THE TECHNIQUE OF THE BEST FEMALE JAVELIN THROWERS IN 1997

A “snapshot” on the basis of biomechanical investigations conducted at the ISTAF Grand Prix 1 meeting in Berlin in 1997

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(Translated from the original German by Jurgen Schiffer.)

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Abstract

The biomechanical parameters of female world-class javelin throwers who competed at the ISTAF meeting in Berlin 1997 were examined. The following top javelin throwers could be evaluated biomechanically and could be compared in terms of their movement parameters: Damaske (GER); Tilea (RUM); Hattestad (NOR); Rantanen (FIN); Nerius (GER); Ingberg (FIN); Shikolenko (RUS); Renk (GER); Forkel (GER). On the basis of a statistical analysis of data taken from an individual data bank and the results of the aforementioned women javelin throwers conclusions are drawn regarding generalizable factors of an effective javelin technique. The release parameters dealt with include: the angle of release, angle of attitude, angle of tilt, height of release as a percentage of body height, angle of arm bend, hip angle; knee angle; trunk and shoulder position during the delivery, trunk bend, turning away of the shoulder. As for as run-up and release preparation are concerned, the focus is on the approach velocity and the length of the last three strides. Additional parameters measured are: acceleration path, hold-back path, lean back angle, extension angle during the push-off of the cross-over stride, take-off angle of the CM.

1 Introduction

At the occasion of the ISTAF meeting in Berlin 1997, which was also the Golden-Four-Final, a study was made of the biomechanical parameters of the women’s javelin throw which are relevant to performance.

The ISTAF meeting took place immediately after the World Championships on August 26, 1997. The weather was good.

World-class athletes competed at this attractive athletics meeting. All the top athletes, with the exception of Mendez and Bizet (Cuba) and the silver medalist at the World Championships in Athletics 1997 Athens, Stone, who had already returned to Australia, could be evaluated biomechanically and compared in terms of their movement parameters. As the criteria of an optimal movement technique are also dependent on the athlete's current athletic form and on additional factors of influence, the results must be regarded as merely a “snapshot”. However, this does not reduce the significance of the findings regarding different varieties of individual movement techniques.

In fact, because of the high competitive age of the athletes, their international athletic maturity and the short space of time between the most important competition of the year and the ISTAF meeting, a considerable number of different movement techniques could be observed. It may be assumed, therefore, that some of the findings can be generalized, that they can be used by coaches for the refinement of their methodical approach and can also contribute to the perfecting of the model technique of the event. Our analysis can also provide the incentive to continue with goal-oriented work in the area of training methods and will indicate the state of performance achieved by the athletes.

In the long term we plan to make a contribution to the further development of the biomechanical model technique.

The 35 tests currently used for the analysis of the movement structure of the javelin throw are still inadequate. Nevertheless, we were able to verify our hypotheses in many technical elements of the movement processes by finding significant relationships. The results and extensive definition of parameters were published in BOTTCHER/KUHL (1996). For reasons of clarity they will not be dealt with in this article.

Thus the following explanations will show the top athletes' state of performance and will be a starting point for the further development of the event, including the prevention of injury and the development of young athletes.

We would also like to use this opportunity to thank the meeting management for their support.

2 Objective of the investigation

The goal of this investigation of the women's javelin throw is to compare the different movement techniques demonstrated by the world-best women javelin throwers. On the basis of a statistical analysis of data taken from an individual data bank, together with the results of the women javelin throwers participating in the ISTAF meeting, further conclusions can be drawn regarding generalizable factors of an effective javelin technique in the area of high—performance athletics.

In this context, the representation of the difference between defined elementary movement phases and the guideline parameters, as well as the observance of individual deviations of biomechanical parameters, are of great interest for possible conclusions about the performance potential in the individual movement phases.

3 Methods and test execution

Two fixed cameras were placed at a distance of approx. 30m from the release, and were aligned approximately 110° apart. The filming distances could be bridged easily by zoom lenses. To avoid 3D calculation errors, the cameras were installed at an angle greater than 30° and smaller than 150°.

Standard S-VHS video cameras were used for continuous filming, to avoid disturbances by switching the cameras on and off.

The locations of the cameras were chosen in such a way that as few as possible body points were hidden when digitizing the athletes and that there was a large section of the picture. A calibration cuboid with an edge length of 2m was used, and the synchronization of the camera sequences was be resolved by the allocation of event pictures. Depending on the light conditions, a shutter frequency as high as possible, not below 1/125 second, was used.

Measuring was accomplished as follows:

- Test method:
    - 3D Kinemetry.
- Filming:
    - 2 fixed cameras at an angle of about 110° towards one another; filming was carried out without zoom or panning.
- Camera distance:
    - About 30 m.
- Camera:
    - S-VHS — full format, 50 Hz, PAL
- Shutter frequency:
    - 1/500 second.

- Standard:
  - Cuboid with an edge length of 2m.
- Method of evaluation:
  - APAS video picture analysis system, interpolated to 100 Hz.
- Synchronisation:
  - Using event pictures.

3.1 Advantages and limits of the video picture analysis

To guarantee a sufficiently accurate and complex analysis and assessment of the movement technique, a considerable amount of technology and staff was necessary.

The reasons for this are the variety of demands in the area of training methods and the associated necessity to carry out 3D investigations. Frequently the movement technique is so complex that a 2D analysis could produce faulty information. In the case of spatial movements, a 2D standard determination is difficult and, because of parallactic distortions, neither angle nor velocity parameters can be measured exactly. It is not so important what video picture method is used. However, a video recorder with suppressed frame reproduction should be available, i.e. 50 (half) pictures per second with PAL (60 with NTSC). For a true reproduction of the characteristic parameter lines, it is important to have a graphically visible smoothing and to be able to correct the spatial co-ordinates.

We know that the precision of the video picture systems is sufficient for making statements about the correction of the movement technique. Our experiences of more than 600 3D analyses in 10 athletic events indicate that the inaccuracy of the system is not so problematic as the following factors: camera locations, quality of the video shots, digitizing of covered body points and spatial vision during digitizing. Evaluations which were repeated could be well reproduced with all parameters, as, for example, with heights of the centre of mass, stride lengths and approach velocities. The frame repetition rate of video systems is inadequate for the exact measurement of the approach velocities or the ground contact times.

4 Data of the athletes

The athletes are presented in Table 1.

Table 1: The trials evaluated at the ISTAF and the athletes' performances

Name	Nation	Performance at the W.Ch. in Athens 1997	Performance at the ISTAF in Berlin	Evaluated trial	Best international result
Damaske	GER	Bronze	66.58m	66.58m	W.Ch. Athens 1997 bronze
Tilea	RUM	5th place	65.46m	65.46m	W.Ch. Göteborg 1995 silver
Hattestad	NOR	Gold	64.98m	64.20m*	World Champion 1993 and 1997
Rantanen	FIN	Heats	64.64m	64.64m	Olympic champion 1996
Nerius	GER	No	64.20m	64.20m	World best female javelin thrower in 1996
Ingberg	FIN	4th place	63.70m	63.70m	W.Ch. Göteborg 1995 bronze
Shikolenko	RUS	8th place	62.70m	62.12m*	W.Ch. Stuttgart 1993 4th place
Renk	GER	Qualification	62.10m	62.10m	Olympic champion 1992
Forkel	GER	Qualification	60.32m	60.14m*	W.Ch. Stuttgart 1993 silver

* The best trial of these athletes could not be evaluated, as filming was not possible because of camera obstruction problems. In these cases, the second best trial was used. However, since there were only relatively slight differences between the best and the second best result, we hope that the significance of the statements about the individual movement technique is not reduced.

5 Results of the standard parameters during the release

The angles of release, attitude and tilt are given in Table 2.

Table 2: Angle of release, angle of attitude and angle of tilt

Parameter	Dim.	Dam	Til	Ran	Ner	Hat	Ing	Shi	Ren	For	Standard value >70m
Distances evaluated	m	66.58	65.46	64.64	64.2	64.2	63.7	62.12	62.1	60.14	
Angle of release	Degrees	38	44	31	31	31	39	38	36	38	W 36
Angle of attitude	Degrees	38	36	34	43	36	41	36	31	50	W 36
Angle of tilt	Degrees	18	23	13	13	9	9	12	12	23	T < 3

Key: Dim. = Dimension; Dam = Damaske; Til = Tilea; Ran = Rantanen; Ner = Nerius; Hat = Hattestad; Ing =Ingberg; Shi = Shikolenko; Ren = Renk; For = Forkel
T Trend value for distances longer than 70m as a result of our data bank analysis.
W The standard value is valid only in the case of no wind at all.

5.1 Angle of release (the ballistic angle was calculated from the velocity vectors Vy and Vx)

The ballistic angle of release of the point of the grip should be 36° and should be identical with the angle of attitude.

The angles were identical only with Damaske, but were 2° above the optimum. Shikolenko's angle of attitude of 36° and angle of release of 38° can be regarded as comparable.

Tilea and Hattestad both had 36° angles of release but only achieved angles of attitude of 44° and 31° respectively.

The deviations of the angles of attitude and the angles of release from the target value of 36° are unexpectedly high. Great differences between the angle of attitude and the angle of release prevent an optimal energy transfer and cause the javelin to vibrate, so that there is an increase in air resistance and a worsening of the flow of air past the javelin during the flight phase.

5.2 Angle of attitude (2D angle between the axis of the javelin and the horizontal plane of the runway)

The angles of attitude at the moment of release for all athletes are shown in Figure 1.

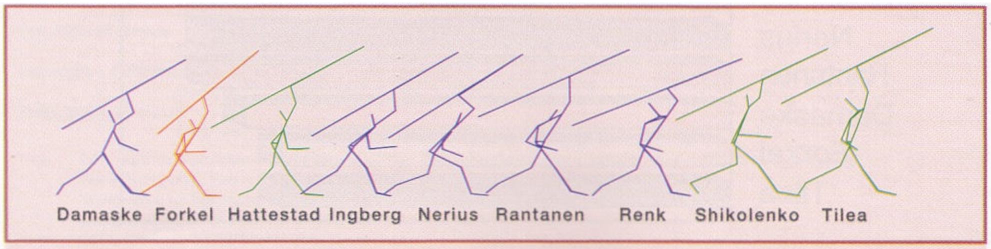

Figure 1: Angle of attitude at the moment of release

During the run-up the athletes demonstrated many variations of javelin carry, from a flat carry to a carry with the javelin pointing steeply upwards. Shikolenko started with an extremely flat carry of the javelin and had a good throw. She increased the angle of attitude on the last three strides from 8° to 36° at the delivery and to 37° at the release. Tilea had a similar throw. She started with a 26° angle, increased it to 33°, and to 36° at the time of the release. However, in both athletes the angle of attitude did not correspond with the angle of release.

Both Damaske and Nerius started with an angle of attitude of 41°. Damaske finally reached an acceptable angle of attitude of 38°, while Nerius increased the angle of attitude to 43°. Forkel demonstrated a medium angle of 29° at the moment her left foot left the ground and increased this angle very markedly to 50°. Mattestad also started with a medium angle of attitude of 26° and eventually reached an ideal value of 36°.

In general, there is no verifiable correlation between the angle of attitude when carrying the javelin during the run-up and the angle of attitude at the moment of release.

5.3 Angle of tilt (as measured from viewing the javelin from above in the throwing direction — the throwing direction is defined as a line in the running direction)

Figure 2 shows a comparison of the percentage deviation of the angle of tilt. The angle of tilt has an important function in the preparation of the delivery and in connection with the maximization of the path of acceleration. In the power position the angle of tilt can be about 30° and should be reduced to 0° by the time of the release. The angle of tilt correlates significantly with the throwing distance. For a target distance of 70m an individually calculated regression produced an angle < 3°. The technical problem is how to achieve zero degrees without creating a moment of force. Ideally the angle of release should be 36°, with an angle of tilt of 0° and also no difference between the angle of attitude and the angle of release. No athlete achieved the target value of <3°. In fact an angle of as much as 23° was measured, and only two athletes registered 9°.

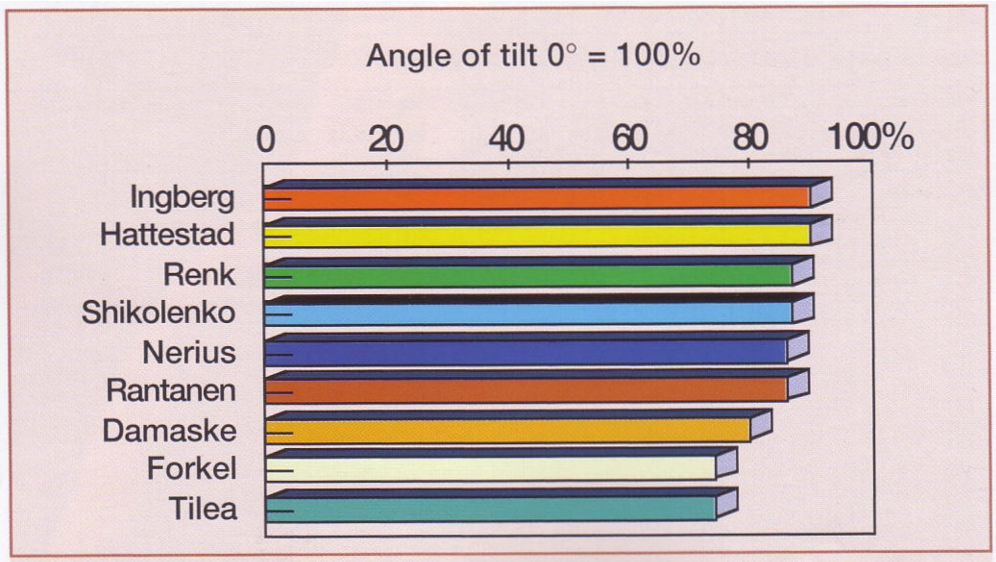

Figure 2: Comparison of the percentage deviation of the angle of tilt

Theoretically it is favorable to throw with a zero angle of tilt. However, as we could not measure this ideal state, it is possible that there are other factors counteracting a zero degree solution.

On the other hand, to aim in training to achieve this exact value, at the moment when the throwing arm is turned outwards shortly before the release, seems to be of great significance for the maximization of the paths of velocity during the delivery phase.

5.4 Height of release as a percentage of body height (highest point of the grip hand at the moment of release)

Table 3 contains the percentage release heights. The height of release has little effect on the distance of the javelin throw. However, it is a sign of a favorable body posture. Taking into consideration an optimal angle of release of 36°, the trunk posture and the correct hip and knee extension, a local curve height of the throwing hand of approx. 105% of the body height was measured. This is confirmed by the measuring values, which show that Hattestad bent too far to the side and that Nerius reached a knee angle of only 147° at the release.

Table 3: Percentage release heights

Parameter	Dim.	Dam	Til	Ran	Ner	Hat	Ing	Shi	Ren	For	Standard value >70m
Height of release	% of body height	105	108	102	97	98	102	101	102	105	approx. 105
Angle of arm bend	Degrees	73	78	96	60	97	76	88	82	92	T 90

Key: Dim. = Dimension; Dam = Damaske; Til = Tilea; Ran = Rantanen; Ner = Nerius; Hat = Hattestad; Ing =Ingberg; Shi = Shikolenko; Ren = Renk; For = Forkel

approx. The test value can deviate in the complex movement.

T Trend value for distances longer than 70m as a result of our data bank analysis.

5.5 Angle of arm bend (smallest 3D elbow angle at the lower arm whip)

An angle of arm bend which is significantly smaller than 90° reduces the effectiveness of the acceleration of the javelin. In the case of angles greater than 90° the relationship is not known, as such angles were extremely rare.

Rantanen and Hattestad exhibited a somewhat too great angle of arm bend (96°, 97°), and both of them also showed by far the least pronounced lean back. We do not have an explanation for this; perhaps the relationship is an accidental one. With the exception of Forkel and Shikolenko, the other athletes had a rather too small angle of arm bend.

5.6 Hip angle (measured during the right and left foot strike in the course of the delivery and the differences produced by possible yielding or extension movements; (—) means yielding).

Knee and hip angles during the delivery phase are given in Table 4.

Table 4: Knee and hip angle during the delivery phase

Parameter	Dim.	Dam	Til	Ran	Ner	Hat	Ing	Shi	Ren	For	Standard value >70m
Hip angle at left foot strike											
	Degrees	114	141	118	134	131	134	128	131	127	T 113
Hip angle – Difference 1											
	Degrees	0	-12	-11	-28	-15	-31	-15	-9	-11	T min. 0
Hip angle at release											
	Degrees	140	120	116	90	102	96	119	127	120	>120
Hip angle – Difference 2											
	Degrees	26	-9	9	-16	-14	-7	6	5	4	>5
Knee angle at release											
	Degrees	175	173	170	147	179	177	176	178	175	180

Key: Dim. = Dimension; Dam = Damaske; Til = Tilea; Ran = Rantanen; Ner = Nerius; Hat = Hattestad; Ing =Ingberg; Shi = Shikolenko; Ren = Renk; For = Forkel
T Trend value for distances longer than 70m as a result of our data bank analysis. Cross-over stride and for the antepenultimate stride 0.91 times cross-over stride
min At least zero because the hip should not yield.
>120 Greater than 120° for an active hip extension at release.

The leg and hip work are partly responsible for an optimal transfer of energy during the delivery. After the left foot plant the force is transmitted from bottom to top, i.e. to the javelin, by means of well timed extension movements.

Individual analyses showed that the hips should not be too extended at the plant of the left foot, in order to enable a subsequent active extension of the left hip with the support of the push-up leg.

We assume that an over-exaggerated hip extension at the time of the left foot plant can lead to a subsequent hip bend, which is demonstrated by Nerius in Figure 3. Without doubt, it is useful to extend the hip and knee during the delivery, but a hip already extended cannot be extended even more.

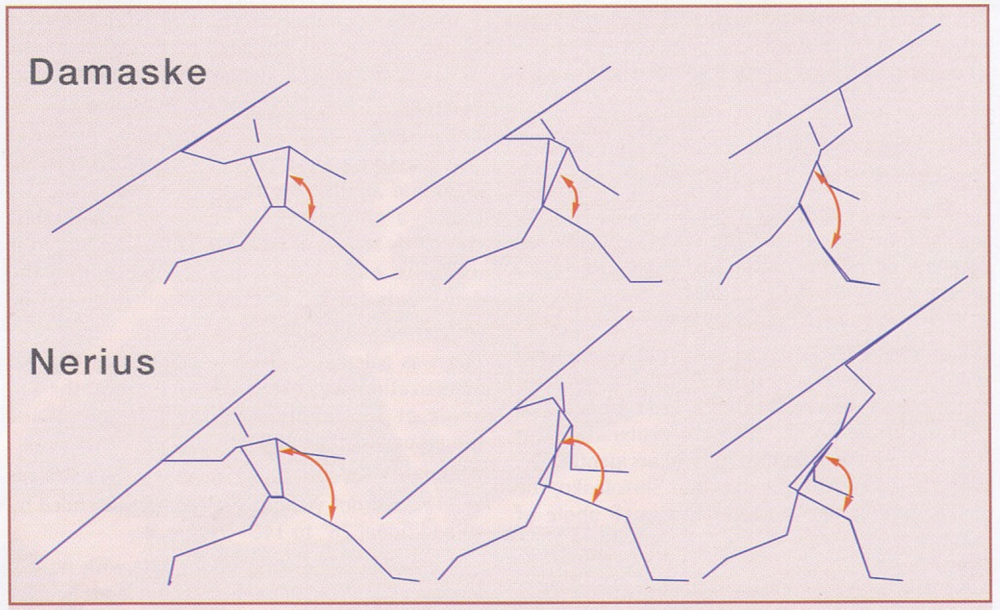

Figure 3: Hip angle during the delivery phase

It was calculated that, to achieve an optimal amortization and extension of the hip, the hip angle at the moment of the left foot plant should be less than 120°.

At the ISTAF meeting Damaske touched down at 114°, did not yield at the hip and extended by an additional 26° to 140° (Figure 3).

A continuous bending of the hip, with no extension even after the amortization, is particularly unfavorable. This occurred with Hattestad, Nerius, Ingberg and Tilea.

5.7 Knee angle, at the moment of the left foot plant during the delivery — amortization and extension of the hip

As is the case with the hip angle, there is an optimal value for the knee angle at the moment of the left foot strike. This value is around 160° and was achieved by every athlete except Shikolenko. Yielding at the knee joint would make an effective energy transfer difficult. Therefore the knee should be extended after a short amortization. Actually every athlete, except Damaske and Hattestad, yielded more or less at the knee joint — Nerius, Ingberg and Renk clearly too much.

This is a special problem for Nerius, as she increases her knee flexion by 28° and then increases her knee extension by only 15°. Thus she achieves a knee angle of only 147°, while all other athletes reach a knee angle of more than 170°.

5.8 Trunk and shoulder position during the delivery

Figure 4 shows the delivery phases from the frontal view, arranged according to the degree of lateral body lean. Trunk lean and shoulder torsion at release are given in Table 5.

Table 5: Trunk lean and shoulder torsion at release

Parameter	Dim.	Dam	Shi	Ren	For	Ner	Til	Ran	Ing	Hat	Standard value >70m
Bending of the trunk											
	Degrees	10	17	24	27	28	29	39	40	50	max 0
Turning away of the shoulder											
	Degrees	10	11	50	48	21	34	57	41	33	max 0

Key: Dim. = Dimension; Dam = Damaske; Til = Tilea; Ran = Rantanen; Ner = Nerius; Hat = Hattestad; Ing =Ingberg; Shi = Shikolenko; Ren = Renk; For = Forkel

max 0° Is the deviation from 90° of the measuring value - in the case of 0° at release the trunk would be ideally vertical and there would be no rotation of the shoulders.

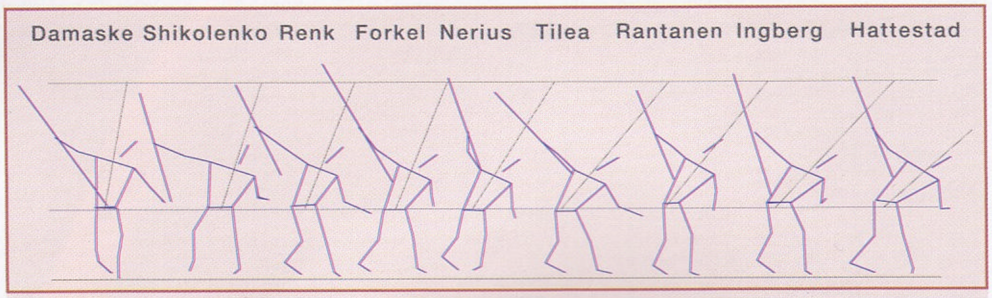

Figure 4: Delivery phases from the frontal view, arranged according to the degree of lateral body lean

5.8.1 Trunk bend (lateral lean to the horizontal plane of the central line through the trunk)

Diverging movements weaken the delivery of the javelin. Turning the shoulder away and bending the trunk lead to a reduction of the inertia masses necessary for the release. The bending of the trunk was defined as a deviation from the vertical with zero degrees bend denoting an upright body posture.

Damaske showed the least deviation, followed by Shikolenko. Hattestad, Ingberg and Rantanen deviated most markedly from the standard value.

5.8.2 Turning away of the shoulder (deviation of the shoulder from a position parallel with the line of release)

Like the lateral lean of the trunk, the turning away of the shoulder is an unfavorable deviation.

Damaske, Shikolenko and Nerius show the slightest deviation, with the shoulder turned away by only 10° to 21°. Rantanen, Forkel, Renk, Ingberg and Tile show too much deviation.

6 Run-up and release preparation

Figure 5 shows CM- (centre of mass) velocity of the last three strides and depiction of the movement phases and the connection between the loss of velocity during the last stride and the throwing distance.

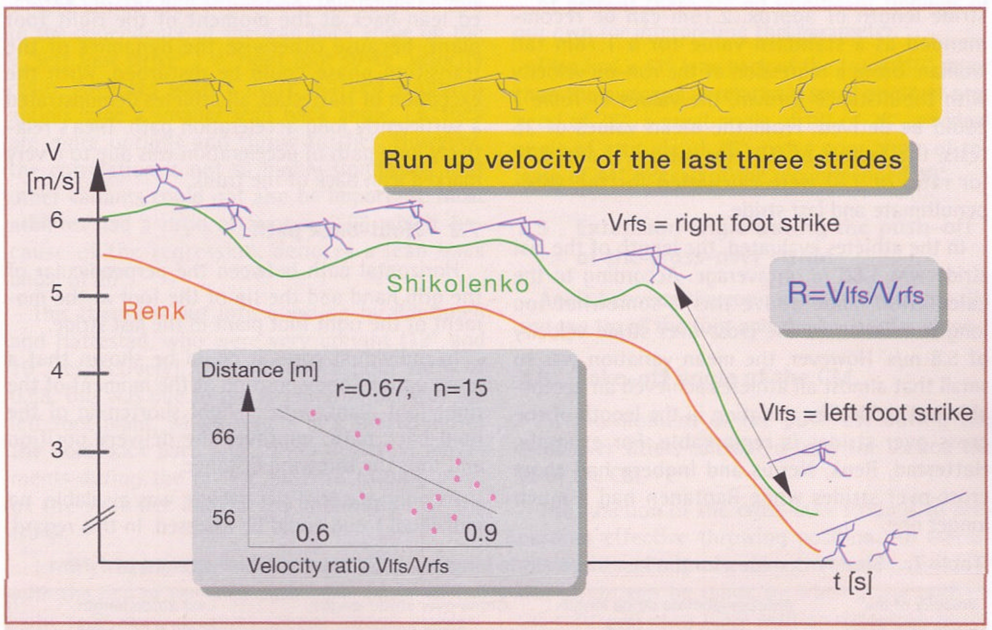

Figure 5: CM-velocity of the last three strides and depiction of the movement phases
Inner figure: Connection between the loss of velocity during the last stride and the throwing distance.
R = ratio, lfs = left foot strike, rfs = right foot strike, V = velocity

During the run-up the velocity of the CM varies, depending on the support and extension phases and because of technical faults. The characteristic lines of Shikolenko and Renk during the last three strides show differences in loss of velocity, height of velocity and braking movement (cf. Table 6).

Table 6: Run-up parameters

Parameter	Dim.	Dam	Til	Ran	Ner	Hat	Ing	Shi	Ren	For	Standard value >70m
Velocity of antepenultimate stride	m/s	6.1	6.9	6.7	6.5	6.9	6.4	6.1	5.7	6.6	No
Velocity of cross-over stride	m/s	6.7	5.4	5.7	6.1	5.9	5.6	5.6	5	5.9	T 7.0
Velocity of last stride	m/s	6.3	5.4	5.7	5.6	5.6	5.5	5.9	5.1	5.5	No
Length of antepenultimate stride	m	1.99	1.71	1.74	1.73	1.46	1.82	1.82	1.61	1.87	V 2.10
Length of cross-over stride	m	2.09	1.98	2.34	1.8	1.62	1.81	2.41	1.72	2.15	T 2.30
Length of last stride	m	1.68	1.61	1.65	1.74	1.52	1.76	1.46	1.49	1.51	V 1.77
Cross-over stride/bracing stride ratio	q	1.24	1.23	1.42	1.03	1.07	1.03	1.65	1.15	1.42	approx. 1.3
Left foot strike / right foot strike ratio	q	0.59	0.74	0.88	0.73	0.88	0.8	0.66	0.86	0.75	T 0.55

Key: Dim. = Dimension; Dam = Damaske; Til = Tilea; Ran = Rantanen; Ner = Nerius; Hat = Hattestad; Ing =Ingberg; Shi = Shikolenko; Ren = Renk; For = Forkel
approx. The test value can deviate in the complex movement.
T Trend value for distances longer than 70m as a result of our data bank analysis.
V Is the ratio of the trend value. For the bracing stride 0.77 times cross-over stride and for the antepenultimate stride 0.91 times cross-over stride.

6.1 Approach velocity (of the CM in the direction of movement)

Previous investigations have shown a direct relationship between the CM velocity of the cross-over stride and the throwing distance so that the velocity of the cross-over stride was defined as run-up velocity. A too high run-up velocity is conceivable, although it could hardly be verified in this case. As far as the standard value is concerned, the athletes tend to register too slow rather than too high velocities. For an optimal preparation for the delivery, the run-up velocity should be increased up to the antepenultimate stride and then be maintained for two strides. In the last stride an active braking should be the aim, in order transmit the energy of the run-up to the javelin and to come to a secure power position. However, most of the athletes continuously reduced the velocity of the CM during the last three strides.

The braking at the moment of the left foot plant provides a useful transmission of energy to the javelin. In this context the ratio of the CM velocities is significant (V_{CM} left toot plant divided by V_{CM} right foot plant), because a low velocity ratio of approx. 0.55 is an Indication of optimal braking forces.

6.2 Length of the last three strides

In order to prepare a spatially and temporally coordinated power position, a short-long-short stride combination is to be recommended. Calculations have shown that, with a cross-over stride velocity of, for example, 6.5m/s, a cross-over stride length of approx. 2.15m can be recommended as a standard value for a 1.78m tall woman. Using a regression of the run-up velocity with the distance thrown, the values in Table 7 could be derived. From the mean values of 35 tests, the factors of 0.91 (or ratio 1.1) and 0.77 (or ratio of 1.3) were calculated for the antepenultimate and last stride.

Table 7: Standard values for the last three stride lengths in the case of a body height of 1.78m

Velocity of the cross-over stride	Antepenultimate stride length factor 0.91 * COS	Cross-over stride length (COS) factor 1	Last stride length factor 0.77 * COS
7.0m/s	2.09m	2.30m	1.77m
6.5m/s	1.95m	2.15m	1.65m
6.0m/s	1.82m	2.00m	1.54m

In the athletes evaluated, the length of the last stride was 1.60m on average. According to the calculation made above this is somewhat too long in relation to the cross-over stride velocity of 5.8 m/s. However, the mean variation was so small that almost all athletes achieved an acceptable last stride. The variation in the length of the cross-over strides is remarkable. For example, Hattestad, Renk, Nerius and Ingberg had short cross-over strides while Rantanen had a much longer one.

7 Additional parameters

Table 8 contains the parameters of the preparation and delivery phase.

7.1 Acceleration path

Resultant path of the grip hand in space, measured between the moments of right foot strike and V_0 of the javelin.

Table 8: Parameters of the preparation and delivery phase

Parameter	Dim.	Dam	Til	Ran	Ner	Hat	Ing	Shi	Ren	For	Standard value >70m
Extension angle of cross-over stride	Degrees	64	85	79	84	87	77	77	77	81	approx. 85
Take-off angle of CM during cross-over stride	Degrees	13	10	16	11	13	10	16	16	12	ca. 8
Acceleration path	m	3.16	3.16	2.97	3.42	2.53	3.38	3.31	3.25	3.09	ca. 3.0
Hold-back path	m	1.25	1.27	1.11	1.26	1.03	1.12	1.49	1.28	1.28	1.25 ?
Lean back angle	Degrees	23	41	26	37	27	22	25	16	34	approx. 30
Lean back angle of CM	Degrees	21	24	12	19	10	16	27	19	21	approx. 18
Transverse angle	Degrees	28	32	40	27	15	24	20	20	16	(24)

Key: Dim. = Dimension; Dam = Damaske; Til = Tilea; Ran = Rantanen; Ner = Nerius; Hat = Hattestad; Ing =Ingberg; Shi = Shikolenko; Ren = Renk; For = Forkel
? Test value of the winner as the relationship could not be cleared completely.
( ) Average value from 35 tests.
approx. The test value can deviate in the complex movement.

If possible, a prolongation of the acceleration path should be achieved by means of the arm and shoulder, rather than through an exaggerated lean back at the moment of the right foot plant, because otherwise the dynamics of the transition phase could be disturbed. With the exception of Hattestad, all athletes demonstrated a sufficiently long acceleration path. Tilea's relatively long path of acceleration was due to a very marked lean back of the trunk.

7.2 Hold-back path

Horizontal path between the perpendicular of the grip hand and the tip of the foot at the moment of the right foot plant in the last stride.

In individual cases it could be shown that a more upright body position at the moment of the right foot plant, with a slight shortening of the hold-back path, improves the delivery position and thus the throwing distance.

As only one trial per athlete was available, no individual trend could be assessed. In this regard, a value of 1.20m for a body height of 1.78m seems to be reasonable. Thus Shikolenko's hold-back path was too long, while Hattestad's was too short. The hold-back path is partly influenced by the velocity and stride length ratio.

7.3 Lean back angle

Inner angle of the line from the CM to the tip of the foot to the plane of the ground.

There is a significant, though negative, correlation between the individual lean back angle and the distance thrown. In other words, the longer distances were thrown when the athlete assumed a more upright power position. This could be due to the dependence of the lean back angle on the V "left foot strike" / V "right foot strike" velocity ratio. Athletes with a more marked stopping action have a smaller lean back angle, i.e. they are more upright and throw further. However, the correlation is not so highly significant that other variants could not also be important. Most athletes had a ratio of approx. 0.68 which, because of the regression, denotes a lean back angle of 20°.

This theory is put into question by Rantanen and Hattestad, who were very upright (12 and 10° respectively), but still had a poor ratio of 0.88. This was due to the too high velocity of the left foot plant, which results in a shortening of the hold-back path and strong deviating movements during the release, such as turning away of the shoulder and lateral inclination of the trunk.

In this regard, the method of touching down with the ball of the foot during the phase of the right foot plant deserves special attention. Here very high velocities seem to be achieved at the touch down of the bracing leg because of the active, inward rotation of the foot of the push-off leg. However, these velocities are more difficult to brake or to transfer into the throwing action, because of the necessarily more upright position (lean back angle) employed. Unfortunately only a few trials could be evaluated because too few world-class athletes favor the variation of touching down with the ball of the foot (e.g. Rantanen and Hattestad).

7.4 Lean back angle

2D angle of the right side of the body to the horizontal plane, measured at the moment of the right foot plant of the last stride.

At present there are no significant findings of our own for interpreting this parameter.

Tilea had a 41° lean back of the trunk (10° more than the average), a relatively small angle of arm bend of 78°, a great angle of tilt of 28°, an ideal angle of attitude of 36°, but a poor angle of release of 44° instead of the recommended 36°.

7.5 Extension angle during the push-off of the cross-over stride

Angle between the connection between the CM and the tip of the foot and the horizontal plane.

7.6 Take-off angle of the CM

At the moment of the push-off during the cross-over stride, calculated from the Vx and the Vz of the CM.

The function of the cross-over stride is to prepare an effective throwing position. An assessment of the flat push-off technique required for this stride can be made by tracing the path of the centre of mass (CM) with an extension angle. This distinction is necessary because static extension angles do not tell much about the further course of the CM trajectory. A high take-off angle of the CM can be produced in spite of an upright body posture. Taking into consideration both angles facilitates the determination of cause and effect, which will be of use in the future modification of training methods.

As tar as statistics are concerned, the two angles have no very high significance, although it is very interesting that their behavior is contradictory. In other words, the more upright the body position (>74°) and the flatter the trajectory of the CM ($\leq$9) during the cross-over stride, the longer the distance thrown.

The best value was achieved by Tilea; she was very upright (85° angle) and had a ballistic angle of the CM of 10°, and thus a sufficiently flat push-off. The flat push-off for the cross-over stride should take place from a more upright body position, with a consequent shortening of the cross-over flight time.

8 Summary of the results

Figure 6 shows the phase structure during the last two strides and a column diagram as a percentage deviation from 100% of the guideline table for distances longer than 70m. In the case of variations of the movement technique, greater deviations from the standard value can occur without being technical faults.

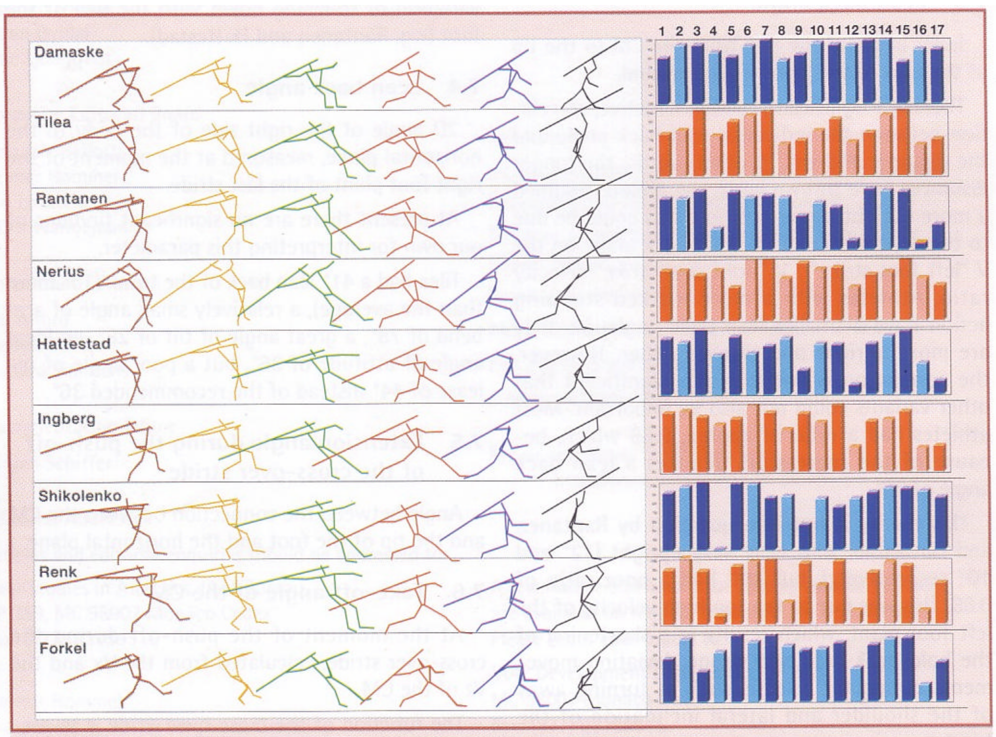

Figure 6: Phase structure during the last two strides and column diagram as a percentage deviation from 100% of the guideline table for distances longer than 70m

1 = angle of tilt, 2 = angle of release, 3 = angle of attitude, 4 = angle of attitude at the moment of the left foot strike during the cross-cver stride, 5 = angle of arm bend, 6 = acceleration path, 7 = hold back path, 8 = trunk lean back, 9 = angle of lean back, 10 = run-up velocity, 11 = length of cross-over stride,12 = V-ratio, 13 = hip angle, 14 = hip angle difference, 15 = cm extension angle during the cross-over stride, 16 = turning away of the shoulder, 17 = bending of the trunk

8.1 Remarks about Damaske's technique (Figure 7)

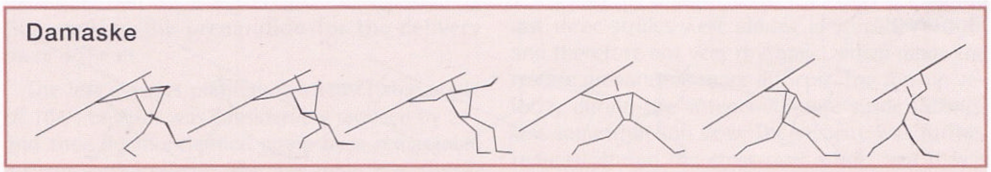

Figure 7: Phase structure of Damaske

As expected, the athlete demonstrated a high approximation to the standard values, as she had been oriented to these target values through systematic, biomechanically sound, coaching methods. Her last three strides were especially good and were very fast.

Damaskes technique is extremely dynamic; the transition from the push-off leg to the bracing leg is very effective and the loss of velocity is optimal.

Damaske's angle of tilt of 18° was fairly great -5° more than her average measurement. The slight deviating movements of the trunk and shoulder axes at the release are economical; they help to reduce the risk of injury and to optimize the force transmission from the bottom to the top.

8.2 Remarks about Tilea's technique (Figure 8)

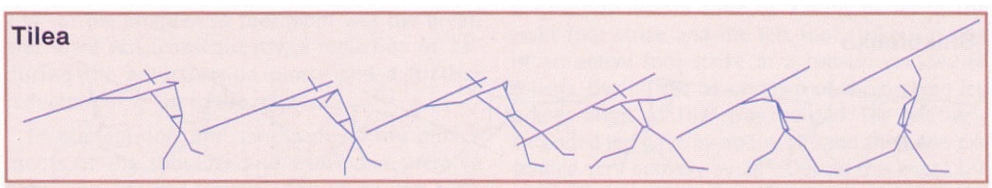

Figure 8: Phase structure of Tilea

As far as the standard parameters are concerned, Tilea's longest throw was a foul and she later barely reached the distance of that throw. She did not hit the javelin well (tilt 23°, angle of release with a light head wind 44°, difference between the angle of attitude and the angle of release 8°).Moreover, with a high angle of lean back and a fairly good stride length ratio of the last three strides, the velocity loss of the crossover stride is relatively great. The total functional delay of the apparatus (hold-back path 1.27m) and the work of the bracing leg, with a useful angle of extension from the push-off for the cross-over stride, were good prerequisites for a high strength effort in the final acceleration phase. However, there were relatively great deviating movements of the trunk and shoulder axes during the phase of release.

8.3 Remarks about Rantanen's technique (Figure 9)

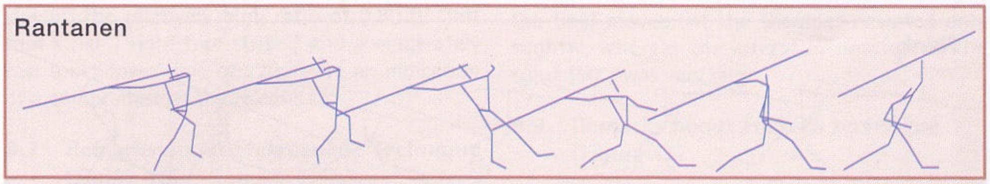

Figure 9: Phase structure of Rantanen

The Olympic winner hit the javelin at the release fairly well. The small angle of release of 31° was acceptable at the time of the competition because of the slight head wind.

The good correspondence of 3° between the angle of attitude and the angle of release and the angle of tilt of 13°, are similar to the standard measurements.

The very dynamic structure of the last three strides, with a cross-over stride length of 2.34m, which is quite close to the hypothetically ideal value, could not prevent the high loss of velocity during the cross-over stride, in spite of the right foot plant on the ball of the foot. Considerable deviating movements of the trunk and shoulder axes during the release phase are characteristic of an attempt to use great strength with a less than optimal direction of force of the partial impulses.

8.4 Remarks about Nerius' technique (Figure 10)

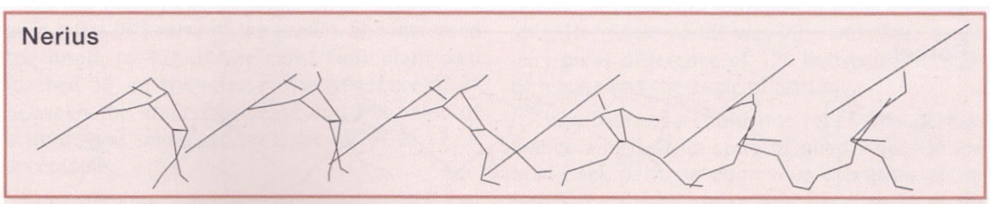

Figure 10: Phase structure of Nerius

Although, taking into account the head wind, the angle of tilt of 13° and an angle of release of 31° were acceptable, the difference from the angle of attitude of 12° was too great. Although the passive execution of the last three strides, with a significantly reduced work of the left leg (fast left foot strike), was not as marked as with Hattestad, Ingberg and Renk, it is an indication of the same basic idea of technique. The touchdown of the left leg at the release was emphasized, to guarantee an extremely strong effort during the release phase. In this regard, the pattern of the last three strides played a minor role, as these strides were almost equal in length.

The leg and hip work after the left foot plant at the release must be regarded as especially problematical. At the moment of the foot plant the knee angle was 160°, which is acceptable, but it was then considerably reduced by 28° to 132°. The final extension of the left leg, giving a knee angle of 147° was inadequate. The hip work was similarly ineffective. An extension angle of 134° at the hip at the moment of the foot plant was too great and the angle was consequently reduced by 28° during the amortization phase and by an additional 16° at to the release.

8.5 Remarks about Hattestad's technique (Figure 11)

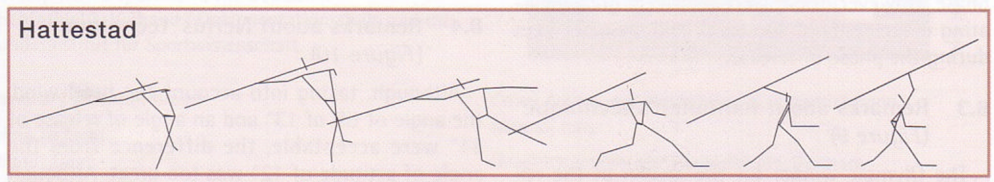

Figure 11: Phase structure of Hattestad

As compared to the other participants, and considering the predominating slight head wind, the release was quite good. This is underlined by the small tilt of 9° and the acceptable angle of release of 31°, with a difference of 5° between the angle of attitude and the angle of release.

Hattestad registered the highest velocity of all the throwers from the push-off of the antepenultimate stride but she could not maintain it in the cross-over stride, and there was a further reduction of the total velocity during the bracing stride. The last three strides were relatively passive in terms of stride lengths. A very active and very fast plant of the right and left foot in the last stride could compensate, to a certain degree, for the uniformity of the strides and the poor braking work. Consequently, the high left foot/ right foot plant" ratio of 0.88 was of no great consequence. Unlike the hip work, which was characterized by a continuously reduced extension, the knee extension, from the foot plant to the release, was ideal. The strong deviating movements of the shoulder and the trunk axis may have had a negative effect.

8.6 Remarks about Ingberg's technique (Figure 12)

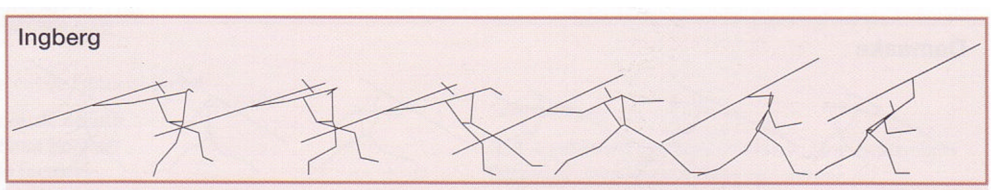

Figure 12: Phase structure of Ingberg

Ingberg's angles of attitude and release of 4° and 39° respectively were too steep, although their correspondence was relatively good. As compared to the other athletes, the angle of tilt of 9° was fairly close to the standard value. The last three strides were almost of identical length, indicating that there was no accentuated rhythm, thus making the preparation for the delivery more difficult.

The left leg was planted at a reasonable angle of 164°, but this was considerably reduced by 21° and then again extended again by a remarkable 34° up to the release. The hip angle was almost as unfavorable. The angle of hip extension of

134° at the moment of foot plant was too great, and there was, consequently, a reduction of 31° during the amortization phase and a further reduction of 7° up to the release.

In our opinion, the strong deviating movements of the shoulder and trunk axis seem to hinder an optimal transmission of energy from the legs via the trunk and throwing arm to the javelin. The relatively high ratio of 0.80 (V “left foot strike / right foot strike”) and a moderately fast touchdown time of 220ms are an indication of a compromise at the release.

8.7 Remarks about Shikolenko’s technique (Figure 13)

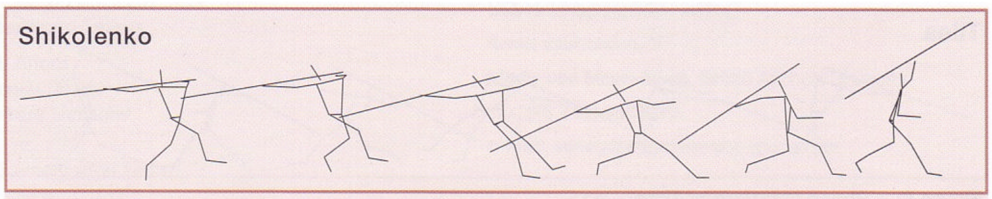

Figure 13: Phase structure of Shikolenko

During the antepenultimate stride Shikolenko used a flat (8°) carry of the javelin. She increased the angle to 17° at the right foot plant and reached 36° at the release. The difference of 2° between the angle of release and the angle of attitude was small, and an angle of tilt of 12° is acceptable.

An extremely aggressive execution of the last three strides, with a cross-over stride length of 2.41 m as compared to a bracing stride length of 1.46m, testify to a consistent training regime. As a result of this, there was also an efficient transmission of the energy of the run-up to the javelin, with a left foot / right foot plant ratio of 0.66. The athlete almost succeeded in compensating for the velocity loss during the cross-over stride by an active right foot plant for the last stride. At the plant of the left foot the leg was bent rather too much, with a knee angle of 152°. It then “gave” to an angle of 161° and subsequently was extended very actively to 12° The hip angle was 128°, it ‘gave” by 15° and was finally extended to an acceptable 119°. Corresponding to our standard values, only a small lateral lean of the trunk and a slight turning-away of the shoulder were measured.

8.8 Remarks about Renk’s technique (Figure 14)

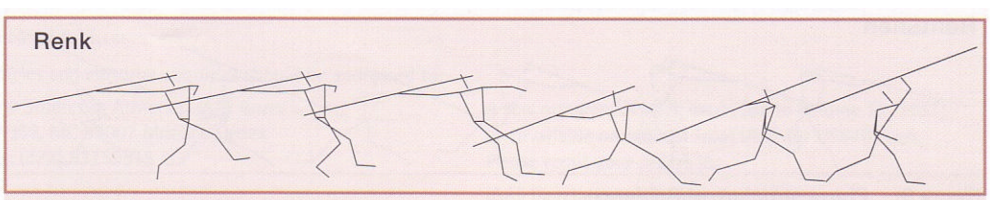

Figure 14: Phase structure of Renk

The Olympic champion of 1992 achieved an angle of attitude of 31°, an angle of release of 36° and an angle of tilt of 12° and thus an acceptable correspondence of the release parameters.

Table 9: Parameters of the javelin analysis at the ISTAF on August 26, 1997

Parameter	Dim.	Dam	Til	Ran	Ner	Hat	Ing	Shi	Ren	For	Standard value >70m
Distances evaluated	m	66,58	65,46	64,64	64,2	64,2	63,7	62,12	62,1	60,14	
Angle of tilt	Degrees	18	23	13	13	9	9	12	12	23	T < 3
Angle of release	Degrees	38	44	31	31	31	39	38	36	38	W 36
Angle of attitude at release	Degrees	38	36	34	43	36	41	36	31	50	W 36
Angle of attitude when left foot leaves the ground	Degrees	41	26	19	41	26	28	8	14	29	ca. 36
Angle of arm bend	Degrees	73	78	96	60	97	76	88	82	92	T 90
Transverse angle	Degrees	28	32	40	27	15	24	20	20	16	(24)
Acceleration path	m	3,16	3,16	2,97	3,42	2,53	3,38	3,31	3,25	3,09	3,0
Hold-back path	m	1,25	1,27	1,11	1,26	1,03	1,12	1,49	1,28	1,28	1,25?
Angle of trunk lean back	Degrees	23	41	26	37	27	22	25	16	34	approx. 30
Angle of lean back of CM	Degrees	21	24	12	19	10	16	27	19	21	approx. 18
Velocity of antepenultimate stride	m/s	6,1	6,9	6,7	6,5	6,9	6,4	6,1	5,7	6,6	No
Velocity of cross-over stride	m/s	6,7	5,4	5,7	6,1	5,9	5,6	5,6	5	5,9	T 7,0
Velocity of last stride	m/s	6,3	5,4	5,7	5,6	5,6	5,5	5,9	5,1	5,5	No
Velocity of antepenultimate stride	m	1,99	1,71	1,74	1,73	1,46	1,82	1,82	1,61	1,87	V 2,10
Length of cross-over stride	m	2,09	1,98	2,34	1,8	1,62	1,81	2,41	1,72	2,15	T 2,30
Length of last stride	m	1,68	1,61	1,65	1,74	1,52	1,76	1,46	1,49	1,51	V 1,77
Cross-over stride/bracing stride ratio	—	1,24	1,23	1,42	1,03	1,07	1,03	1,65	1,15	1,42	approx. 1,3
V left foot plant /V right foot plant ratio	—	0,59	0,74	0,88	0,73	0,88	0,8	0,66	0,86	0,75	T 0,55
Contact time betw. right and left foot plant	ms	220	260	200	240	170	220	230	220	220	T < 200
Hip angle at left foot plant	Degrees	114	141	118	134	131	134	128	131	127	T 113
Hip angle - Difference 1	Degrees	0	-12	-11	-28	-15	-31	-15	-9	-11	T min. 0
Hip angle at release	Degrees	140	120	116	90	102	96	119	127	120	>120
Hip angle - Difference 2	Degrees	26	-9	9	-16	-14	-7	6	5	4	(>5)
Knee angle at release	Degrees	175	173	170	147	179	177	176	178	175	180
Extension angle of cross-over stride	Degrees	64	85	79	84	87	77	77	77	81	approx. 85
Release angle of CM during cross-over stride	Degrees	13	10	16	11	13	10	16	16	12	approx. 8
CM angle at release	Degrees	21	29	35	27	10	18	50	32	15	approx. 12
Relative height of release H0	% of body height	105	108	102	97	98	102	101	102	105	approx. 105
Trunk bend	Degrees	10	29	39	28	50	40	17	24	27	max 0
Turning away of the shoulder	Degrees	10	34	57	21	33	41	11	50	48	max 0

Key: Dim. = Dimension; Dam = Damaske; Til = Tilea; Ran = Rantanen; Ner = Nerius; Hat = Hattestad; Ing =Ingberg; Shi = Shikolenko; Ren = Renk; For = Forkel

? Test value of the winner as the relationship could not be cleared completely.

() Average value from 35 tests.

approx. The test value can deviate in the complex movement.

T Trend value for distances longer than 70m as a result of our data bank analysis.

V Is the relation to the trend value. For the bracing stride 0.77 time cross-over stride and for the antepenultimate stride 0.91 times cross-over stride.

min At least zero because the hip should not give in.

>120 Greater than 120° for an active hip extension at release.

max 0° Is the deviation from 90° of the measuring value – in the case of 0° at the release the trunk would be ideally vertical, and there would be no rotation of the shoulder.

W The standard value is only valid in the case of no wind at all.

Because of a too short cross-over stride the last three strides were almost identical in length and therefore not very rhythmic, which made the release preparation more difficult. The run-up velocity during the antepenultimate stride (5.7m/s) was somewhat too slow. The velocity was further reduced during the cross-over stride, and it was insufficiently delayed during the left foot strike. A ground contact time of 220ms between the right foot strike and the left foot strike is a sign of an active foot strike at a run-up velocity of 5.1m/s. During the touchdown of the bracing leg a knee angle of 167° was realized. The relatively extended leg gave by about 17° and then was extended very actively by 28°. During this event the hip angle was 131°, it yielded by 9° and until the release was extended by acceptable 5°. During the final movement the shoulder deviated only slightly, whereas the lateral inclination of the trunk (50°) was very large.

8.9 Remarks about Forkel's technique (Figure 15)

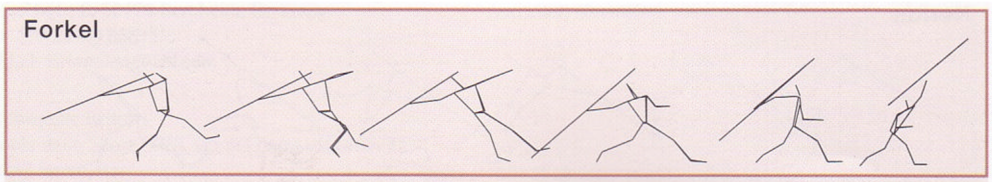

Figure 15: Phase structure of Forkel

Forkel did not succeed in executing an optimal release because her parameters were unfavorable. Her angle of tilt was 23°, and there was a very great difference of 12° between the angle of release and the angle of attitude.

Therefore, she could not reach the performance aimed at, in spite of good values in the hold-back path, an aggressive execution of the last three strides and a well fixed angle at the knee of the bracing leg.

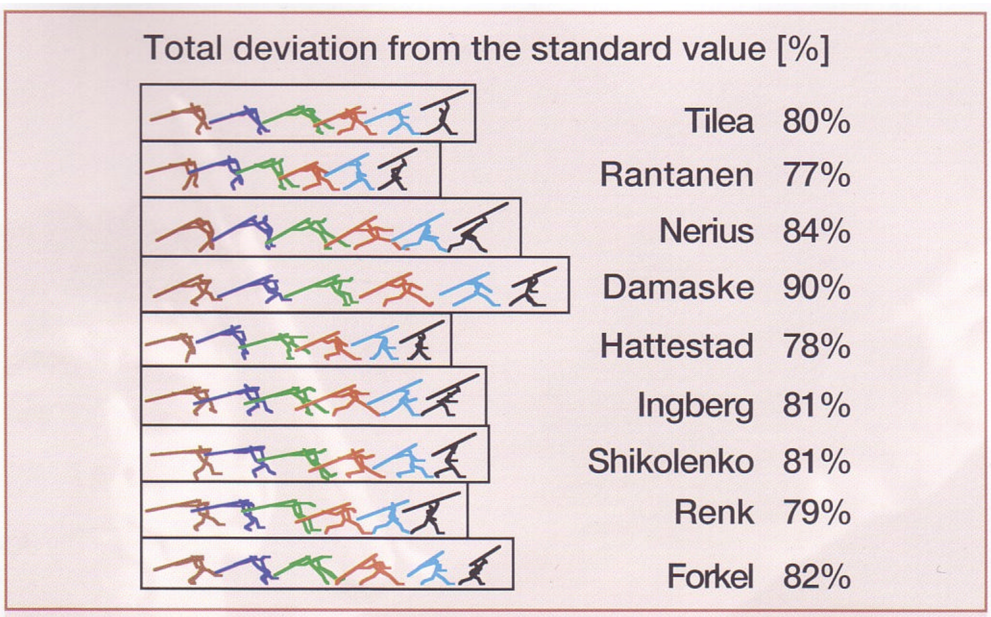

Figure 16: Percentage comparison of the standard values

9 Percentage differences of between the standard values taken together

Figure 16 is of more an informative than a comparative character. However, as far as their special features and deviations are concerned, there are much fewer differences between the techniques demonstrated by the top throwers than expected. Therefore, the most important components of our “snapshot” of the javelin technique may still be of interest in clarifying the structures of movement technique in the javelin throw.

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