's best in the final. Thorkildsen's domination of the competition is highlighted by the fact that his second best throw of 88.95m would also have been good enough to win. The bronze medal went to Yukifumi Murakami (JPN), who threw 82.97m.

Table 1: Results of the javelin throw at the 2009 IAAF World Championships in Athletics

Pos	Athlete (Country)	Round					
		1	2	3	4	5	6
Men's Final – 23 August – 16:20							
1	Andreas Thorkildsen (NOR)	77.80	89.59	88.95	X	-	-
2	Guillermo Martínez (CUB)	83.43	83.28	78.22	77.27	-	86.41
3	Yukifumi Murakami (JPN)	76.01	82.97	X	X	-	77.90
4	Vadims Vasilevskis (LAT)	X	82.05	X	X	X	82.37
5	Tero Pitkämäki (FIN)	81.90	81.14	80.50	X	80.17	81.14
6	Antti Ruuskanen (FIN)	75.36	75.67	81.87	78.65	X	80.87
7	Ainars Kovals (LAT)	X	81.54	X	X	75.98	76.39
8	Mark Frank (GER)	73.77	79.86	X	X	X	81.32
9	Teemu Wirkkala (FIN)	79.76	X	79.82			
10	Petr Frydrych (CZE)	78.57	X	79.29			
11	Tero Järvenpää (FIN)	75.43	X	75.57			
12	Sean Furey (USA)	73.18	74.51	73.77			
Women's Final 18 August –19:225							
1	Steffi Nerius (GER)	67.30	62.79	65.81	X	62.27	X
2	Barbora Špotáková (CZE)	64.94	64.26	66.42	61.29	62.25	59.74
3	Maria Abakumova (RUS)	63.01	X	65.39	X	59.71	66.06
4	Monica Stoian (ROU)	64.51	X	61.90	59.62	61.84	61.53
5	Christina Obergföll (GER)	X	60.37	64.34	X	63.02	X
6	Linda Stahl (GER)	61.64	63.23	63.18	59.00	61.33	60.90
7	Olisdeilys Menéndez (CUB)	63.11	X	X	X	61.56	58.27
8	Sávva Líka (GRE)	56.55	57.33	58.80	57.29	X	60.29
9	Vira Rebryk (UKR)	58.25	56.78	57.50			
10	Maria Nicoleta Negoita (ROU)	57.59	57.65	X			
11	Martina Ratej (SLO)	57.57	X	X			
12	Rachel Yurkovich (USA)	51.15	50.05	X			

In this report, the results of biomechanical analyses of the two competitions made by a team from the IAT (Institute for Applied Training Science) in Leipzig, Germany, are presented. The throws in both the preliminary round and the final were recorded with video cameras and then a three-dimensional photogrammetric analysis was used with the aim of obtaining the latest data and insight into the technical condition of the world's current best throwers. Specifically, we wanted to quantify key parameters of javelin throwing technique and calculate correlations that could guide athletes and coaches preparing for top-level competitions in the future.

Table 1 gives the complete results of the two finals.

Methods

Recording and Camera Set-up

The DV camera and analogous camera used were hardware-synchronised. The frame rate of the video recordings was 50 Hz (25 full frames, 50 half frames). An IAT-developed capture-program enabled synchronised recording of the movements onto a notebook computer. This required the use of an A/D-converter for the analogous camera.

The cameras had to be positioned in the seating area of the stadium, as the research team could not access the infield during the event. This meant that the cameras were about 20-25m above the infield and there were very large distances between their positions and the competition site (between 70 and 100m), making the use of telephoto lenses necessary. There was also a reduction of image quality due to complicated and changing lighting conditions. In the case of the women's event, this was aggravated by the fact that the installation and calibration of the cameras had to be completed before commencement of the afternoon competitions (daylight conditions) and the camera settings could not be changed during the competitions, which ended in the evening (partly floodlight conditions).

Calibration

Due to the difference in height between the camera positions and the infield, increased requirements for calibration were demanded. The process applied was developed at IAT (Figure 1). It is based on a selective entry of spatial co-ordinates, i.e. each point in the calibrated space is allocated to a three-dimensional co-ordinate. The origin of this co-ordinate system (zero point, x, y, and z each 0.00) was a point at the start of the runway, which lies on an ordinate running through the centre of the runway and the middle of the landing sector. As the side camera was panned, a calibration of each relevant video frame was necessary prior to the actual 3-D analysis. (LEHMANN et al.2009)

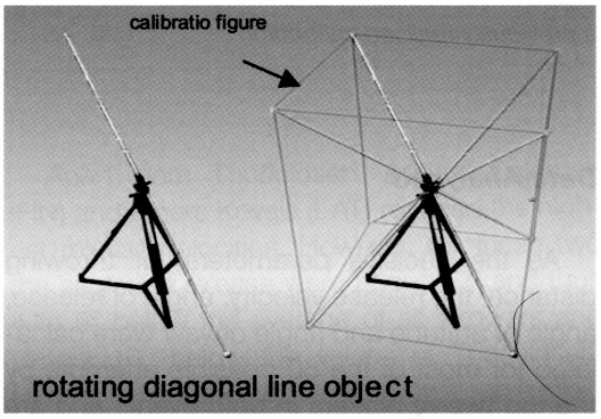

Figure 1: Diagonal rotating object for calibration of spatial co-ordinates

The differences in height between the camera positions and the infield also made verification of the angles of the spatial co-ordinates in the release area especially important for the evaluation of the calculated angles (angle of release, etc.). Hence, after calibration, the angle of inclination was determined for a fixed pole by calculating the spatial co-ordinates of six small balls (centres) attached to the pole and comparing them with the actual value, measured by a digital spirit level, also attached to the pole (Figure 2). This was done for three different measurements, each time varying the angle of inclination in the x- and z-axis (side view), as well as the angles of turn in the x-y-

level (view from behind). On average, the deviations ranged between 0.9 and 1.05%. This means that at an angle of release of 40° the error rate amounted to 0.4°.

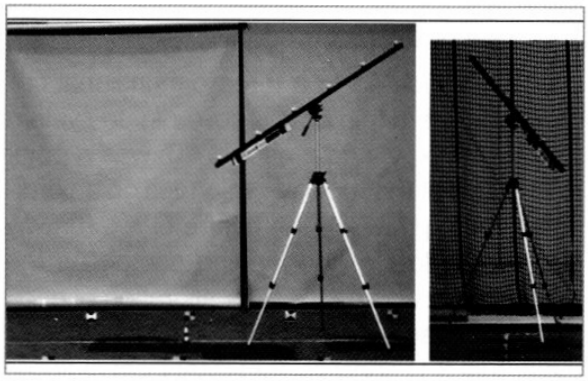

Figure 2: Verification of spatial angles on the basis of a previously realised calibration

Data Analysed

As the decisive parameters for throwing distance, the release velocity, angle of release, angle of attitude and angle of yaw were calculated for most of the 60 possible attempts by the top twelve placers in both events and are the main focus of this report. In the men's final, 56 attempts were taken (Thorkildsen passed his last two attempts while the other two medallists passed their penultimate attempts). The fourth attempt of Vadims Vasilevskis (LAT) could not be analyzed due to recording problems. Thus 55 attempts (38 valid, 17 fouls) in the men's final were analysed. In the women's competition 59 attempts (43 valid, 16 fouls) were analysed.

Generally the best attempt by each thrower in both competitions was extensively analysed with respect to the whole movement. If this was not possible due to recording problems - usually judges, photographers or others on the infield obstructing the view - the thrower's second best attempt was analysed. This is notably the case for Thorkildsen, whose second best throw had to be analysed in detail because of recording problems with his winning throw. The extensive analysis of the best throws also included a number of biomechanical factors related to the throwing technique. A selection of these has been addressed through comparisons of the average values for the top three throwers and the remaining finalists in both competitions.

Analysis of the Men's Competition

Release Parameters

In Table 2 we see that the average distance of the 38 valid attempts was 79.53m. This was achieved with averages for release velocity of 28.7 m/s, angle of release of 33.6°, angle of attitude of 37.1° and an angle of yaw of 9.9°.

Comparison of the release parameter correlations for the 17 valid throws over 80m with the 21 valid throws that were below 80m shows that the difference in average distance, a little over 6m, can almost exclusively be reduced to release velocity and that the difference in the averages for angle of release were very small and statistically not significant. There is no difference between the furthest and the shortest throws in respect to the angles of yaw, which remain below 10°on average and hence comply with the demands. Likewise the differences between the angles of attitude and release correspond to the current orientations, below 4° for both groups. The values for these parameters corresponded with demands established in earlier findings, which were based on the analysis of more than 1000 throws (ADAMCZEWSKI & PERLT, 2004; LEHMANN & RITSCHEL, 2007).

In individual cases (Table 3) we can see that there were considerable deviations from the averages. For example, Martinez had an average angle of release of 35.3° for his five throws but on his last attempt his angle of release was 36.5° and he threw 86.41m, his best in the competition. In this case, his low angle of yaw (8.3°) is was noticeable as the high release velocity.

Table 2: Average values of relevant release parameters for the throws of the top men javelin throwers at the 2009 IAAF World Championships in Athletics

	n	Distance [m]	release velocity (V_0) [m/s]	release angle (ar) [°]	angle of attitude (aatt) [°]	angle of yaw (ay) [°]
Beyond 80m (valid)	17	82.91	29.4	33.9	37.8	9.7
Less than 80m (valid)	21	76.80	28.2	33.3	36.5	9.4
Average for all attempts	55	79.53	28.5	33.1	36.9	9.9
All valid throws	38	79.53	28.7	33.6	37.1	9.5
All invalid throws	17		28.0	32.0	36.5	10.7

In previously analysed throws (ISTAF 2008 36.7°; ISTAF 2009 38.5°) Thorkildsen has shown comparably higher angles of release than his competitors (own results; LEHMANN 2008, LEHMANN 2009). In Berlin, he had an angle of release of 42° degrees on his first attempt! The javelin dropped down at 78m. In the second and third attempts he succeeded in reducing the angle of release to around 38-39° (apparently optimal under the given circumstances). The result was impressive. Typical of his first three attempts: the angle of release almost matches the angle of attitude (Figure 3), although this was not the case in his invalid fourth attempt.

This suggests that Thorkildsen can secure a small, aerodynamically favourable difference between the angle of release and angle of attitude even if he changes the angle of release. Apparently, he can influence the angle of release via the angle of attitude and deliver his throws as consistently as if they were from a javagun. Most of the other finalists in Berlin did not fully succeed in this respect. On his third attempt, Tero Pitkämäki (FIN) had a difference between the angle of attitude and the angle of release of below 3° but on his fourth attempt it was more than 10°.

Apart from Thorkildsen, Antti Ruuskanen (FIN) and Ainars Kovals (LAT) reached the highest release velocities. However, for these two the angles of release were about 29° and thus 4 to 5° below the average of all throwers and almost 10° below the values of Thorkildsen. Hence, the parabolas of their throws can explain the difference of almost 8m between their best marks and the winning mark of Thorkildsen. In this respect, it is not surprising that Ruuskanen and Kovals achieved their best throws in Berlin with their highest angles of release. However, it seems that neither were capable of correcting their apparently too flat angles of release in the course of the competition.

Looking at the other finallists in Berlin, we can state the following:

- Vasilevskis seemed absolutely insecure and unstable in his technique. One had the impression that he had problems with the foot of his brace leg. His release velocities varied between 26.9 and 29.9 m/s, the angles of release between 28.8 and 35.4°.
- Murakami had one attempt at a relatively high release velocity (28.9 m/s) but in the

Table 3: Values of relevant release parameters for all attempts (average) and for the best throws of the top men javelin throwers at the 2009 IAAF World Championships in Athletics

	n	Distance [m]	release velocity (V_0) [m/s]	release angle (ar) [°]	angle of attitude (aatt) [°]	angle of yaw (ay) [°]
Martinez	5	81.72	28.7	35.3	39.7	12.1
best throw		86.41	29.7	36.5	40.6	8.3
Frydrych	3	78.93	28.3	31.2	32.7	21.0
Järvenpää	3	75.50	28.4	34.3	40.0	17.3
Pitkämäki	6	80.97	29.0	33.5	40.4	15.5
best throw		81.90	28.9	34.3	42.7	12.6
Ruuskanen	6	78.48	28.9	29.0	31.0	11.2
best throw		81.87	29.0	32.6	32.3	7.2
Frank	6	78.32	27.9	36.4	39.4	11.8
best throw		81.32	29.0	34.4	38.3	9.2
Murakami	5	78.96	27.6	31.3	36.1	14.8
best throw		82.97	28.9	31.9	34.1	15.9
Wirkkala	3	79.79	28.4	32.3	37.3	15.5
Vasilevskis	5	82.21	28.4	32.4	35.9	10.5
best throw		82.37	29.9	31.3	35.9	13.4
Thorkildsen	4	85.45	29.3	38.2	39.1	12.3
best throw		89.59	29.9	39.0	38.9	11.0
Kovals	6	77.97	28.9	29.0	34.1	12.9
best throw		81.54	29.4	30.0	35.5	15.1
Furey	3	73.82	27.6	36.9	39.1	8.3

other attempts the release velocities were clearly lower.

- Mark Frank (GER) achieved his best throw of the day (81.32m) on his last attempt with his highest release velocity, lowest angle of yaw (9.2°) and lowest angle of release (34.4°, which is relatively flat for him). In his six attempts he had an average angle of release of 36.4°. If he could have achieved this value with the same release velocity he actually had on the sixth attempt, the throw would have been 1.8m further and instead of eighth place he would have taken the bronze medal.

Summarising the whole analysis of the release parameters, we can state:

- The correlation between throwing distance and release velocity is highly significant.
- Although there is no statistical correlation between angle of release and throwing distance, the greatest distances were achieved at angles of release above the average for all the throws (Figure 4) be-

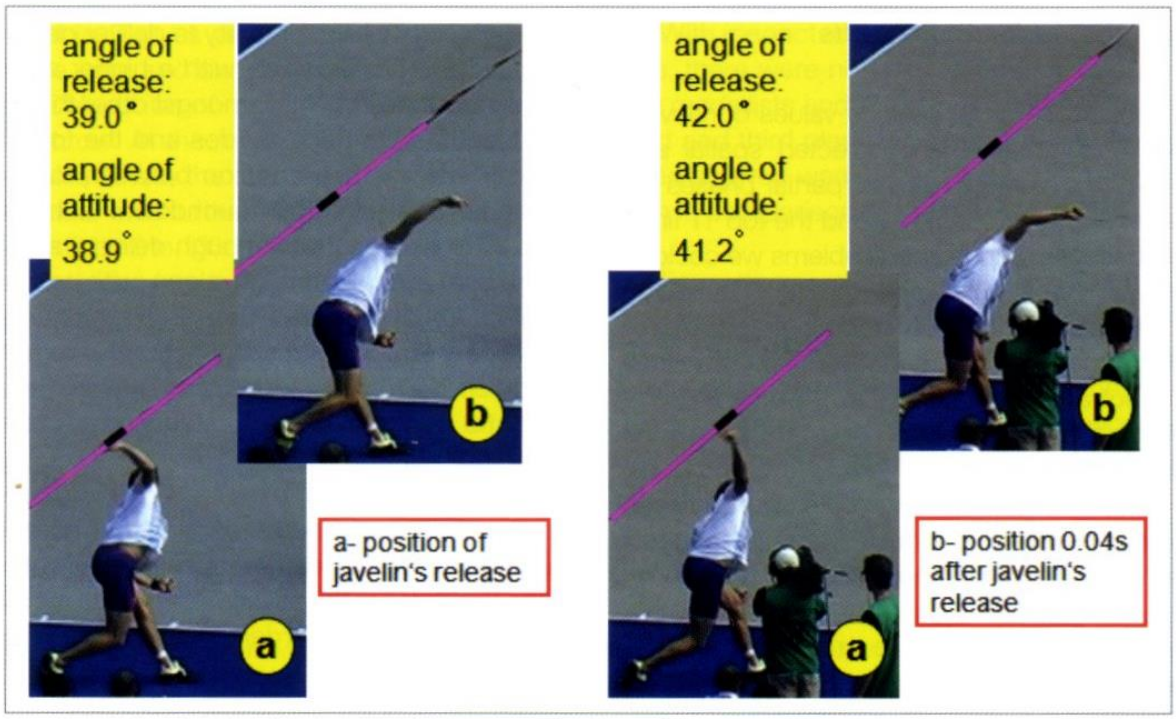

Figure 3: Comparison of the releases of Andreas Thorkildsen's first (right- 77.80m) and second (left- 89.59m) attempts in the javelin throw final at the 2009 IAAF World Championships in Athletics

tween 36 and 39°. Therefore, it seems necessary to discuss an increase in what is considered the optimal angle of release.

- The ability to adjust and correct the angle of release in the course of a competition can be decisive.
- Absolute top performances occur when the angle of release and the angle of attitude match.
- The angle of yaw should be below 10°. This confirms previous guidelines.

A multiple regression analysis between throwing distance (dependent variable) and release velocity and angle of release (independent variable) amounted to the following correlation for the men (all valid attempts; n = 38; r2 = 0.61):

throwing distance = 3.817 x release velocity + 0.454 x angle of release - 45.135

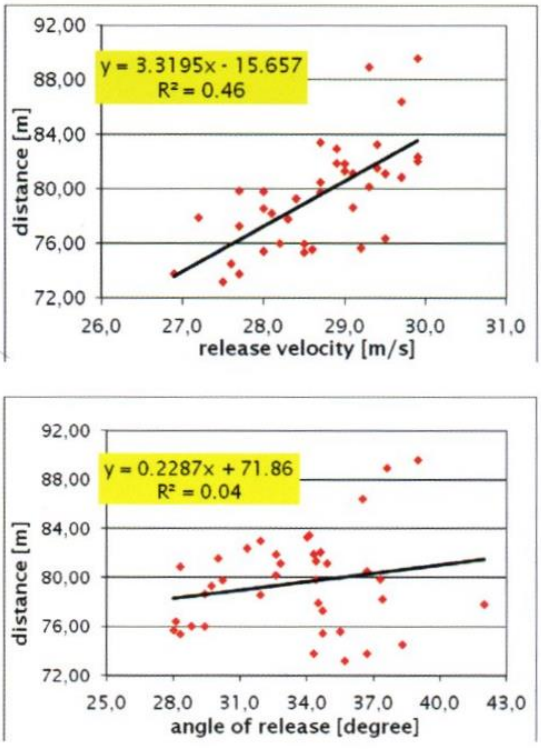

Figure 4: Correlation between throwing distance and release velocity (left) and angle of release (right) in 38 valid throws in the men's javelin throw final at the 2009 IAAF World Championships in Athletics

Selected Additional Results

Table 4 gives the average values of relevant release parameters and selected spatial and time parameters of relevant partial phases for the medallists, places 4-11 and the top 11 finalists (because of technical problems we couldn't analyze the 12th placed thrower). It shows relatively little difference in the average release velocity between the medallists and other finalists, but a significantly higher average angle of release for the medallists. Apart from that, the medallists show a clearly lower average angle of yaw and a lower average difference between angle of attitude in the delivery and the angle of release (2°) than the other finalists.

It seems clear that the primary differentiator between the two groups is not the higher release velocity but the ability to deliver or "hit" the javelin more precisely with a higher angle of release. This involves, amongst other things, the lengths of the final strides and the touchdown durations (the duration between touchdown of right leg and touchdown of brace leg). Here we see that although delivery stride lengths of over 2.00m go along with touchdown durations of more than 200 ms, as observed in Martinez, Ruuskanen, Frank and Petr Frydrych (CZE), Vasilevskis was an exception with 160 ms touchdown duration and a 2.09m delivery stride.

The distance between the point of release and the foul line varied greatly but did not influence the order of the medallists, though it possibly influenced the order of the other group (places 4-8).

Table 4: Comparison of the average values of relevant release parameters and selected spatial and time parameters of relevant partial phases for the analysed attempts of the top men javelin throwers at the 2009 IAAF World Championships in Athletics

	Distance [m]	Release velocity [m/s]	Angle of release [°]	Angle of attitude [°]	Angle of yaw [°]	Distance from foul line [m]	Length third to last step [m]	Length impulse stride [m]	Length delivery stride [m]	Duration t1 [ms]	Duration t2 [ms]	Duration t3 [ms]	Duration t4 [ms]
Average for places 1-3	86.11	29.3	35.3	37.5	12.5	2.97	1.85	2.36	1.84	180	320	193	93
Average for places 4-11	80.46	28.9	32.8	36.9	14.1	2.68	1.67	2.09	2.00	168	268	195	105
Average for places 1-11	82.00	29.0	33.5	37.1	13.6	2.75	1.72	2.16	1.95	171	282	195	102

t1 = Duration from take-off of the third last stride to take-off of the impulse stride

t2 = Duration from take-off before and the touchdown after impulse stride

t3 = Duration from touchdown after impulse stride to touch down brace leg

t4 = Duration from touchdown brace leg to javelin's release

Table 5 gives an analysis of the positions of the hips and shoulders and the velocity of the CM (centre of mass) in relevant phases of the throw. At the moment of push-off into the impulse stride, the medallists held the hip and shoulder axis further back than the rest of the finalists by 7 to 10°. However, at the touchdown of the brace leg, the hip and shoulder axes of the medallists were brought further forwards. They were clearly more active in their hips in preparation for building up tension but they held the throwing shoulder back. In effect, a greater torque between hip and shoulder axis was produced at touchdown of the brace leg in the medallists compared to the other finalists (36° vs 32°; peak value: Thorkildsen 46°).

With respect to the course of the CM velocities, there were no basic differences between the medallists and the remaining finalists. Second and third placers Martinez and Murakami even showed weaknesses in the brace leg action in comparison to the others finalists.

Four throwers - Thorkildsen, Pitkämäki, Vasilevskis and Teemu Wirkkala (FIN) – had favourable CM velocity graphs, which showed small drops until the touchdown of the brace leg and immediately afterwards pronounced reductions in velocity ranging from 1.5 m/s for Thorkildsen up to 1.75 m/s Vasilevskis.

Table 5: Comparison of the average values of hip and shoulder axes parameters and CM velocities of relevant partial phases for the analysed attempts of the top men javelin throwers at the 2009 IAAF World Championships in Athletics

	Shoulder axis push-off impulse stride [°]	Hip axis push-off impulse stride [°]	Shoulder axis touch-down right leg [°]	Hip axis touch-down right leg [°]	Shoulder axis touch-down brace leg [°]	Hip axis touch-down brace leg [°]	Shoulder axis javelin release [°]	Hip axis javelin release [°]	Maximum power [kW]	CM velocity during t1 [m/s]	CM velocity during t2 [m/s]	CM velocity between tdrl-and tdrl +0.10s[m/s]	CM velocity tdrl +0.10s - tdbl [m/s]	CM velocity tdbl-tdbl +0.06s [m/s]	CM velocity tdbl +0.06s - javelin release [m/s]
Average for places 1-3	206	158	194	150	135	99	52	75	5.54	6.91	6.66	6.25	6.22	5.12	4.14
Average for places 4-11	197	151	191	144	142	110	50	78	4.88	6.1	6.66	6.29	6.23	5.01	4.08
Average for places 1-11	199	153	192	146	140	107	51	77	5.06	6.76	6.66	6.27	6.23	5.04	4.10

t1 = between take-off of the third last stride and take-off of the impulse stride on average

t2 = between take-off before and the touchdown after impulse stride on average

tdrl= touchdown right leg (after impulse stride)

tdbl= touchdown brace leg

The average for the delay in the throw in respect to the elbow movement was similar for both groups. There were only a few clear deviations from the average values: Murakami (101°) and repeatedly Pitkämäki (100°) showed comparably small angles in the elbow at touchdown of the brace leg.

Table 6 shows the average values for the parameters that define the elbow and brace leg activity (BARTONIECZ, EMMRICH, 1997). The medallists planted their brace legs almost straight (171 or 172°) and stood more stable in the course of the bracing phase (reduction of the angel by about 16°) than the remaining finalists (reduction by 25°).

Table 6: Comparison of the average values of elbow and brace leg activity parameters of relevant partial phases for the analysed attempts of the top men javelin throwers at the 2009 IAAF World Championships in Athletics

	Acceleration javelin tdbl	Velocity javelin tdbl [m/s]	Angle elbow tdrl [°]	Angle elbow tdbl [°]	Minimal angle elbow tdbl-javelin release [°]	Point of time reaching minimum angle elbow prior to delivery [s]	Angle elbow javelin release [°]	Angle torso axis/horiz. push-off impulse stride [°]	Angle torso axis / horiz. tdrl[°]	Angle torso axis / horiz. touchdown brace leg [°]	Angle torso axis / horiz. javelin release [°]	Knee angle tdrl [°]	Knee angle tdbl [°]	Knee angle 0.06s after pbl [°]	Angle brace leg to the ground at tdbl [°]
Average for places 1-3	87	9.9	151	114	101	-0.04	129	75	70	75	122	134	172	156	44
Average for places 4-11	84	9.5	152	116	96	-0.05	131	74	71	76	125	129	171	145	42
Average for places 1-11	85	9.6	152	115	97	-0.04	131	74	71	76	124	131	171	148	42

tdrl= touchdown right leg (after impulse stride)
tdbl= touchdown brace leg
pbl= plant brace leg

Analysis of the Women's Competition

Release Parameters

The average distance of the 43 valid attempts was 61.08m. This was achieved with averages for release velocity of 24.5 m/s, angle of release of 34.6°, angle of attitude of 40.5° and angle of yaw of 10.4°.

Comparison of the release parameter correlations for the 24 valid throws over 61m with the 19 valid throws that were below 61m produces a remarkable finding: about 80% of the difference in average throwing distance (best throws: 63.46m, remaining throws: 58.07m) can be explained by release velocity, which was an average of 1 m/s higher for the best throws. The remaining almost 20% can be attributed to the angle of release, which was an average of slightly over 2° higher for the best throws. Interestingly, the differences in the angles of attitude and yaw contradict technical orientations (these are according to the men): the best throws (and by implication the best throwers) had, on average, greater differences between the angles of attitude and release and greater angles of yaw. This indicates technical problems and opportunities for improvement for even the top throwers in the world.

Spotakova's performance drop in Berlin with respect to her 2008 world record throw in Stuttgart can be attributed, among other reasons, to the fact that the difference between the angle of attitude and angle of release of 0.1 degrees (LEHMANN, 2008) in the record throw widened to 5.9° in Berlin. This means the javelin was not delivered/'hit' precisely (see Figure 5).

On the same line of thought, we note that in the qualification Abakumova threw 68.92m in a very relaxed manner but starting with her first attempt in the final she seemed under pressure. Both on average for her throws in the final and on her sixth and furthest throw in the final, she achieved higher release velocities than in the qualification. However, her throw in the qualification was marked by a more precise release – a slightly higher angle of release, a smaller difference between angle of attitude and angle of release (3.9° in comparison to an average of 7.8° for her throws in the final) and a clearly smaller angle of yaw of (6.3°, in comparison to an average of 13.3° for her throws in the final).

Table 7: Average values of relevant release parameters for the throws of the top women javelin throwers at the 2009 IAAF World Championships in Athletics

	n	Distance [m]	release velocity (V_0) [m/s]	release angle (ar) [°]	angle of attitude (aatt) [°]	angle of yaw (ay) [°]
Beyond 61m (valid)	24	63.46	25.0	35.4	42.0	11.1
Less than 61m (valid)	19	58.07	24.0	33.6	39.6	10.3
Average for all attempts	59	61.08	24.5	34.6	40.5	10.4
All valid throws	43	61.08	24.6	34.6	41.0	10.8
All invalid throws	16		24.3	34.6	39.4	9.1

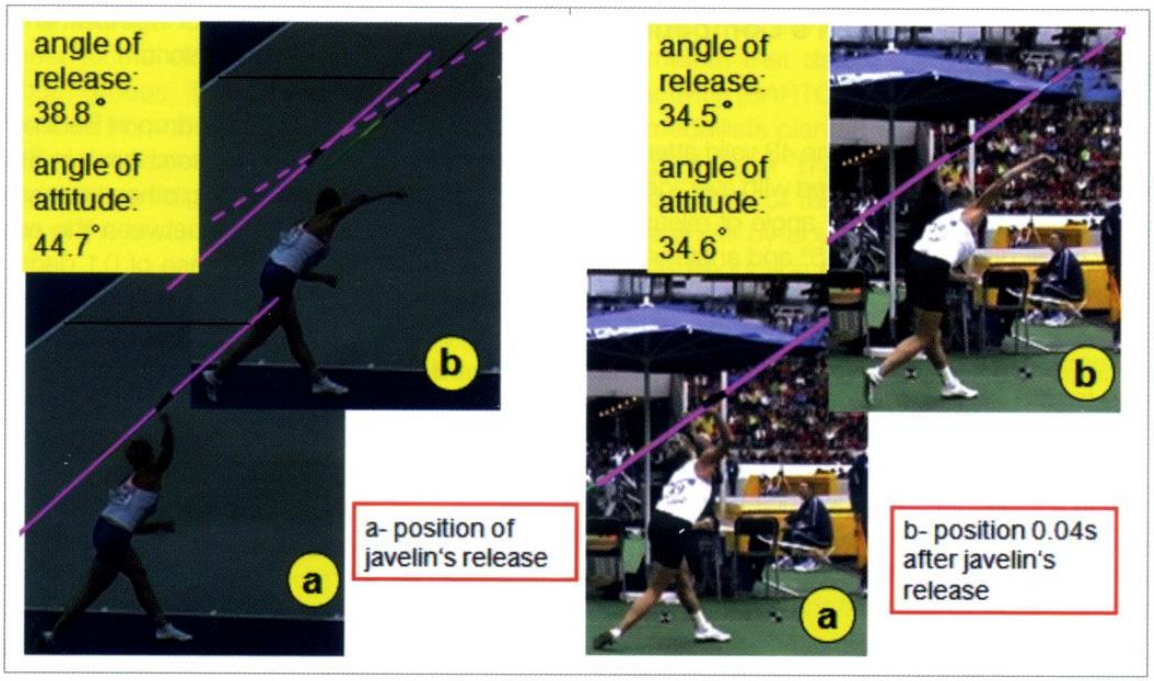

Figure 5: Comparison of the releases of Barbora Sportakova's 72.28m world record in 2008 (right) and 66.42m throw in the javelin throw final at the 2009 IAAF World Championships in Athletics(left)

In Table 8 we see that Spotakova and Abakumova had the highest angles of release among the finalists (Spotakova: six throw average 39.3°, best throw 38.8°, Abakumova: four throw average 36.1°, best throw 36.3°). Stoian averaged 36.4° for her five valid throws but her best throw was 33.5°. Apart from ninth placer Vera Rebryk (UKR) who had a three throw average of 27.8° all other throwers showed an angle of release between 33° and 34°. The angle of attitude at release was steeper than the angle of release in all throwers with the exception of tenth placer Maria Nicoleta Negoita (ROU).

Table 8 also features data for African record holder Sunette Viljoen (RSA), who arrived in Berlin ranked number 5 in the world but did not make it through the qualification where she showed a very unconventional release action. Analysis of her throws showed that in respect to release velocity she nearly matched the very top throwers. However, her best throw was with a very flat angle of release (25.6°) and the approximate 20° difference between angle of release and angle of attitude and the angle of yaw of about 21° show that she did not deliver/'hit' the javelin precisely at all. If she could simply increase the angle of release it would add about one metre of distance per degree to her performance up to about 34°. (HINZ, 1991)

Summarising the whole analysis of the release parameters, we can state:

- The correlation between throwing distance and release velocity is highly significant (but slightly lower than expected, see Figure 6).
- There is no correlation between throwing distance and angle of release (trends indicating accordance with throws parabola, see Figure 6) or between release velocity and angle of release.

Table 8: Values of relevant release parameters for all attempts and for the best throws of the top women javelin throwers at the 2009 IAAF World Championships in Athletics

	n	Distance [m]	release velocity (V_0) [m/s]	release angle (ar) [°]	angle of attitude (aatt) [°]	angle of yaw (ay) [°]
Menendez	6	60.98	24.4	33.4	39.6	8.2
best attempt		63.11	25.7	33.9	41.1	8.4
Spotakova	6	63.15	24.9	39.3	44.3	12.4
best attempt		66.42	25.0	38.8	44.7	13.4
Nerius	6	64.54	24.7	33.6	42.8	13.2
best attempt		67.30	25.6	33.6	40.5	12.2
Obergföll	6	62.58	24.8	33.8	36.0	6.4
best attempt		64.34	24.9	34.1	37.6	8.0
Stahl	6	61.55	24.7	33.8	43.2	11.8
best attempt		63.23	24.6	33.9	40.2	10.0
Lika	6	58.05	23.5	33.6	37.6	7.5
best attempt		60.29	24.3	33.2	35.4	10.9
Stoian	6	61.88	24.3	36.4	40.1	10.3
best attempt		64.51	24.9	33.5	37.4	10.8
Abakumova	6	63.54	25.8	36.1	43.9	13.3
best attempt		66.06	26.1	36.3	43.0	10.8
qualification		68.92	25.4	38.7	42.6	7.4
Rebryk	3	57.51	24.8	27.8	42.2	15.8
best attempt		58.25	24.7	28.1	42.1	16.4
Negoita	3	57.62	23.3	34.1	32.1	8.4
Ratej	3		24.4	35.2	36.2	4.9
Yurkovich	2		22.9	33.0	47.8	12.1
Viljoen						
qualification		56.83	25.1	25.6	45.8	21.9

Selected Additional Results

The medallists had an average distance from the release point to the foul line that was greater than the rest of the finalists. In individual cases this concerns both Spotakova and Abakumova (3.00m and 2.90m, respectively on their best throws). The difference between these distances and that of Nerius (1.90m) was greater than the winning margin. To put it simply, both throwers could be said to have given away the chance to be world champion by releasing so far from the foul line.

With respect to the absolute values and the relationship of the impulse and delivery stride lengths, there were various individual technique variations. While the lengths of the two strides were carried out according to current orientations (relation:(2.5-3.0):2; LEHMANN 2009) by Nerius (Impulse stride: 2.02m/ Delivery stride: 1.73m), Abakumova (2.11m/1.74m in the final and 2.14m/1.71m in the qualification), Stahl (2.09m/1.65m) and Negoita (2.06m/1.65m), the brace step was longer than the impulse stride with some throwers Spotakova (1.73/1.89), Stoian (1.52m/1.78m), Menendez (1.86m/1.98m), Obergföll (1.92m/1.93m) and Rebryk (1.74m/1.95m).

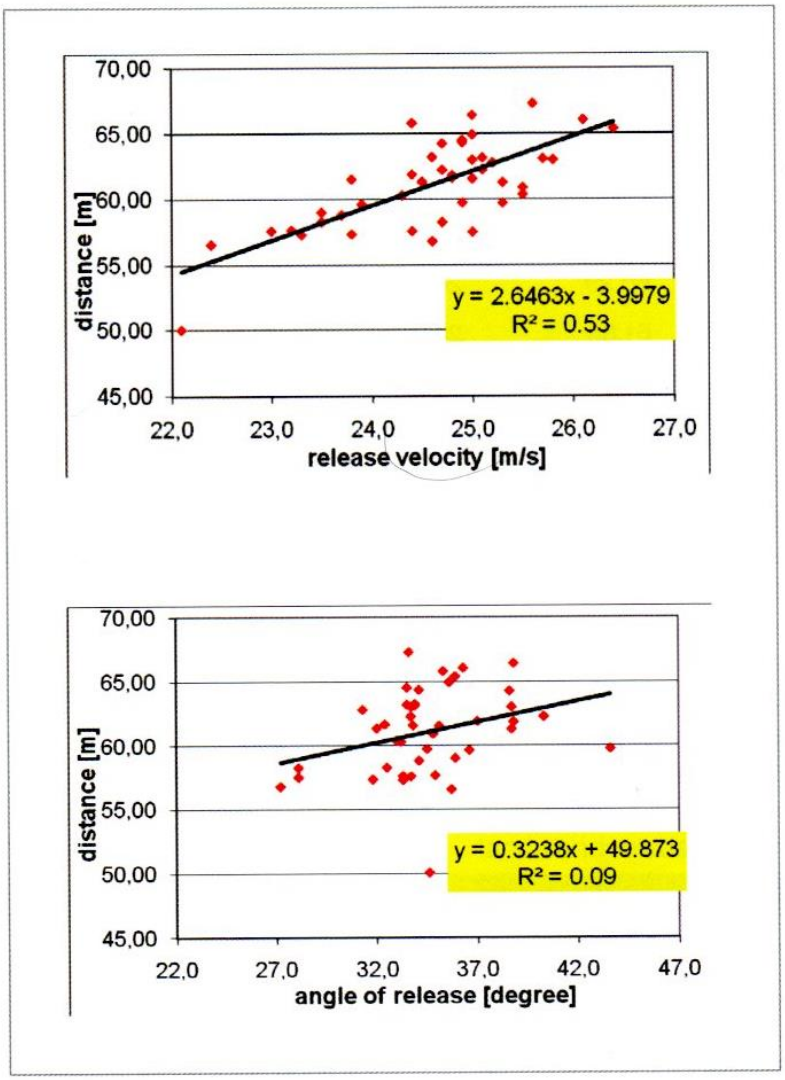

Figure 6: Correlation between throwing distance and release velocity (left) and angle of release (right) in 43 valid throws in the women's javelin throw final at the 2009 IAAF World Championships in Athletics

Table 9: Comparison of the average values of hip and shoulder axes parameters and CM velocities of relevant partial phases for the analysed attempts of the top women javelin throwers at the 2009 IAAF World Championships in Athletics

	Shoulder axis push-off impulse stride [°]	Hip axis push-off impulse stride [°]	Shoulder axis touch-down right leg [°]	Hip axis touch-down right leg [°]	Shoulder axis touch-down brace leg [°]	Hip axis touch-down brace leg [°]	Shoulder axis javelin release [°]	Hip axis javelin release [°]	Maximum power [kW]	CM velocity during t1 [m/s]	CM velocity during t2 [m/s]	CM velocity between tdrl-and tdrl +0.10s[m/s]	CM velocity tdrl +0.10s - tdbl [m/s]	CM velocity tdbl-tdbl +0.06s [m/s]	CM velocity tdbl +0.06s - javelin release [m/s]
Average for places 1-3	191	151	185	129	131	82	47	55	2.58	6.23	6.11	5.81	5.66	4.57	3.75
Average for places 4-11	188	142	190	145	137	107	48	71	2.53	6.06	5.84	5.47	5.47	4.36	3.26
Average for places 1-11	189	144	188	141	136	101	48	67	2.54	6.10	5.91	5.56	5.52	4.42	3.38

t1 = between take-off of the third last stride and take-off of the impulse stride on average
t2 = between take-off before and the touchdown after impulse stride on average
tdrl= touchdown right leg
tdbl= touchdown brace leg

Table 9 gives an analysis of the positions of the hips and shoulders and the velocity of the CM (centre of mass) in relevant phases of the throw. Analogous to the men's event, at the moment of push-off into the impulse stride, the medallists held the hip and shoulder axis further back than the rest of the finalists by 7 to 10°. Likewise, at the touchdown of the brace leg, the hip and shoulder axes of the medallists were brought further forwards. In effect, a greater torque between hip and shoulder axis is produced at touchdown of the brace leg in the medallists (average 49°; peak value Abakumova 65°) in comparison to the other finalists (average 30°).

There were slight differences with respect to the course of the CM velocities (the average for the medallists was higher by 0.2 m/s). Abakumova and Obergföll showed the best levels by a long way. While Nerius and Stahl have slightly improved in comparison to previous results, Spotakova has declined slightly in comparison to the previous year (World Record; own findings; LEHMANN, 2008).

Table 10 shows the average values for the parameters that define the elbow and brace leg activity. Concerning the achieved velocity maxima of relevant joints the differences between the average values for the medallists and the other finalists amounted to approximately 0.2 m/s in the CM velocity at touchdown of the brace leg, 0.4 m/s in the maximum hip velocity, 0.5 m/s in the maximum shoulder velocity and 0.9 m/s in the maximum elbow velocity. The result of this apparently more effective build-up of velocity is a 1.1 m/s higher average release velocity for the medallists.

Considering the side view of holding the javelin, the angle of attitude was, on average, the same at touchdown of the right leg for both the medallists and the other finalists. Up to this point, the medallists held it more level and after this point they held it at a steeper angle. This possibly has to do with the fact that the graph of the javelin grip is directed further upwards as the better athletes hold the upper body further back.

On average, the delay in throw with respect to the elbow movement (slight differences in the elbow angle at touch-down of the brace leg)

Table 10: Comparison of the average values of velocity maxima in relevant joints and of angle of attitude in selected phases for the analysed attempts of the top women javelin throwers at the 2009 IAAF World Championships in Athletics

	Maximum hip velocity [m/s]	Point of time of max. prior to release [s]	Velocity of javelin at max. hip velocity [m/s]	maximum shoulder velocity [m/s]	Point of time of max. prior to release [s]	Velocity of javelin at max. shoulder velocity [m/s]	Maximum elbow velocity [m/s]	Point of time of max. prior to release [s]	Velocity of javelin at max. elbow velocity [m/s]	velocity of elbow at release of javelin [s]	aatt javelin (xz) push-off third but last stride [°]	aatt javelin (xz) push-off impulse stride [°]	aatt javelin (xz) tdrl [°]	aatt javelin (xz) tdbl [°]	aatt javelin (xz) at release [°]
Average for places 1-3	6.3	-0.23	6.2	8.1	-0.07	10.8	11.7	-0.05	12.7	9.4	18.7	25.6	34.9	42.6	43.0
Average for places 4-11	5.9	-0.23	6.2	7.6	-0.09	9.5	10.8	-0.06	12.6	8.7	22.8	31.0	34.5	37.7	38.9
Average for places 1-11	6.0	-0.23	6.2	7.7	-0.09	9.8	11.0	-0.06	12.6	8.8	21.7	29.7	34.6	39.0	40.0

aatt= angle of attitude
tdrl= touchdown right leg (after impulse stride)
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was similar for all the finalists. In the course of the delivery phase, the elbow of the throwing arm had a more pronounced bend in the medallists (average of 95° for the minimal elbow angle) than for the rest finalists (average of 104°).

With regard to the brace leg activity, there was hardly any difference between the medallists and the remaining finalists. In this respect Nerius in particular and Abakumova to some extent show room for improvement, as highlighted by the excessive bending of the knee joint of the brace leg (20° and more).

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