

Scientific Research Project Biomechanical Analyses

at the



Final Report

Throwing Events

**Biomechanical analyses of selected events at the
12th IAAF World Championships in Athletics,
Berlin 15–23 August 2009**

A Project by the German Athletics Federation

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in co-operation with

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DLV Scientific Research Project

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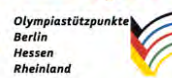
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Shot Put

Presented by Wilko Schaa

Men

The men's shot put event took place on Saturday, 15th August 2009, at 8:15 pm under warm and dry weather conditions.

The average age of the top eight putters was 30.4 ± 2.5 years, which was over one year older than the finalist at the last World Championships 2007 in Osaka (29.1 ± 2.3). From the current world's top twelve shot putters two did not compete in Berlin and three athletes did not make the final. But among the top eight finalists seven athletes were ranking among the world's top twelve.

In recent years athletes who practice the rotational shot put technique dominated the world ranking and the major events. This trend was confirmed in the 2009 World Championship shot put final. Five of the eight finalists used the rotational style. Just three athletes performed the glide technique, but two of these three of the traditional style on a medal in Berlin (table 1).

Table 1: *Official competition result of the men's shot put final in relation to season's best (SB) before the World Championships (WCh) and used technique style*

Rank	Athlete	result WCh [m]	SB before WCh [m]		style
1.	Cantwell, C. (USA)	22.03	21.82	+0.95 %	rotational
2.	Majewski, T. (POL)	21.91	21.95	-0.18 %	glide
3.	Bartels, R. (GER)	21.37	21.11	+1.23 %	glide
4.	Hoffa, R. (USA)	21.28	21.89	-2.79 %	rotational
5.	Nelson, A. (USA)	21.11	21.07	+0.19 %	rotational
6.	Lyzhin, P. (BLR)	20.98	20.83	+0,7 %	rotational
7.	Mikhnevich, A. (BLR)	20.74	21.02	-1,33 %	glide
8.	Vodovnik, M. (SLO)	20.50	20.18	+1,59 %	rotational

The mean putting distance was 21.24 ± 0.53 m and on a higher level compared to the World Championships in Osaka two years ago (21.04 ± 0.6 m). Five athletes in the final improved their personal best or seasonal best performance. C. Cantwell (USA) won with a seasonal best of 22.03 m (+0.95 %) and set a new world lead. The silver medal performance of the Polish Olympic Champion T. Majewski (21.91 m) was very close to his seasonal best (-0.18 %). The current European Champion R. Bartels (GER) even set a new personal best with 21.37 m for winning the bronze medal (+1.23 %).

Greater negative differences to their season best were only noticed for the Belorussian A. Mikhnevich (-1.33 %) and the World Champion from Osaka R. Hoffa (USA/-2.79 %) who just achieved a disappointing fourth place.

Table 2: Selected kinematic data of the men's shot put final

athlete	analysed attempt	result [m]	release velocity [m/s]	release angle [°]	release height [m]	final acceleration distance [m]*	angular velocity shoulder [°/s]**	angular velocity pelvis [°/s]**
Cantwell, C. (USA)	5	22.03	14.0	37.8	2.29	1.62	1007	492
Majewski, T. (POL)	5	21.91	13.8	39.3	2.43	2.08	708	516
Bartels, R. (GER)	3	21.37	14.0	33.6	2.12	1.79	734	309
Hoffa, R. (USA)	6	21.28	14.0	34.4	2.06	1.53	891	425
Nelson, A. (USA)	1	21.11	14.1	32.9	2.05	1.54	1025	562
Lyzhin, P. (BLR)	2	20.98	13.6	39.2	2.22	1.75	859	632
Mikhnevich, A. (BLR)	4	20.74	13.4	37.7	2.43	1.93	724	446
Vodovnik, M. (SLO)	3	20.50	13.7	33.1	2.25	1.88	927	638
Mean		21.24	13.8	36.0	2.23	1.77	859.4	502.5

* distance of shot between power position (touch down brace leg) and delivery position (release shot)

** average between power position (touch down brace leg) and delivery position (release shot)

Some selected kinematic data of the men's shot put final are shown in table 2. It is conspicuous that there are no big differences between the values of release velocity of the finalists overall and particularly between the top five shot putters. Furthermore we found no significant correlation between throwing distance and release velocity in this final.

Therefore the fluctuations in performance in this event can be related to the other release parameters such as angle and height of release (according to the throwing equation). It seems that these factors become more importance on top level shot putting as the release velocity in areas of high amounts comes up to a plateau.

This impression is supported for example by the kinematic data for the winning performance of C. Cantwell (USA). He achieved the same release velocity as bronze medallist R. Bartels (GER) and 4th placed R. Hoffa (USA), but his release velocity was lower than of A. Nelson (USA) ranking 5th. But his result in the competition was clearly better. This can be explained by the steeper angle and the superior height of release he achieved, which is unusual for athletes using the rotational technique (table 2).

The rotational style shot putters achieved a higher angular velocities of shoulder based on higher separation of the hip axis from shoulder line at the beginning of the final acceleration. We assume that this is one requirement to compensate the shorter distance of the final shot's acceleration in the rotational shot put technique to achieve the same or even better performance respectively acceleration in the release phase compared to the athletes applying the glide technique.



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Women

The women's shot put event took place on Sunday, 16th August 2009, at 8:15 pm under very warm and dry weather conditions.

The average age of the top eight putters (26.4 ± 4.4) was over two years older than at the last World Championships two years ago in Osaka (24.1 ± 3.9). From the current top twelve shot putters in the world just one lacked and two did not make the final. But among the top eight finalists we noticed seven athletes from the world's top twelve.

The dominating technique style in the Women's shot put is still the glide. Only 5th placed A. Avdeeva (RUS) used the "leg reverse - technique".

The mean putting distance was $19,54 \pm 0,65$ m and in general on a higher level compared to the 2007 World Championships in Osaka (19.42 ± 0.80 m). However, the result of the gold and silver medallist could not compare with the 2007 results (20.32 m vs. 20.51 m).

Although V. Vili's 20.44 m was clearly below her current seasonal best (-1.21 %), she managed her third win in a row at a major event. The silver medallist from Germany N. Kleinert achieved with 20.20 m a new personal best just like Chinese bronze medallist L. Gong (19.89 m). For the athletes ranking 4th-8th we found great negative differences to their seasonal best (table 3).

Table 3: Official competition result of the women's shot put final in relation to season best before the World Championship and used technique style

rank	Athlete	result WCh [m]	SB before WCh [m]		style
1.	Vili, V. (NZL)	20.44	20.69	-1.21 %	glide
2.	Kleinert, N. (GER)	20.20	19.80	+1.98 %	glide
3.	Gong, L. (CHN)	19.89	19.82	+0.35 %	glide
4.	Mikhnevich, N. (BLR)	19.66	20.03	-1.88 %	glide
5.	Avdeeva, A. (RUS)	19.66	20.07	-2.09 %	changing
6.	Carter, M (USA)	18.96	19.13	-0.90 %	glide
7.	Meiju, L. (CHN)	18.76	18.93	-0.91 %	glide
8.	Gonzalez, M. (CUB)	18.74	19.13	-2.04 %	glide

The analysis of kinematic data (table 4) showed a correlation between putting distance and velocity of release ($r = 0.9$; $p > .01$). That is in contradiction to the men's shot put final where we did not find any relationship between these parameters. It illustrates the importance of the velocity of release in women's shot put where the general level of performance is relatively low.

Therefore the medallists are characterized by greater amounts of velocity of release and angle of release as well.

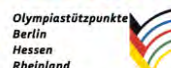
Table 4: Selected kinematic data of the women's shot put final

athlete	analysed attempt	result [m]	release velocity [m/s]	release angle [°]	release height [m]	angular velocity shoulder [°/s]**	angular velocity pelvis [°/s]**
Vili, V. (NZL)	5	20.44	13.6	37.5	2,16	769	520
Kleinert, N. (GER)	3	20.20	13.5	39.6	1,93	742	644
Gong, L. (CHN)	2	19.89	13.4	35.7	1,99	838	354
Mikhnevich, N. (BLR)	1	19.66	13.2	37.3	2,08	688	482
Avdeeva, A. (RUS)	4	19.66	13.3	36.0	2,03	791	445
Carter, M (USA)	3	18.96	13.0	37.2	2,07	842	429
Meiju, L. (CHN)	1	18.76	13.0	36.8	1,91	751	409
Gonzalez, M. (CUB)	5	18.74	13.2	34.2	1,84	711	518
Mean		19,54	13.3	36.9	2.10		

* distance of shot between power (touch down brace leg) and delivery position (release shot)

** average between power position (touch down brace leg) and delivery position (release shot)

*** in the load phase



Discus Throw

Presented by Marko Badura

Men

The event started on Wednesday 8:10 pm under optimal weather conditions. The average age of the eight best athletes (finalists) was 29.5 ± 3.6 years. This is about one year older than the average age (28.8 ± 3.9 years) last year in Beijing.

From the best twelve athletes of the current top list eight male throwers competed. The qualification result of four throwers was better than their ranking in the top list so they made the final. But, at the end, the best from the top list could improve their performance in the final, although not in the current sequence.

The results of this throwing event were on a high level comparable to the Olympic Games last year which was the highest since 2001. The average throwing distance of the finalists was 66.59 ± 1.59 m in Beijing and 66.41 ± 1.97 m in Berlin. The average of the top 3 is the absolute best since 2001. Nevertheless we did not find a progression in the performance development of the finalists and the top 30 in the annual top lists too during the last decade.

There are similar differences in the performed results in comparison to the current seasonal best between first (place 1-4: -2.2 %) and second group (place 5-8: -2.4 %) on average. Only the two best competitors could improve their seasonal best as is shown in table 1.

Table 1: Competition results in relation to the season's best 2009 (before the World Championships)

athlete	SB 2009 [m]	WCh Berlin 2009 [m]	difference [%]
Harting, R. (GER)	68.10	69.43	2.0
Malachowski, P. (POL)	68.75	69.15	0.6
Kanter, G. (EST)	71.64	66.88	-6.6
Alekna, V. (LIT)	69.59	66.36	-4.6
Malone, C. (USA)	68.49	66.06	-3.5
Kövago, Z. (HUN)	67.64	65.17	-3.7
Pishchalnikov, B. (RUS)	65.58	65.02	-0.9
Mayer, G. (AUT)	64.16	63.17	-1.5

When analysing the kinematic data (table 2) we expected a significant correlation between throwing distance and release velocity, but our analyses did not confirm this expectation. The mean value of the release velocity amounted to 24.48 m/s and the value of the angle of release to 36.4 degrees. This is about 0.5 m/s (2 %) and 1.3 degree (3.5 %) more than the values at last years World Athletic Final. In this context both standard deviations were less and indicate a higher level in this year. The average of the aerodynamic impact on throwing distance was 9.3 % (WAF 2008: 11 %).

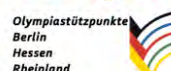


Table 2: Kinematic data analyzed at the discus throw of the men

athlete	result [m]	release velocity [m/s]	angle of release [°]	average velocity of the centre of mass [m/s]	aerodynamic quality of the throw [%]
Harting, R. (GER)	69.43	24.9	37.3	1.79	9.5
Malachowski, P. (POL)	69.15	24.9	35.4	2.01	10.7
Kanter, G. (EST)	66.88	24.4	37.5	1.79	9.0
Alekna, V. (LIT)	66.36	24.2	32.4	1.82	15.2
Malone, C. (USA)	66.06	23.9	36.5	1.95	12.6
Kövago, Z. (HUN)	65.17	24.6	38.9	1.69	4.4
Pishchalnikov, B. (RUS)	65.02	24.4	38.3	2.05	7.0
Mayer, G. (AUT)	63.17	24.5	34.5	1.95	5.8

Women

The event started on Friday 9:33 pm under pleasant dry weather conditions. The average age of the eight best (finalists) was 29.1 ± 5.7 years. This is about three years younger than the average age (32.0 ± 6.7 years) last year in Beijing and the spread is smaller.

As mentioned in the foreword, some recordings of the women's discus throwing final were unfortunately impossible to analyse (covert view). In that case we use another (next best) attempt for our analysis.

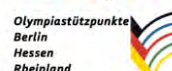
Eight female throwers of the best twelve athletes of the current top list competed in the final. Four throwers performed better in qualification than their ranking in the top list so they made the final. Surprisingly this is the same relation as for the men's discus throwing final. In contrast, the top thrower in the seasonal best ranking, Olympic champion S. Brown-Trafton (USA) ranked 12th (last) in this final and D. Samuels (AUS), who became quite an unexpected world champion, had the worst seasonal ranking. She advanced 15 ranks (average advancement without D. Samuels is about one rank).

As already mentioned the best in this year's ranking list, S. Brown-Trafton (USA), could not come up to the great expectations. D. Samuels (AUS), who ranked 9th in the 2008 Olympic Games, could unexpectedly win the championships. On the following ranks the same women are to be found as in the years before and as supposed in accordance with the 2009 ranking.

The average throwing distance of the finalists (last 8) was 62.14 ± 1.39 m in Beijing and 63.22 ± 1.69 m in Berlin. The average difference between the performed results and the current seasonal best was -1.1 percent. That would mean that all finalists could improve their performance in this championship. But, in detail, there is a great difference between the top ranking throwers (rank 1-4: +1.1 %) and second half



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(rank 5-8: -3.2 %). The medal winners did improve their season's best as you can see in table 3.

Table 3: Competition results in relation to season's best 2009 (before the world championships)

athlete	SB 2009 [m]	WCh Berlin 2009 [m]	difference [%]
Samuels, D. (AUS)	62.89	65.44	4.1
Barrios, Y. (CUB)	64.67	65.31	1.0
Grasu, N. (ROU)	64.40	65.20	1.2
Glanc, Z. (POL)	63.96	62.66	-2.0
Song, A. (CHN)	64.83	62.42	-3.7
Müller, N. (GER)	63.46	62.04	-2.2
Sadova, N. (RUS)	65.40	61.78	-5.5
Robert-Michon, M. (FRA)	61.69	60.92	-1.2

The analysis of the kinematic data (Table 4) showed no significant correlation between the throwing distance and the release velocity. However, there is an unexpected correlation between the throwing distance and the release angle ($p < .05$).

The mean value of the release velocities is 23.60 ± 0.36 m/s. This is almost 1 m/s (3.8 %) more than in the World Athletic Final last year although the average throwing distance is 3.7 m (5.8 %) longer than in 2008 WAF. This emphasizes the importance of the release angle. The mean value of this angle was 34.7 ± 2.6 degree. Aerodynamics had a greater impact on the throwing distance in the women's throws (mean 12.1 %) than in the men's (mean 9.3 %) at the WCh in Berlin.

Table 4: Kinematic data analyzed at the discus throw of the women

athlete	result [m]	analyzed attempt [m]	release velocity [m/s]	angle of release [°]	average velocity of the centre of mass [m/s]	aerodynamic quality of the throw [%]
Samuels, D. (AUS)	65.44	65.44	24.2	36.6	1.77	10.0
Barrios, Y. (CUB)	65.31	65.31	23.9	38.6	1.94	10.2
Grasu, N. (ROU)	65.20	63.41	23.1	35.8	1.71	16.2
Glanc, Z. (POL)	62.66	57.71	23.5	31.6	1.83	8.4
Song, A. (CHN)	62.42	62.42	23.3	33.0	1.64	16.0
Müller, N. (GER)	62.04	61.63	23.2	34.2	1.76	14.4
Sadova, N. (RUS)	61.78	61.94	23.7	36.9	1.51	8.4
Robert-Michon, M. (FRA)	60.92	61.53	23.9	30.8	1.95	13.3



Javelin Throw

Presented by Frank Lehmann

Men

When comparing men’s javelin throw at the 2009 World Championships (WC) with the 2008 Olympic Games (OG) we found some similarities. At the WC 2009 only three out of 47 javelin throwers (starting in two groups) cleared the qualification standard (82.00 m at the OG 2008: four from 38). V. Vasilevskis achieved the best result in the qualification without winning a medal in the final two days later and A. Thorkildsen had some problems and was a bit lucky to advance to the final.

All four Finnish throwers and two of three throwers from Latvia reached the final. Five of the other six throwers who qualified for the final competed for countries with long traditions in javelin (except Japan).

The final competition was characterized by the outstanding performance of A. Thorkildsen, meanwhile G. Martinez (seasonal best, only 76 cm below personal best) and Y. Murakami (in the final only 13 cm below his personal best from the qualification) confirmed their good results in the qualification.

Table 1: Kinematic data analyzed at the javelin throw of the men

athlete	seasonal best (SB 2009) [m]	result [m]	release velocity [m/s]	angle of release [degree]	angle of attitude [degree]	angle of yaw [degree]	length of impulse stride [m]	length of delivery stride [m]	distance to foul line [m]	duration of impulse stride [ms]	duration of delivery stride [ms]	duration to release [ms]
Thorkildsen, A. (NOR)	88.97	88.95*	29.3	37.6	37.9	10.5	2.36	1.75	2.70	320	160	100
Thorkildsen, A. (NOR)		77.80	28.3	42.0	41.2	7.9	2.35	1.72	2.40	320	160	100
Martinez, G. (CUB)	82.76	86.41	29.7	36.5	40.6	7.4	2.26	2.02	3.30	340	220	100
Murakami, Y. (JPN)	80.54	82.97	28.9	31.9	34.1	11.6	2.45	1.75	2.90	300	200	80
Vasilevskis, V. (LAT)	90.71	82.37	29.9	31.3	35.9	8.6	2.37	2.09	1.20	320	160	100
Pitkämäki, T. (FIN)	87.71	81.90	28.9	34.3	42.7	13.3	2.24	1.93	3.50	260	200	100
Ruuskanen, A. (FIN)	85.03	81.87	29.0	32.6	32.3	4.9	2.15	2.16	2.70	260	200	100
Kovals, A. (LAT)	82.47	81.54	29.4	30.0	35.5	11.5	1.97	1.84	3.00	260	200	120
Frank, M. (GER)	83.86	81.32	29.0	34.4	38.3	6.6	2.28	2.21	3.20	240	240	100
average medallists		86.11	29.3	35.3	37.5	9.8	2.36	1.84	2.97	320	193	93
average other finalists		81.80	29.2	32.5	36.9	9.0	2.20	2.05	2.72	268	200	104

* the best attempt (89.59 m) couldn't analyzed.

Even though we recognize these good results – the other throwers disappointed. On average the Finns were six metres below their seasonal best, A. Kovals could not increase his performance in a similar way as in Peking 2008 and M. Frank saw the possibility to win a medal – but he made too many technical mistakes even though he had the highest running up velocity. Therefore it was a good result for the winner but a result below 83 metres has never been enough to win a medal at World championships in men's javelin.

Opposite to the women's javelin (see below) there is almost no difference between the medallists and the other finalists in the release velocities (see table 1).

The medallists, first of all the gold and silver medal winners had a higher angle of release than the others and the difference between angle of attitude and the angle of release is lower (on average 2.2 degree). Obviously the ability to change the release angle was one of the deciding facts for winning medals. In the first attempt A. Kovals performed an angle of release of 29.9 degrees, A. Ruuskanen of 28.3 degrees. Both were hardly able to increase this flat angle of release during the final competition. Even they reached their best results with their individual highest angles of release – but these angles were too flat (table 1).

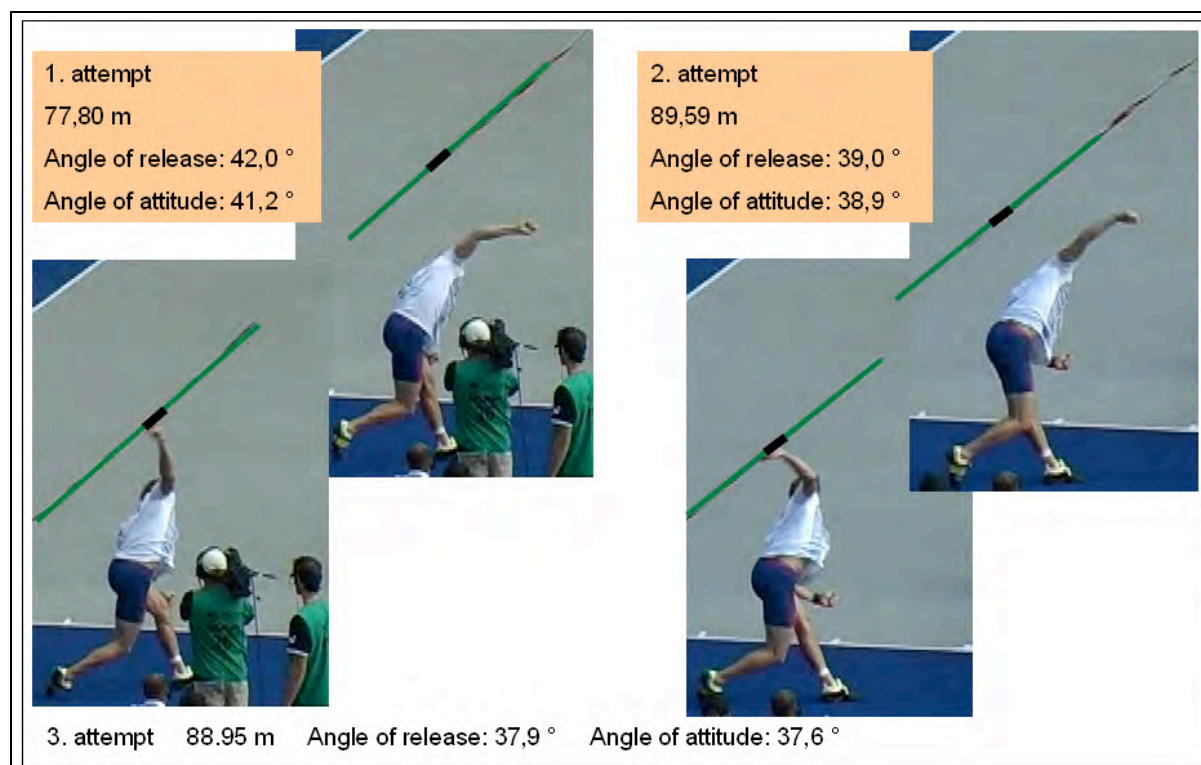


Figure 1: The angle of attitude and the angle of release at A. Thorkildsen at his first attempt in comparison to his second attempt at the world championships- final in Berlin 2009

A. Thorkildsen competed with a high angle of release (42.0 degree) in his first attempt – the javelin dropped down before landing – which was very different to A. Kovals and A. Ruuskanen. In the second and third attempt he decreased the

angle of release (figure 1). It is remarkable that he not only decreased the angle of release - he changed the angle of attitude in the same way: In the first three attempts there we found no difference between angle of attitude and angle of release for the Norwegian World Champion (4th throw: 4.2 degree difference).

Furthermore we found some differences in the rhythm and the relation of the last strides between the medallists and the other finalists. The first one had a much longer length of the impulse stride in comparison to the delivery stride. For the other finalists the relations between both strides got closer to 1:1 – it means both stride lengths are the same. We can see this for A. Ruuskanen, A. Kovals and M. Frank (table 1).

Women

M. Abakumova seemed to be unbeatable because of her performance in the first attempt in the qualification in the women's javelin competition. The two German candidates for the medals did not reach the qualification standard (62.00 m) in this qualification competition.

In the final S. Nerius performed 67.30 m in her first attempt (second best result in her long lasting career). The other throwers were obviously shocked and could not give the right answer. M. Abakumova showed her best result in the final in the last attempt – it was very close to S. Nerius if we take into consideration the distance to the foul line (table 2). It was similar to the third attempt, when B. Spotakova performed 66.42 m and had a distance to the foul line which was 1.10 m longer than S. Nerius. These data show – it was very close. But finally S. Nerius could win her first gold medal at WCh or OG in a long career and in her last major competition ever after winning several silver and bronze medals.

Meanwhile the world record holder B. Spotakova took the second place, the bronze medallist of the 2008 Olympic Games C. Obergföll ranked 5th more than 4 m below her seasonal best.

M. Stoian improved her personal best enormously to 64.51 m similar to S. Nerius in the first attempt and got the 4th place. L. Stahl performed very stable both in the qualification and in the final. After 2007 it was the second time that she was in the javelin final at the WCh.

The best throwers of the last years were the best athletes in Berlin (excepted C. Obergföll). M. Abakumova (in comparison to the qualification) and B. Spotakova (in comparison to her world record one year ago) had some problems in the final concerning their javelin technique.

As expected the best female throwers had the highest release velocities. Besides the medallists C. Obergföll (silver medal at the 2007 WCh and bronze medal at the 2008 OG) and O. Menendez (former world record holder and world champion 2005) belonged to this group. Except B. Spotakova and A. Abakumova all throwers had almost the same angle of release (33.2 to 33.9 degree, table 2).

Table 2: Kinematic data analyzed at the javelin throw of the women

athlete	seasonal best (SB 2009 before WCh) [m]	result [m]	release velocity [m/s]	angle of release [degree]	angle of attitude [degree]	angle of yaw [degree]	length of impulse stride [m]	length of delivery stride [m]	distance to foul line [m]	duration of impulse stride [ms]	duration of delivery stride [ms]	duration to release [ms]
Nerius, S. (GER)	66,82	67,30	25,6	33,6	40,5	12,2	1,81	1,49	1,90	260	180	100
Spotakova, B. (CZE)	68,23	66,42	25,0	38,8	44,7	13,4	1,73	1,89	3,00	220	220	100
Abakumova, M. (RUS)	66,89	66,06	26,1	36,3	43,9	10,8	2,11	1,74	2,90	260	180	120
Abakumova, M. (RUS)	Qual.:	68,92	25,4	38,7	42,6	7,4	2,14	1,71	2,70	260	180	120
Stoian, M. (ROU)	61,88	64,51	24,9	33,5	37,4	10,8	1,52	1,78	1,50	200	220	120
Obergföll, C. (GER)	68,59	63,02	25,8	33,7	35,2	8,0	1,92	1,93	2,30	220	180	120
Stahl, L. (GER)	62,67	63,23	24,6	33,9	40,2	10,0	2,09	1,65	1,68	260	200	120
Menendez, O. (CUB)	62,74	63,11	25,7	33,9	41,1	8,4	1,86	1,98	1,40	260	240	120
Lika, S. (GRE)	60,97	60,29	24,3	33,2	35,4	10,9	1,99	1,48	1,40	280	200	100
average medallists		66,59	25,6	36,2	43,0	12,1	1,88	1,71	2,60	247	193	107
average other finalists		62,83	25,1	33,6	37,9	9,6	1,88	1,76	1,94	244	208	116

* the largest attempt of C. Obergföll (64.31 m) couldn't analyzed;
 Qual. at A. Abakumova means it was her throw from the qualification

In the WCh final B. Spotakova obviously had some problems to find the optimal release angle. In her third attempt it was 38.8 degree (in comparison to 34.5 degree at her world record throw last year). In the final she continuously increased the release angle from 35.6 degree in the first attempt via 38.8 degree in the best third attempt to 43.6 degree in the last attempt (59.74 m). In contrast to her world record last year (72.28 m no difference) she had a greater difference between the angle of attitude and the release angle (nearly 6 degree, table 2 and figure 2).

M. Abakumova was not able to throw in the same relaxed way as she did in the qualification competition (68.92 m) obviously because of the psychological pressure after the first attempt of S. Nerius. Although the release velocity was higher in the final (6th attempt 66.06 m) she had a lower release angle, a greater difference between the angle of attitude and the release angle (almost twice as much) and a greater angle of yaw.

There is no difference between the medallists and the other finalists regarding the length and the duration of the impulse stride on average. According to the shorter length of the delivery stride its duration is shorter for the medallists in comparison to the other finalists. Concerning the relation between impulse and delivery stride length there are some individual differences. This relation seems to be normal for S. Nerius, A. Abakumova, L. Stahl and S. Lika, while the delivery stride length is longer than the impulse stride length at B. Spotakova, C. Obergföll, M. Stoian and O. Menendez.

B. Spotakova

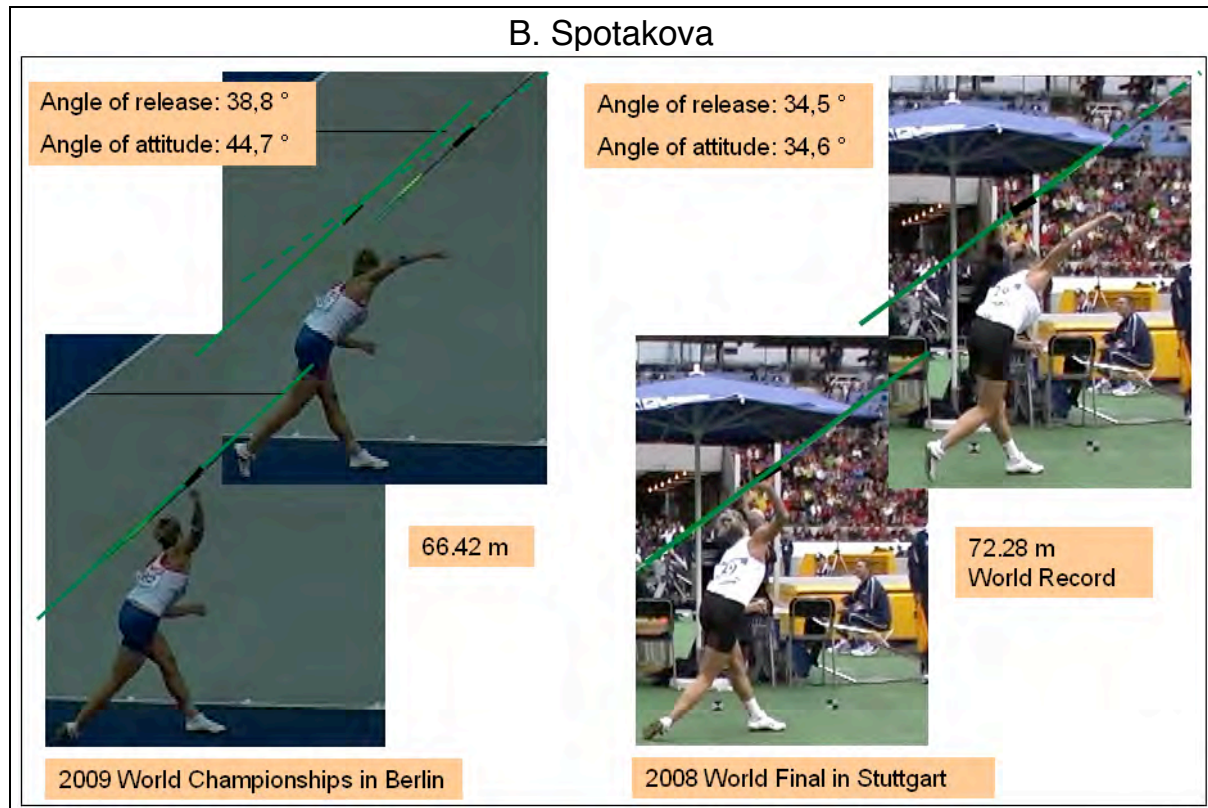
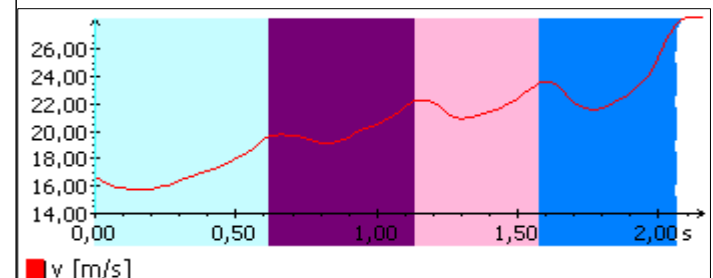
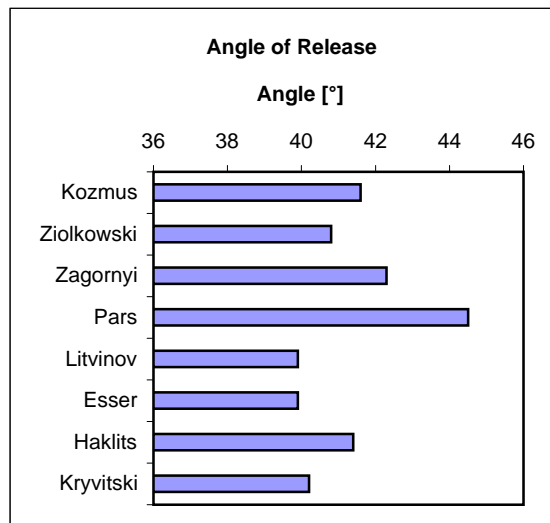
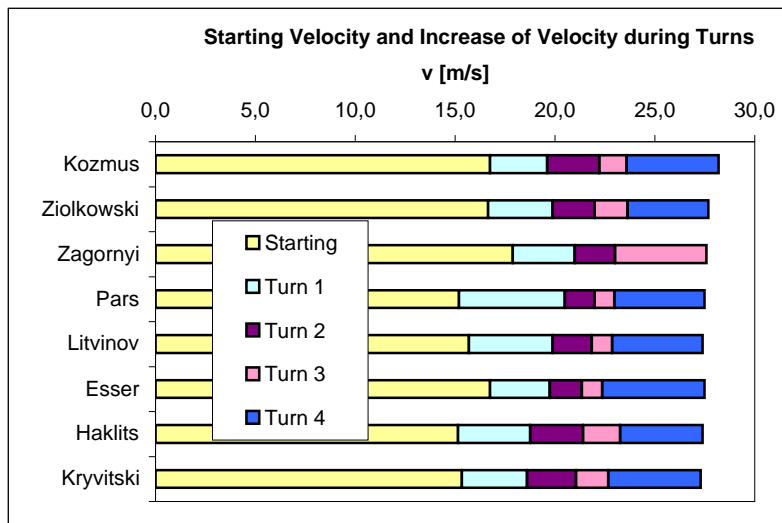


Figure 2. The angle of attitude and the angle of release at B. Spotakova

Biomechanical Analysis of the Hammer Throw Men Final 12th IAAF World Championships in Athletics - Berlin - 15 August to 23 August 2009

Name	Attempt	Distance [m]	Starting Velocity [m/s]	Increase of Velocity				Velocity at Release [m/s]	Angle of Release [°]
				Turn 1 [m/s]	Turn 2 [m/s]	Turn 3 [m/s]	Turn 4 [m/s]		
Kozmus	6	80,84	16,8	2,9	2,6	1,4	4,6	28,2	41,6
Ziolkowski	5	78,09	16,7	3,2	2,1	1,7	4,1	27,7	40,8
Zagorny	6	78,09	17,9	3,1	2,0	4,6		27,6	42,3
Pars	4	77,45	15,2	5,3	1,5	1,0	4,5	27,5	44,5
Litvinov	5	76,00	15,7	4,2	2,0	1,0	4,5	27,4	39,9
Esser	2	76,27	16,8	3,0	1,6	1,0	5,1	27,5	39,9
Haklits	6	76,26	15,1	3,6	2,7	1,9	4,1	27,4	41,4
Kryvitski	6	76,00	15,3	3,3	2,5	1,6	4,6	27,3	40,2

* Better throws could not be analysed since the hammer head or the feet of the thrower were hidden by photographers or officials

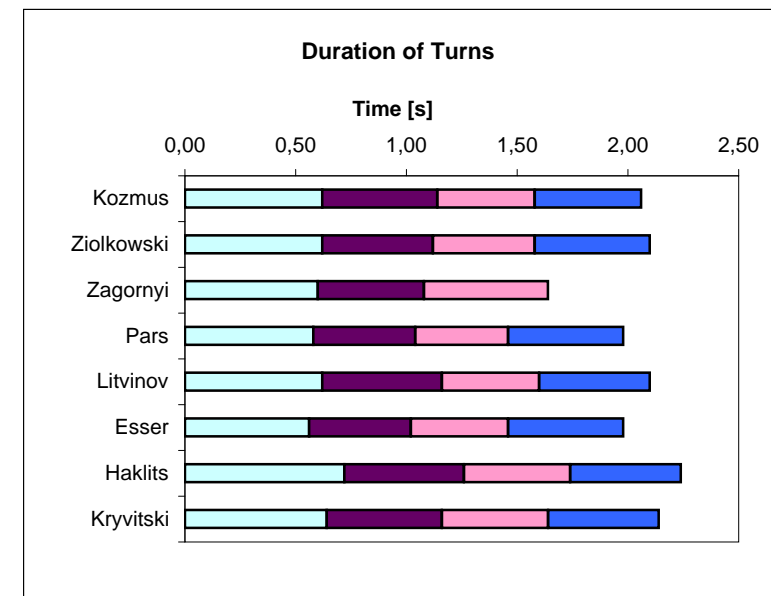
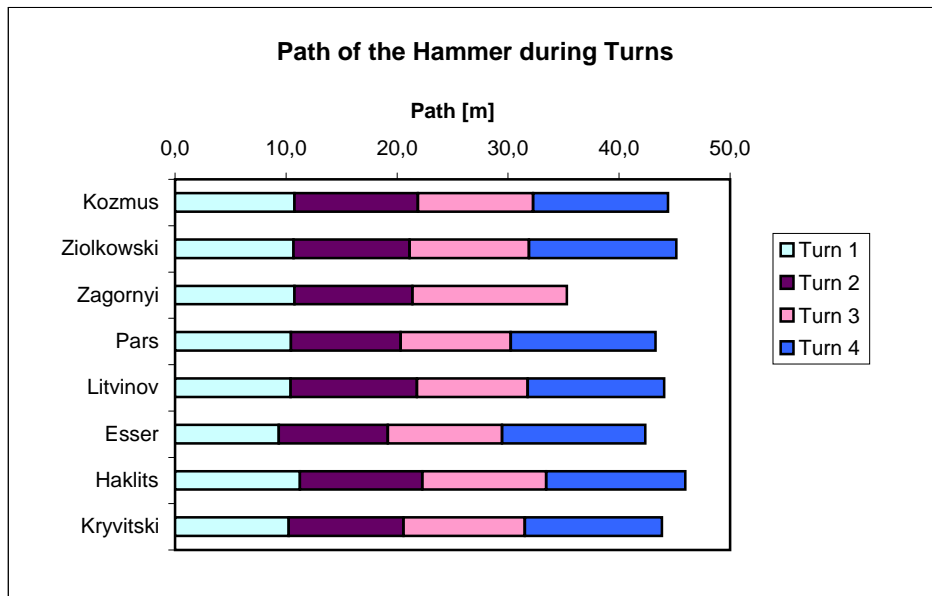


Velocity during turns, e.g. Kozmus

Biomechanical Analysis of the Hammer Throw Men Final 12th IAAF World Championships in Athletics - Berlin - 15 August to 23 August 2009

Path of the Hammer during Turns					
Name	Turn 1	Turn 2	Turn 3	Turn 4	Total
	[m]	[m]	[m]	[m]	[m]
Kozmus	10,8	11,1	10,4	12,2	44,4
Ziolkowski	10,7	10,5	10,7	13,3	45,2
Zagorny	10,8	10,7	13,9		35,3
Pars	10,5	9,9	9,9	13,1	43,3
Litvinov	10,4	11,4	10,0	12,3	44,1
Esser	9,3	9,9	10,3	12,9	42,4
Haklits	11,3	11,0	11,2	12,5	46,0
Kryvitski	10,2	10,4	10,9	12,4	43,9

Duration of Turns					
Name	Turn 1	Turn 2	Turn 3	Turn 4	Total
	[s]	[s]	[s]	[s]	[s]
Kozmus	0,62	0,52	0,44	0,48	2,06
Ziolkowski	0,62	0,50	0,46	0,52	2,10
Zagorny	0,60	0,48	0,56		1,64
Pars	0,58	0,46	0,42	0,52	1,98
Litvinov	0,62	0,54	0,44	0,50	2,10
Esser	0,56	0,46	0,44	0,52	1,98
Haklits	0,72	0,54	0,48	0,50	2,24
Kryvitski	0,64	0,52	0,48	0,50	2,14

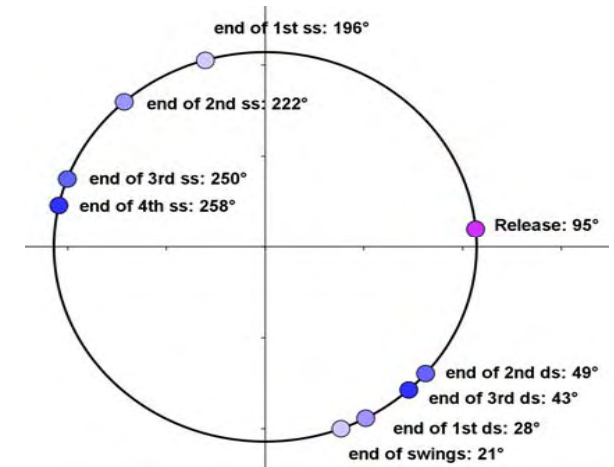


Biomechanical Analysis of the Hammer Throw Men Final 12th IAAF World Championships in Athletics - Berlin - 15 August to 23 August 2009

Parameters of body angles: e.g. Kozmus, 6th attempt, 80,84 m

Azimuthal angle								
End of swings	end 1st ss	end 1 ds	end 2nd ss	end 2nd ds	end 3rd ss	end 3rd ds	end 4ss	release
[Degrees]								
21	196	28	222	49	250	43	258	95

ss: single support
ds: double support

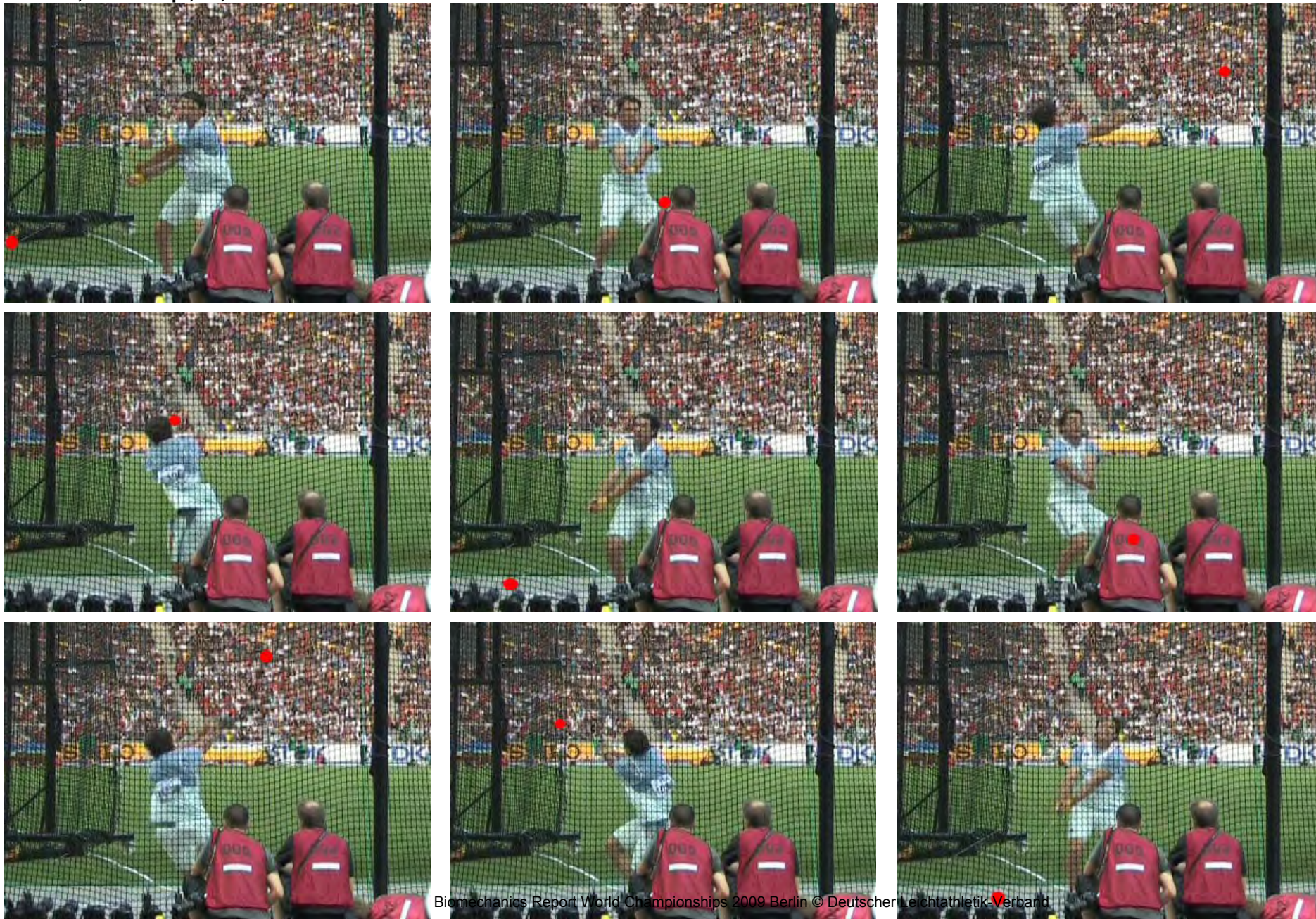


Angle of Twisting (between shoulder and hip axis)								
End of swings	end 1st ss	end 1 ds	end 2nd ss	end 2nd ds	end 3rd ss	end 3rd ds	end 4ss	release
[Degrees]								
21	28	25	73	22	88	9	29	17

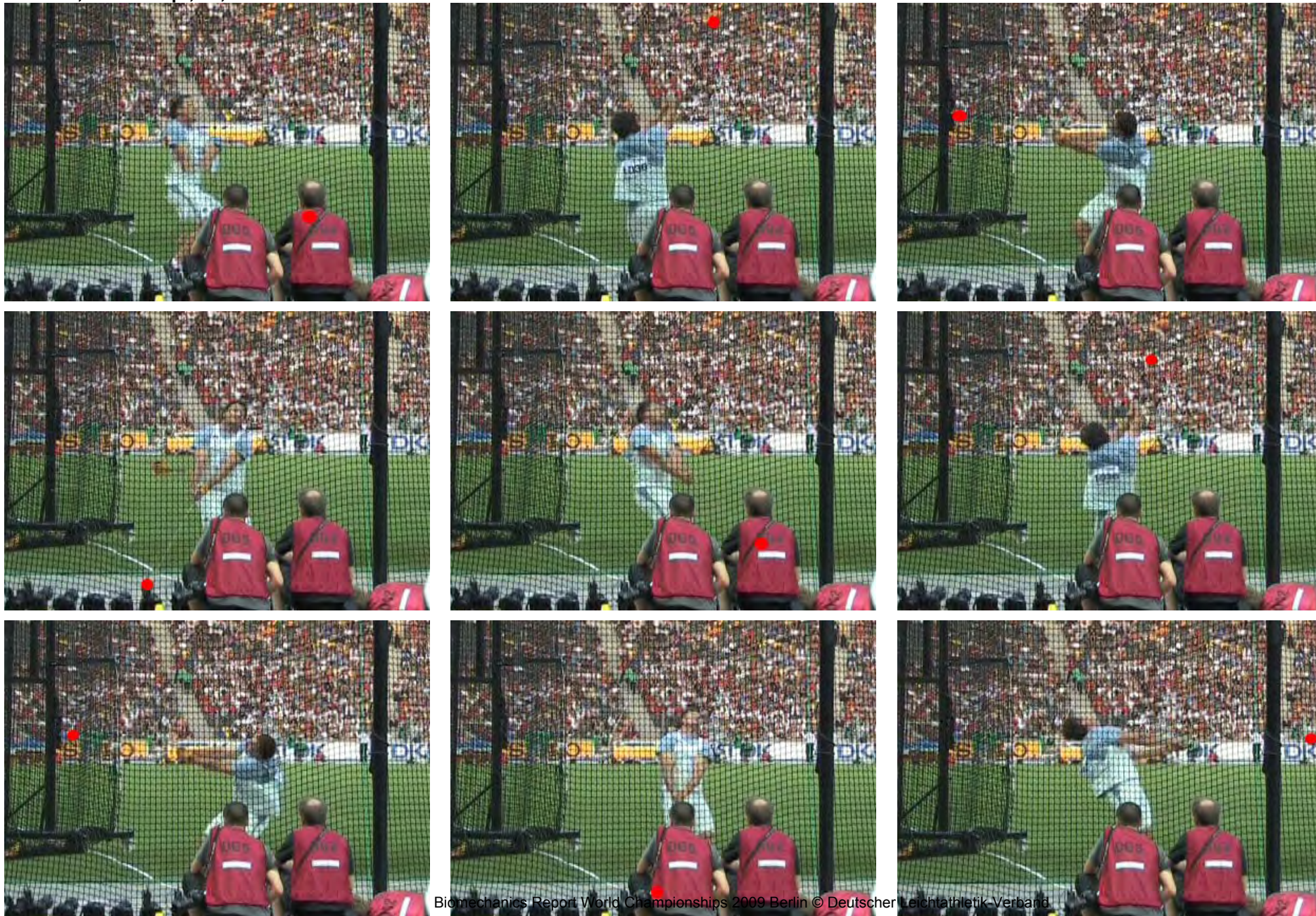
Angle between shoulder axis and hammer wire								
End of swings	end 1st ss	end 1 ds	end 2nd ss	end 2nd ds	end 3rd ss	end 3rd ds	end 4ss	release
[Degrees]								
88	113	94	103	96	86	100	126	91

This angle amounts to 90° when the hammer is directly in front of the body.
When trailing the hammer this angle increases, a "running ahead" of the hammer results in value under 90°.

Kozmus, 6th attempt, 80,84 m



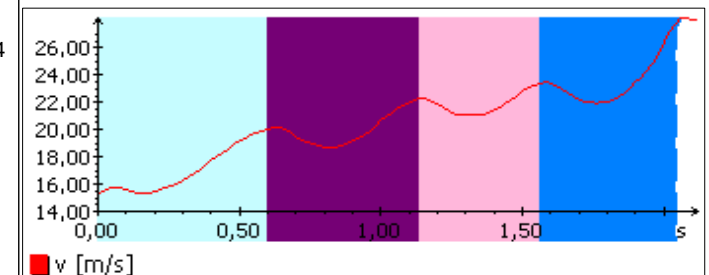
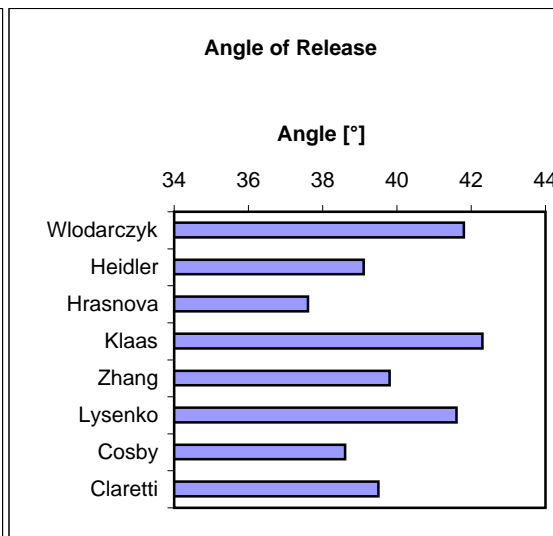
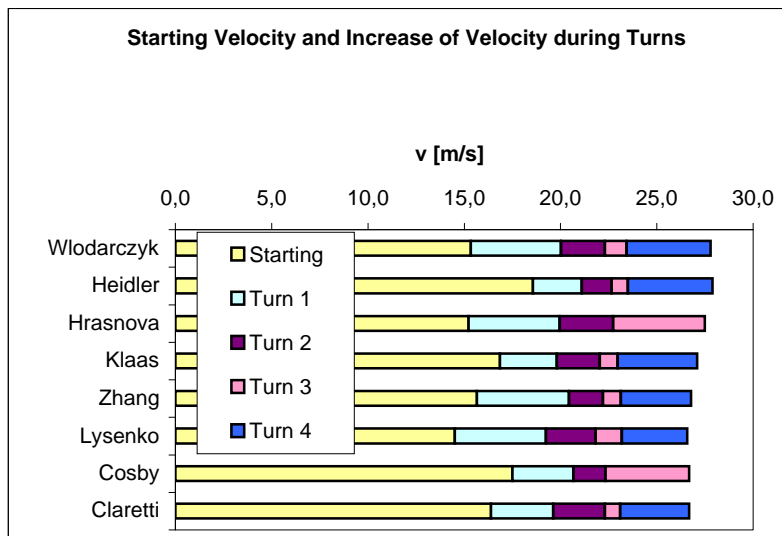
Kozmus, 6th attempt, 80,84 m



Biomechanical Analysis of the Hammer Throw Women Final 12th IAAF World Championships in Athletics - Berlin - 15 August to 23 August 2009

Name	Attempt	Distance [m]	Starting Velocity [m/s]	Increase of Velocity				Velocity at Release [m/s]	Angle of Release [°]
				Turn 1 [m/s]	Turn 2 [m/s]	Turn 3 [m/s]	Turn 4 [m/s]		
Wlodarczyk	2	77,96	15,3	4,7	2,3	1,1	4,4	27,8	41,8
Heidler	6	77,12	18,6	2,5	1,6	0,9	4,4	27,9	39,1
Hrasnova	5	74,79	15,2	4,7	2,8	4,8		27,5	37,6
Klaas	3	74,23	16,9	3,0	2,2	0,9	4,1	27,1	42,3
Zhang	4	71,80	15,7	4,8	1,8	0,9	3,7	26,8	39,8
Lysenko	3	71,36	14,5	4,7	2,6	1,4	3,4	26,6	41,6
Cosby	6	71,35	17,5	3,2	1,7	4,4		26,7	38,6
Claretti	1	71,56	16,4	3,3	2,7	0,8	3,6	26,7	39,5

* Better throws could not be analysed since the hammer head or the feet of the thrower were hidden by photographers or officials



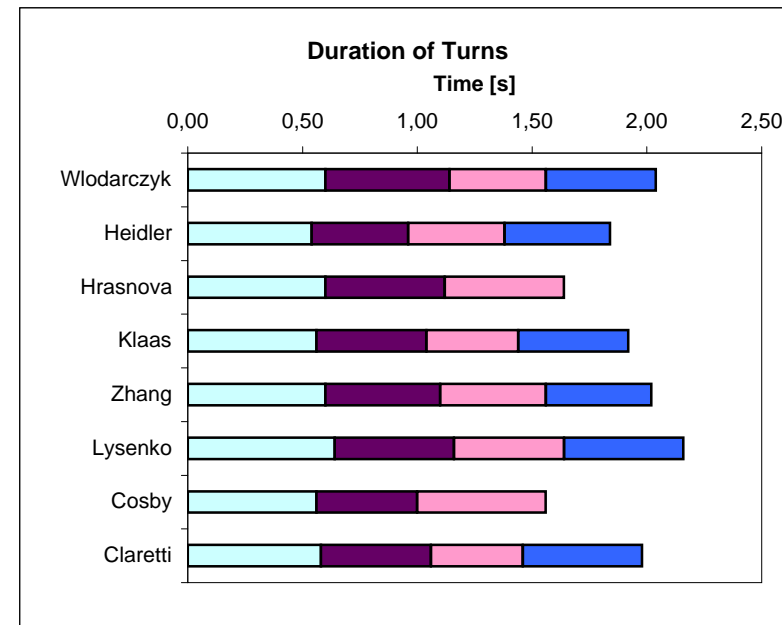
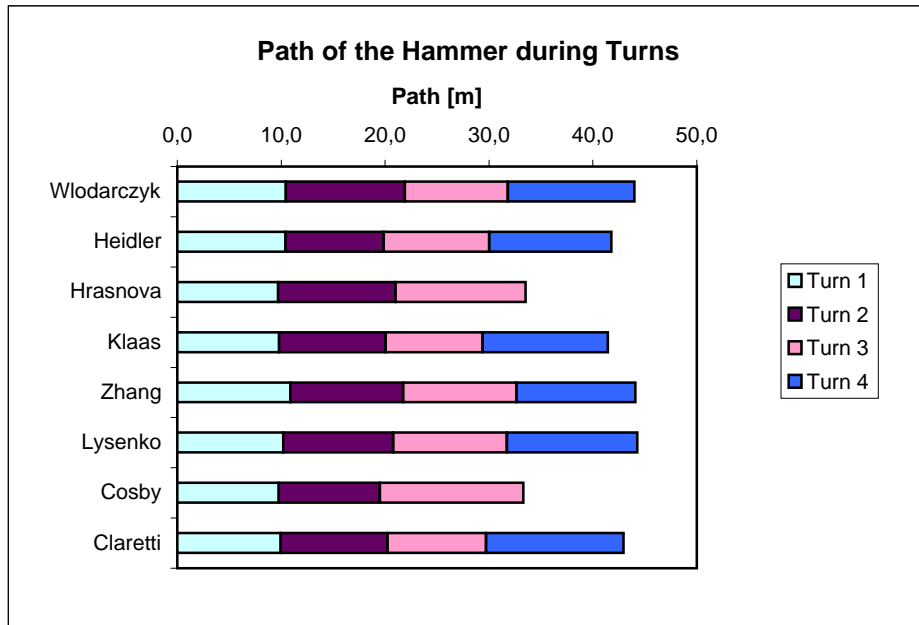
Velocity during turns, e.g. Wlodarczyk

Biomechanical Analysis of the Hammer Throw Women Final

12th IAAF World Championships in Athletics - Berlin - 15 August to 23 August 2009

Path of the Hammer during Turns					
Name	Turn 1	Turn 2	Turn 3	Turn 4	Total
	[m]	[m]	[m]	[m]	[m]
Wlodarczyk	10,5	11,5	9,9	12,2	44,0
Heidler	10,4	9,5	10,2	11,8	41,8
Hrasnova	9,7	11,3	12,6		33,6
Klaas	9,8	10,3	9,3	12,1	41,5
Zhang	10,9	10,9	10,9	11,5	44,1
Lysenko	10,2	10,6	10,9	12,6	44,3
Cosby	9,8	9,7	13,8		33,3
Claretti	10,0	10,3	9,5	13,3	43,0

Duration of Turns					
Name	Turn 1	Turn 2	Turn 3	Turn 4	Total
	[s]	[s]	[s]	[s]	[s]
Wlodarczyk	0,60	0,54	0,42	0,48	2,04
Heidler	0,54	0,42	0,42	0,46	1,84
Hrasnova	0,60	0,52	0,52		1,64
Klaas	0,56	0,48	0,40	0,48	1,92
Zhang	0,60	0,50	0,46	0,46	2,02
Lysenko	0,64	0,52	0,48	0,52	2,16
Cosby	0,56	0,44	0,56		1,56
Claretti	0,58	0,48	0,40	0,52	1,98



12th IAAF World Championships in Athletics - Berlin - 15 August to 23 August 2009

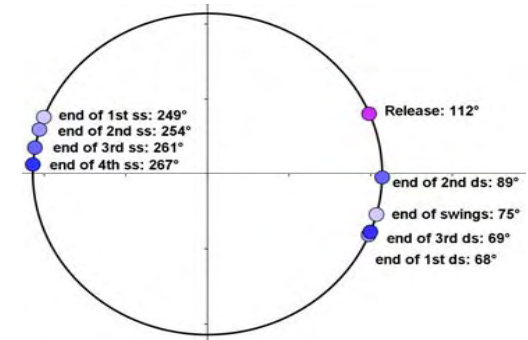
Parameters of body angles: e.g. Wlodarczyk, 2nd attempt, 77,96 m (WR)

y

Azimuthal angle								
End of swings	end 1st ss	end 1 ds	end 2nd ss	end 2nd ds	end 3rd ss	end 3rd ds	end 4ss	release
[Degrees]								
75	249	68	254	89	261	69	268	112

ss: single support

ds: double support



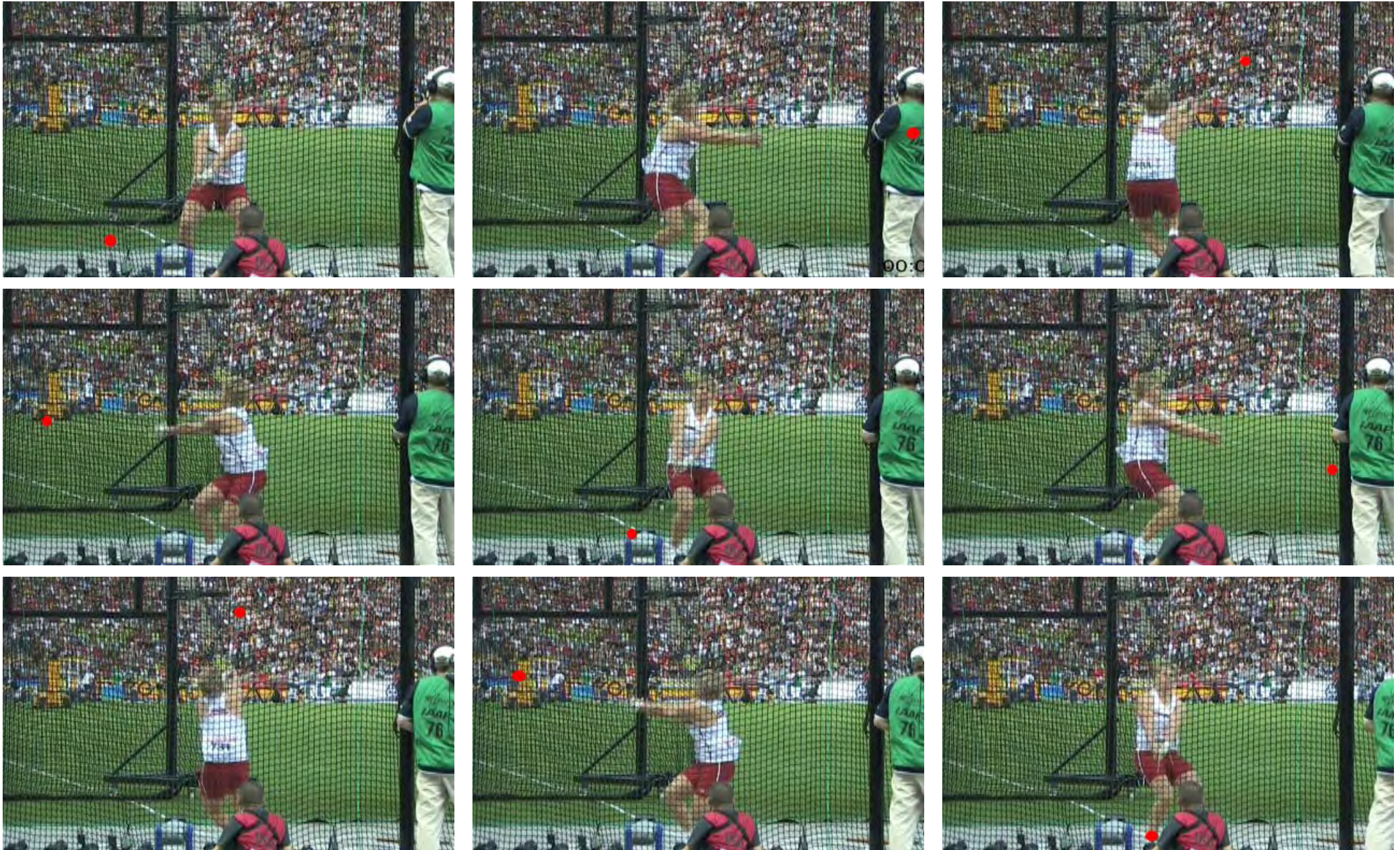
Angle of Twisting (between shoulder and hip axis)								
End of swings	end 1st ss	end 1 ds	end 2nd ss	end 2nd ds	end 3rd ss	end 3rd ds	end 4ss	release
[Degrees]								
27	51	5	17	49	29	17	36	12

Angle between shoulder axis and hammer wire								
End of swings	end 1st ss	end 1 ds	end 2nd ss	end 2nd ds	end 3rd ss	end 3rd ds	end 4ss	release
[Degrees]								
71	94	104	120	82	123	97	110	79

This angle amounts to 90° when the hammer is directly in front of the body.

When trailing the hammer this angle increases, a "running ahead" of the hammer results in value under 90°.

Wlodarczyk, 2nd attempt, 77,96 m (WR)



Wlodarczyk, 2nd attempt, 77,96 m (WR)

