Biomechanical analysis of the men's javelin throw at the 1995 World Championships in Athletics

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This paper presents an analysis of some of the best throws in the men's javelin final at the 1995 World Championships held in Sweden. For each throw, the release conditions are given, as is a technical breakdown of each athlete's movements. Certain technical factors which are considered fundamental to the throwing techniques of elite athletes such as the hip and shoulder axes alignment, maintenance of a long acceleration path and the ability to block effectively were studied and full details are provided within the report. It was notable that all the medallists showed a definite ability to generate the highest release speeds. However, the upper body movements used to produce these speeds varied considerably between throwers. Therefore, the muscles that each athlete uses to accelerate the implement should receive similar stresses when training. Without knowledge of an athlete's competitive throwing movement patterns, this is a very difficult task.

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1 Introduction

In the javelin throw, the speed at which the performer releases the implement is by far the most important factor. For an 80m throw, the release speed will be approximately $30 m \cdot s^{-1}$ (75 miles per hour or 121 $km \cdot h^{-1}$). For some elite athletes over 70% of this speed is developed in the 50ms immediately before the javelin's release (MORRISS and BARTLETT 1996). This high percentage shows just how important the movements of the smaller body segments are to the acceleration of the implement. Because the movements of the athlete are so fast during the delivery action, biomechanical analysis equipment (normally high speed cameras) is often used to provide an objective measure of the throwing techniques of elite athletes. The accurate record that biomechanical analyses provide can be used to develop a better understanding of how release speeds in excess of $30 m \cdot s^{-1}$ are achieved. This paper highlights some of the findings of a study of the techniques of the twelve athletes competing in the 1995 World Athletics Championships men's javelin final.

2 Methods

The throws analysed are listed in *Table 1*. For most athletes this was their best throw; however because of camera obstruction problems the best throw could not be analysed for all throwers. Also listed in *Table 1* are the distance of each analysed throw and discrepancy between this and the best throw of each athlete.

Table 1: Analyzed throws

Thrower	Distance [m]	Rank	Discrepancy [m]
Zelezny	89.06	1	-0.52
Backley	86.30	2	0.00
Henry	86.08	3	0.00
Hecht	83.30	4	0.00
Wennlund	82.04	5	0.00
Hill	81.06	6	0.00
Rybin	79.54	7	-1.46
Linden	79.72	8	-1.04
Parviainen	79.58	9	0.00
Moruyev	79.14	10	0.00
Raty	78.76	11	0.00
Hakkarainen	78.16	12	0.00

2.1 Filming procedures

The methods adopted were as reported previously (MORRISS and BARTLETT 1992, 1993) and conformed in all respects to the current biomechanics guidelines of the British Association of Sport and Exercise Sciences (BARTLETT et al. 1992). Two Photosonics 1PL high speed cine cameras, operating at a nominal frame rate of 100Hz for the first three rounds and 200Hz for rounds four to six, were used to film the men's final. The cameras were phase-locked and aligned with their optical axes approximately horizontal and 90° apart. The lenses were zoomed in on the runway so that all of the thrower's movements plus the first few metres of the javelin's path following release were in view. Event synchronisation was achieved by a manual switch that was activated during the throw after the cameras had reached full speed. This resulted in a synchronisation pulse being recorded on the opposite edge of the film from the timing marks that were used to calibrate the frame rate (98Hz and 196Hz). Before the competition, three poles, each 3.2m in height, were placed at 3 metres intervals along the left side of the runway. Spherical markers were placed at the top and bottom of each pole and served as reference points for the calibration system. The co-ordinates of these markers were then calculated using an Elta 3 tachymeter, and the poles were filmed in this location. This procedure was then repeated with the poles aligned such that they bisected the runway lengthways, and with them aligned along the right side of the run-way. In this way, a total volume of 6m x 4m x 3.2m was calibrated.

For all throws, the co-ordinates of every other frame of each selected throw were digitised by projecting the frame onto a TDS HR48 digitising tablet interfaced to an Acorn Archimedes 440 microcomputer running software reported by Bartlett (1989). The three-dimensional world co-ordinates of the eighteen points, defining a 14 segment performer model, plus the tip, grip and tail of the javelin were then reconstructed from the two sets of image co-ordinates using a DLT algorithm correcting for linear lens distortion. After computation of the thrower's mass centre, all co-ordinates were smoothed and velocities calculated using cross validated quintic splines. Body angles and other variables needed for the biomechanical analysis were then calculated.

2.2 Analysis procedures

Where possible the biomechanical analysis for each athlete concentrated on the period from left foot strike to begin the last cross-over stride until approximately 0.2s after javelin release. During this selected period there are some important events that occur and enable comparisons between the techniques of the athletes. These key events are:

- LFS left foot strike to begin the cross-over stride
- LFTO left foot take-off during the cross-over stride
- RFS right foot strike to begin the delivery stride
- RFTO right foot take-off (or where it starts to drag along the runway)
- FFS final left foot strike
- REL javelin release.

Analysis of the throws firstly involved the establishment, directly from film, of the duration of the following phases or sub-phases of the movement: from left foot strike to right foot strike in the last cross-over stride (LFS to RFS); from right foot strike to final foot strike (RFS to FFS); and from final foot strike to javelin release (FFS to REL). The films were then digitised to obtain information regarding the throwers movements during these phases. All throwers were right handed.

3 Results

3.1 Release conditions

The release conditions for the twelve throws are shown in *Table 2*. The angle of attack and angle of yaw are illustrated in *Figure 1*.

As expected, the longest throws tended to be achieved by the athletes who attained the largest release speeds. The release speed of 30.2m·s^{-1} with the high angle of release of 40°, for the throw by Zelezny, was particularly impressive. As the release speeds, attack and yaw angles for Backley and Zelezny were so similar, the difference in the distance thrown of 1.76m could be attributed to the 6° higher release angle achieved by Zelezny. The yaw angles of between 11 and 14° for Rybin, Linden and Parviainen are relatively large compared to the other throws; this might have been

Table 2: Release conditions for the twelve throws

Thrower	Distance [m]	Speed [m·s⁻¹]	Angle [°]	Height [m]	Attack [°]	Yaw [°]
Zelezny	89.06	30.2	40	1.81	0	7
Backley	86.30	30.1	34	2.02	-1	4
Henry	86.08	29.4	38	2.02	-6	5
Hecht	83.30	28.9	40	2.13	-6	9
Wennlund	82.04	29.1	36	1.85	-6	1
Hill	81.06	28.4	39	1.84	-2	7
Rybin	79.54	27.7	42	2.06	-4	14
Linden	79.72	28.1	36	1.81	1	14
Zelezny	79.58	28.3	37	2.12	1	11
Moruyev	79.14	28.1	38	1.85	-1	3
Räty	78.76	28.9	37	2.00	-8	8
Hakkarainen	78.16	28.2	39	2.12	-9	1

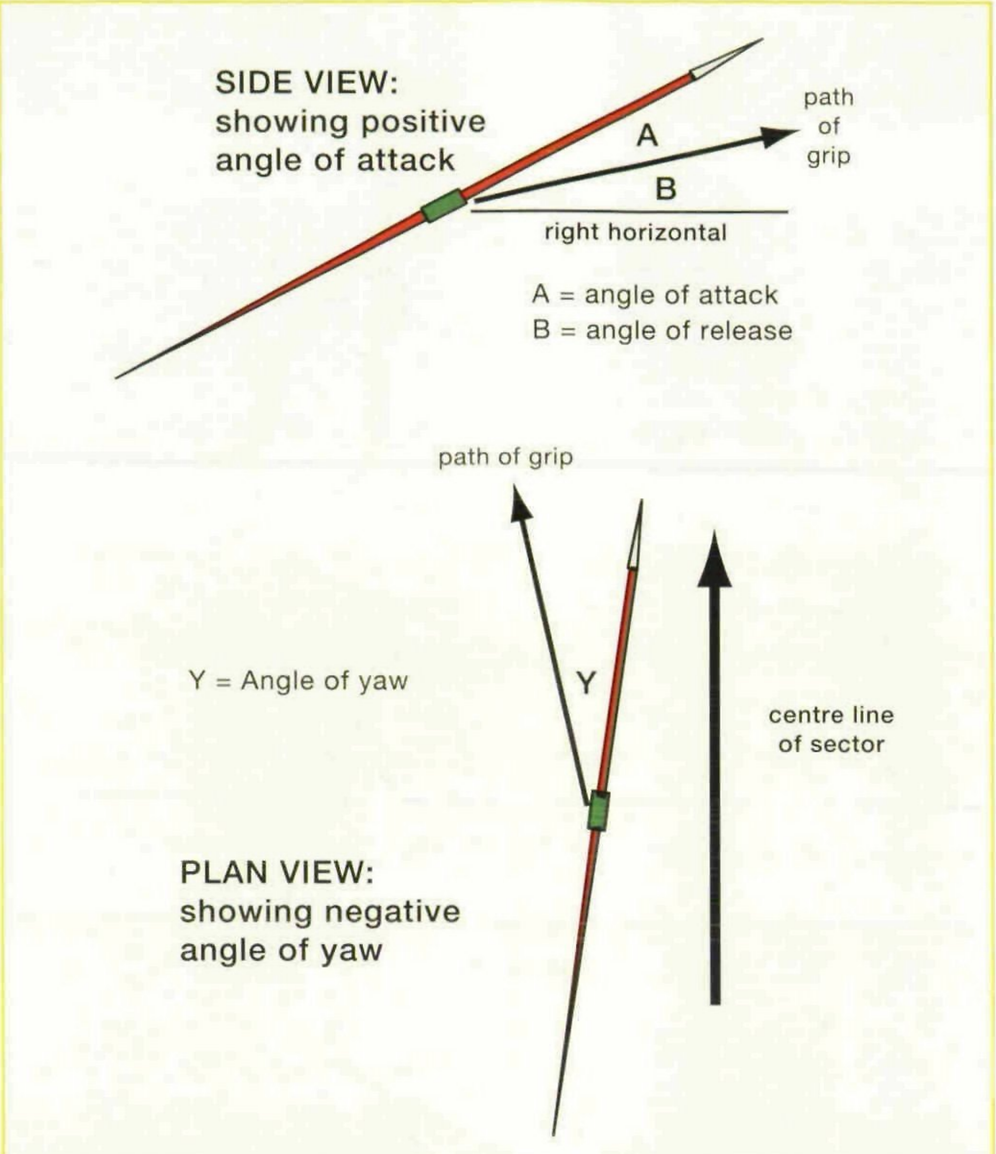

Figure 1: Release angles of yaw and attack

important in limiting the distance of these throws. Similarly, the large negative angles of attack of -8° and -9° for Räty and Hakkarainen would also have increased the aerodynamic drag force acting on the javelin in flight, so reducing the distance thrown.

3.2 Phase timing

Table 3 presents a temporal breakdown of the throws, showing how long the athlete spent in: left foot contact (LFC; LFS-LFTO); flight during cross-over (flight; LFTO-RFS); right foot contact (RFC; RFS-RFTO); the time between right foot contact and final foot strike (RFC-FFS); and the duration of the delivery action (FFS-REL). Where RFC times are omitted, these athletes achieved final foot strike before the right foot left the ground or dragged along the runway. The temporal analysis is useful as it gives an indication of how dynamically the athlete works the lower body during the final stages of the run-up.

The shorter left foot contact times for the more successful athletes are immediately noticeable in *Table 3*. This suggests that these athletes were attempting to continue the momentum of the run-up through to the delivery stride. Before

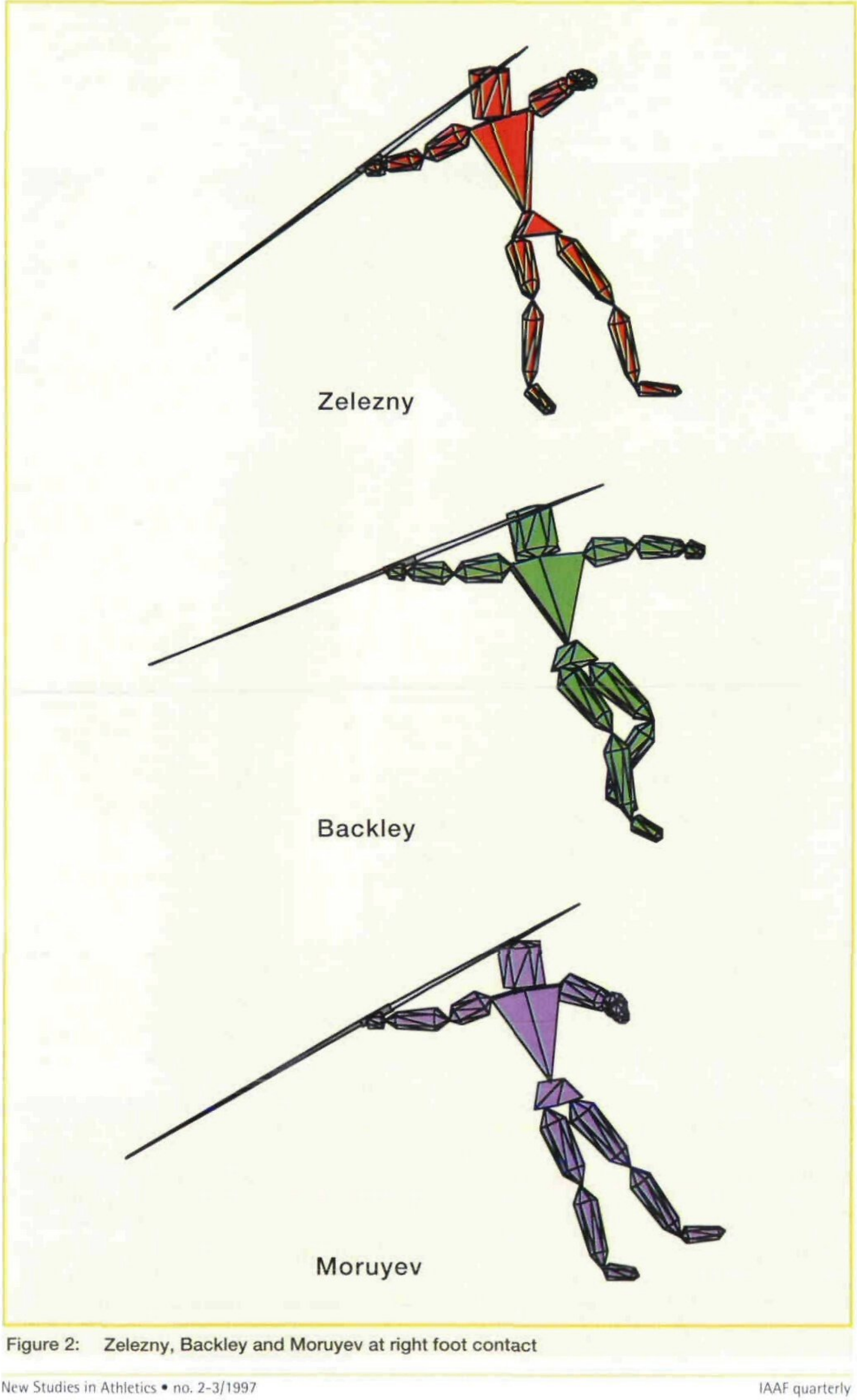

Figure 2: Zelezny, Backley and Moruyev at right foot contact

Table 3: Phase durations in the twelve throws

Thrower	Distance [m]	LFS [s]	Flight [s]	RFS [s]	RFS-FFS [s]	FFS-REL [s]
Zelezny	89.06	0.10	0.24	0.09	0.14	0.12
Backley	86.30	0.12	0.20	0.20	0.21	0.12
Henry	86.08	0.13	0.21	0.17	0.19	0.13
Hecht	83.30	0.13	0.29	–	0.16	0.13
Wennlund	82.04	0.14	0.24	–	0.15	0.13
Hill	81.06	0.14	0.20	0.20	0.22	0.12
Rybin	79.54	0.14	0.24	–	0.16	0.13
Linden	79.72	0.14	0.26	0.20	0.24	0.13
Parviainen	79.58	0.14	0.27	0.22	0.25	0.15
Moruyev	79.14	0.14	0.34	0.17	0.18	0.11
Räty	78.76	0.16	0.21	–	0.22	0.12
Hakkarainen	78.16	0.19	0.20	–	0.20	0.14

right foot contact, the flight time during cross-over varied from 0.20s for Hakkarainen and Backley to 0.34s for Moruyev. In the past a long flight time, achieved by jumping **up** off the left leg, has often been considered beneficial, as it allows the thrower to get the right leg in front of the centre of gravity before foot strike. Such reasoning fails to account for any reduction in the forward momentum of the thrower, generated off the right leg into final foot strike, caused by the shock of landing on the right leg. Also, a high flight tends to promote a premature throwing action, in which the throwing arm is flexed and lowered, shortening the acceleration path. The right elbow angle at final foot strike for Backley was the largest at 153° compared to 116° for Moruyev (see section 3.3.3). After the cross-over, right foot strike begins the delivery stride. To maintain the momentum generated in the run-up through to final foot strike, this right foot contact period should be 'active'. This was best demonstrated by Jan Zelezny, who completed this right foot contact in only 0.09s, approximately half the time for any other thrower. Observation of the cine footage of this throw showed that Zelezny's right heel did not touch the ground at any instant and barely moved down towards the floor during the entire driving movement.

The body positions of Zelezny, Backley and Moruyev at right foot contact are shown in *Figure 2*.

3.3 Technical analysis

3.3.1 Body position leading to final foot strike

After right foot strike, athletes try to get the left foot on the ground as quickly as possible for many reasons. Firstly, the athlete will wish to set up a stable base to facilitate the transfer of the momentum generated in the run-up to the upper body at final foot strike. Secondly, if the left foot is on the ground and the left knee maintained in an extended position, then the thrower can form a pivot at the left hip. The right knee and hip may then be extended, rotating the right hip around the left.

The consequence of this action is to stretch the leftward rotator muscles of the trunk (assuming the shoulder axis remains in a closed position) which may result in forceful leftward rotation of the trunk to begin the delivery action of the upper body. Each athlete will need to reduce the time between the right foot and final foot strikes if the block is to be as effective as possible. Athletes can improve their chances of reducing this time (between single and double support) by achieving right foot strike with an appropriate body position. For example, if the hip axis is relatively closed, the left leg will naturally be ahead of the right (180° would be parallel to the throw direction). The left knee should also be relatively extended to allow for the shock of final foot strike. *Table 4* summarises several aspects of the thrower's body position related to the time between right and left foot strikes.

By abducting the hip and extending the knee, a thrower can put his body in a position to achieve final foot strike very soon after that of the right foot. *Table 4* shows that the throwers who achieved the greatest distance between their right and left ankle joints at right foot contact (Zelezny, Hecht and Wennlund) completed the following period to final foot strike in the shortest times, between 0.14 and 0.16 seconds. In

Table 4: Body position at right foot contact

Thrower	Distance [m]	L Ankle-R Ankle [m]	Hip axis angle at RFC [°]	L knee angle at RFC [°]	Time, RFS to FFS [s]
Zelezny	89.06	0.52	158	151	0.14
Backley	86.30	-0.14	140	116	0.21
Henry	86.08	0.19	152	120	0.19
Hecht	83.30	0.56	147	177	0.16
Wennlund	82.04	0.53	148	149	0.15
Hill	81.06	-0.15	141	71	0.22
Rybin	79.54	0.09	151	143	0.16
Linden	79.72	0.40	153	163	0.24
Parviainen	79.58	0.09	151	132	0.25
Moruyev	79.14	0.37	120	173	0.18
Räty	78.76	0.00	140	121	0.22
Hakkarainen	78.16	0.40	156	156	0.20

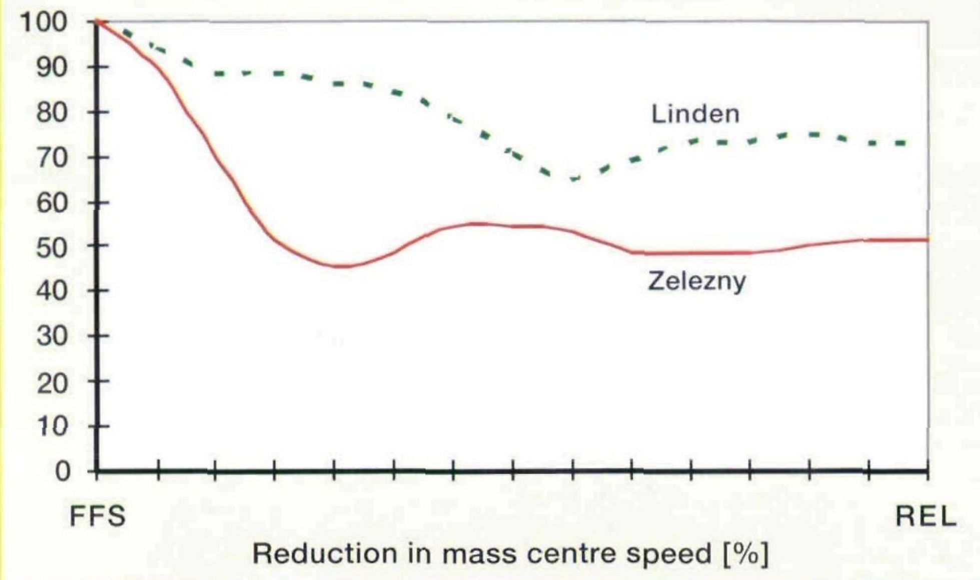

Figure 3: Profile of mass centre speed reduction between final foot strike and release for Zelezny and Linden

contrast, for Backley, Hill and Räty, the left ankle trailed the right at right foot strike. Consequently, the time from right foot to final foot strike was longer at 0.21s to 0.22s. Although non-significant, the Pearson product moment correlation coefficient between these two variables was r=-0.53 at a probability level of *P=0.09. This suggests a link between these two* variables.

3.3.2 Run-up Speed

The horizontal velocity of each thrower at final foot strike and release is shown in *Table 5.* Also shown is the percentage that is lost during the phase between these two instants.

The mass centre speed in the horizontal throw direction varied between $6.7 m \cdot s^{-1}$ and $5.0 m \cdot s^{-1}$, with a mean of approximately $6.0 m \cdot s^{-1}$. The control of this speed also varied between athletes with the percentage loss between final foot strike and release varying between 31% and 59%. Most coaches would advocate maintaining a straight front leg at final foot strike through to release to provide a stable lower body and to facilitate the transfer of momentum to the upper body. It is normally assumed that maintaining a straighter left leg will result in a large reduction in the speed of the centre of mass. This did not appear to be the case for all throwers. For example, Linden maintained an extended left knee throughout the delivery period, but only reduced the speed of his mass centre by 31%.

The placement of the left foot in front of the mass centre is also a factor in determining the extent by which the body's horizontal velocity will be reduced. This placement of the left foot and the degree of left knee flexion will also affect the rate of mass centre deceleration, as well as the total reduction in speed. *Figure 3* shows the percentage of the mass centre velocity at final foot strike maintained during the following period to release for Zelezny and Linden. Notice the very sharp deceleration for Zelezny immediately after final foot strike, as opposed to the more gradual deceleration for Linden. This will probably have consequences for the stretch

Table 5: Horizontal mass centre velocity and left knee angle at selected stages of the throw

	Mass centre speed [m·s-1]			Left leg knee angle [°]				
Thrower	*Distance [m]*	*FFS*	*REL*	*% loss*	*RFS*	*FFS*	*Min*	*REL*
Zelezny	89.06	6.6	3.4	48	151	173	151	165
Backley	86.30	6.0	3.3	45	116	168	138	138
Henry	86.08	6.2	3.9	37	120	168	149	149
Hecht	83.30	6.1	3.6	41	177	172	136	142
Wennlund	82.04	5.5	2.6	53	149	167	162	163
Hill	81.06	6.2	3.0	52	71	169	144	150
Rybin	79.54	6.7	3.4	49	143	179	157	166
Linden	79.72	5.2	3.6	31	163	176	164	177
Parviainen	79.58	6.1	2.5	59	132	172	149	151
Moruyev	79.14	6.4	3.9	39	173	174	126	126
Räty	*78.76*	*5.6*	*2.6*	*54*	*121*	*173*	*148*	*153*
Hakkarainen	78.16	5.0	2.8	44	156	172	158	175

Table 6: **Throwing arm elbow angle at selected stages of the throw**

Thrower	Distance [m]	Throwing arm elbow angle [°] RFS	FFS	Min	REL
Zelezny	89.06	156	123	90	170
Backley	86.30	166	153	118	147
Henry	86.08	150	132	95	154
Hecht	83.30	153	120	84	163
Wennlund	82.04	158	128	93	157
Hill	81.06	153	116	88	155
Rybin	79.54	136	123	88	150
Linden	79.72	129	107	85	140
Parviainen	79.58	159	131	92	164
Moruyev	79.14	151	116	91	149
Räty	78.76	153	110	84	151
Hakkarainen	78.16	151	127	93	148

placed on the abdominal musculature immediately after final foot strike, with Zelezny evoking a more forceful response. Anecdotal support for this is provided (see section 3.3.5) by Zelezny achieving the greatest linear speed of the right shoulder joint following final foot strike. This speed would have been generated by rotation and lateral flexion of the trunk, both of which are partly controlled by muscles of the abdomen.

3.3.3 Throwing arm elbow angle

Table 6 shows values for the throwing arm elbow angle during selected stages of the throw.

The athlete should try to hold the implement as far from his upper body as possible, to maximise the length of the javelin's acceleration path during the delivery, and not to shorten this distance until final foot strike. For example, a totally extended arm at final foot strike (180°) would provide the thrower with the maximum path over which he can accelerate the javelin. At right foot strike the values in *Table 5* show that most throwers were able to maintain a relatively extended elbow. The exceptions were Rybin and Linden, both of whom appeared to have begun to accelerate the arm too early. At final foot strike, only Backley was able to attain a value of over 150°; only Parviainen and Henry also attained values of over 130°. This would suggest that most athletes began the throwing action much earlier than final foot contact. As the peak speed of the throwing shoulder is not reached until after final foot strike, earlier flexion of the throwing arm elbow suggests a muscle recruitment pattern that is not optimal. The body positions of Backley and Linden at final foot strike are shown in *Figure 4*.

3.3.4 Angular displacements of the hip and shoulder axes.

Table 7 shows the values at right foot strike, final foot strike and release for: the angle between the hip axis and the throw direction (hip axis); the angle between the shoulder axis and the throw direction (shoulder axis); and the angle between these two axes (H-S axis angle). All angles were measured in the horizontal plane. An angle of 180° means that the axis is parallel to the throw direction.

At right foot strike all throwers assumed a very closed body position with the hip axis at a mean angle of 146° and the shoulder axis at 181°. At final foot strike the hip axis alignment was relatively similar for all throwers at approximately 115°. The shoulder axis alignment varied between athletes. Zelezny, Henry, Hecht and Hill all assumed a relatively closed shoulder axis, approximately 20° more than Rybin and Linden. Considering the relatively flexed right elbow of the last two of these throwers at final foot strike, highlighted in the previous section, these two athletes might have markedly reduced the acceleration path of the javelin. Front views of Hecht and Rybin at final foot strike are shown in *Figure 5*.

3.3.5 Sequencing of limb movements

Once the run-up is completed the effectiveness of the delivery will determine the distance of the throw. To make the delivery as effective as possible, the athlete should seek to accelerate the larger parts of his body first so that the smaller parts, the wrist and hand, have momentum at the end of the movement. The peak speeds of the most important joints are shown in *Table 8*, with the speed of the body mass centre at that time subtracted from each value. This gives an indication of the athlete's reliance on the upper body to accelerate the javelin.

Table 7: **Hip and shoulder axes alignment at selected stages of the throw**

Thrower	Distance [m]	Hip axis [°] RFS	FFS	Rel	Shoulder axis [°] RFS	FFS	Rel	H-S axis angle [°] RFS	FFS	Rel
Zelezny	89.06	158	119	59	195	143	55	-37	-24	4
Backley	86.30	140	110	59	176	135	45	-36	-25	14
Henry	86.08	152	128	70	188	144	59	-36	-16	11
Hecht	83.30	147	119	69	182	151	62	-35	-32	7
Wennlund	82.04	148	112	50	167	137	52	-19	-25	-2
Hill	81.06	141	114	71	182	145	63	-41	-31	8
Rybin	79.54	151	109	52	169	124	59	-18	-15	-7
Linden	79.72	153	117	52	169	124	55	-17	-7	-3
Parviainen	79.58	151	113	80	189	137	72	-38	-24	8
Moruyev	79.14	120	108	58	179	132	66	-59	-24	-8
Räty	78.76	140	106	56	187	136	57	-47	-30	-1
Hakkarainen	78.16	156	117	53	186	136	57	-30	-19	-4

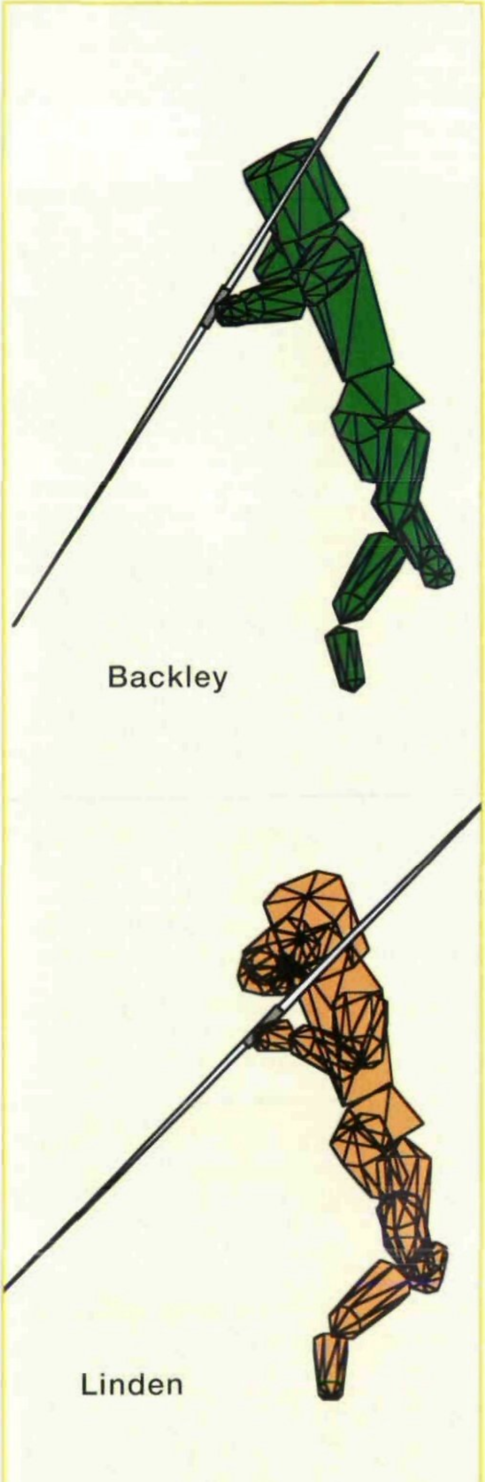

Figure 4: Elevated rear views of Backley and Linden at final foot strike emphasising the right elbow angle

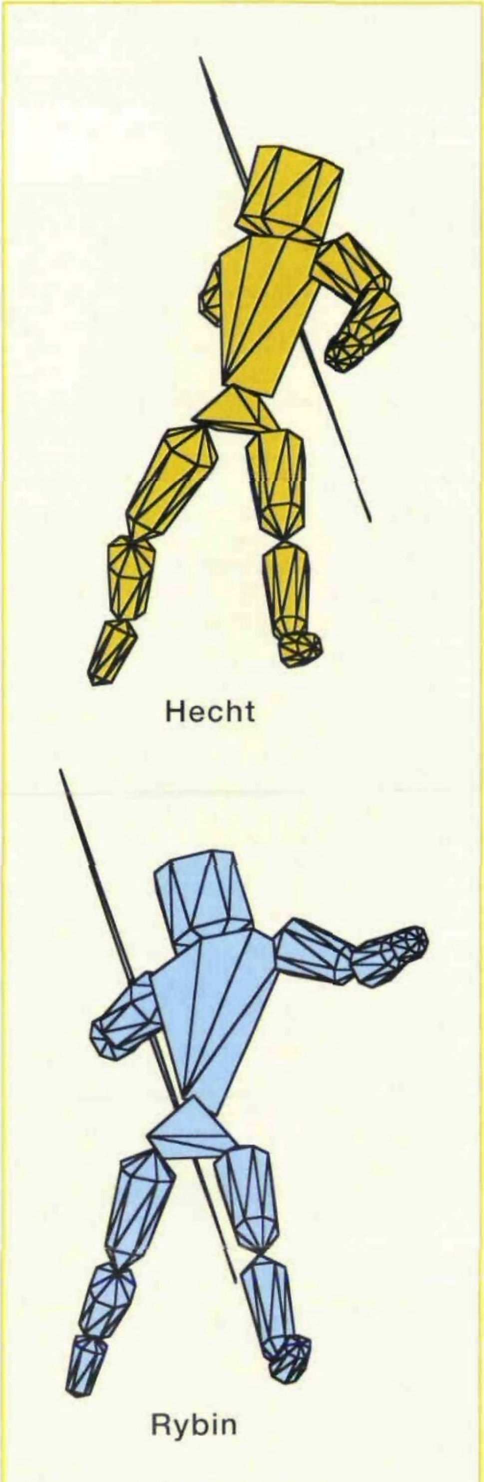

Figure 5: Front views of Hecht and Rybin at final foot strike emphasising the shoulder axis angle

Table 8 shows that only five athletes achieved peak wrist joint speeds relative to the mass centre speed of over 20m·s^{-1}, the largest two of which were for the gold and silver medallists. The wrist joint speed of 18.8m·s^{-1} for the bronze medallist appears quite low, but this athlete maintained the greatest mass centre speed through to release (3.9m·s^{-1}). Also noteworthy is the largest right shoulder joint speed of 7.7m·s^{-1} for Zelezny, showing excellent use of the trunk to give initial momentum to the upper arm. This is probably due to the rotational style of throwing preferred by Zelezny.

Table 9 shows the angular velocities of the upper arm segments at the elbow and shoulder joints. Column one is the peak angular velocity of the humerus about the shoulder joint in a combination of extension, abduction and horizontal flexion. Column two is the peak angular velocity of the elbow in extension. Column three represents the average rate of shoulder joint medial (internal) rotation between the instants of maximum lateral (external) rotation and release. The figures in bold type are the largest recorded in each movement.

It is not surprising that Zelezny and Backley achieved the longest throws as the rotational velocities of the arm segments were greater than those for the other athletes. Their large peak wrist joint speeds would have been the result of the large elbow and shoulder joint angular velocities.

The values in *Table 9* also highlight interesting differences in the throwing styles among the 12 athletes. The very large shoulder angular velocity for Backley (1330°/s) would suggest a reliance on shoulder horizontal flexion and extension to accelerate the javelin; this would suit his very linear style of throwing. The minimum right elbow angle of 118° for Backley is much larger than for any other thrower and would further suggest a dependence on effort from the shoulder joint musculature to accelerate the javelin.

In contrast, Zelezny and Wennlund appear to use medial rotation of the shoulder as a major method of accelerating the javelin (2270°/s and 2050°/s). This movement, combined with an elbow extension angular velocity (3220°/s) that is at least 18% larger than for any other thrower, is the reason why Zelezny was able to achieve the greatest linear velocity of the wrist. Elevated rear views of Zelezny and Backley at final foot strike and release show how the difference in their throwing styles affects the path of the grip during the delivery action (*Figure 6*).

The differences in the movements of the upper arm and forearm between throwers have important implications for their physical training. ENOKA (1994) stated that, when training "the induced change is specific to the exercise stress". This means that the training exercises performed by each thrower should be done in a way that replicates their **individual** movement pattern. For instance, it would seem logical that the movement guidelines Zelezny follows when ball throwing should emphasise shoulder medial rotation and elbow extension. Otherwise, the movement pattern he executes when javelin throwing would not be replicated and the training exercise would lack specificity.

Table 8: Peak joint speeds relative to mass centre speed

Thrower	Distance [m]	R. hip	R. sho	R. Elb	R. Wri	Javelin
Zelezny	89.06	0.7	7.7	12.2	20.9	26.8
Backley	86.30	1.6	6.5	13.1	20.8	26.7
Henry	86.08	1.2	7.2	11.1	18.8	25.2
Hecht	83.30	1.0	4.4	12.0	19.4	25.0
Wennlund	82.04	1.9	5.2	11.3	19.1	26.4
Hill	81.06	1.1	6.7	11.2	18.1	25.0
Rybin	79.54	1.2	5.9	11.4	17.5	24.0
Linden	79.72	1.4	6.3	12.4	20.2	24.3
Parviainen	79.58	1.2	3.6	10.7	20.8	25.2
Moruyev	79.14	1.0	5.1	12.1	18.5	24.0
Räty	78.76	1.7	5.3	12.3	20.0	25.0
Hakkarainen	78.16	1.2	3.9	11.9	19.7	25.1

4 Conclusions

There are a number of technical factors that are fundamental to

Table 9: Angular velocities of elbow extension, shoulder extension and horizontal flexion, and shoulder medial rotation

Thrower	Distance [m]	Shoulder [°/s]	Elbow [°/s]	Shoulder Medial Rotation [°/s]
Zelezny	89.06	1060	3220	2270
Backley	86.30	1330	2590	1230
Henry	86.08	1130	2670	1450
Hecht	83.30	1140	2550	1940
Wennlund	82.04	1020	2060	2050
Hill	81.06	1110	2070	1080
Rybin	79.54	1170	1780	1170
Linden	79.72	824	2500	1260
Parviainen	79.58	1050	2240	1960
Moruyev	79.14	1110	2160	750
Räty	78.76	912	2110	871
Hakkarainen	78.16	713	1980	1660

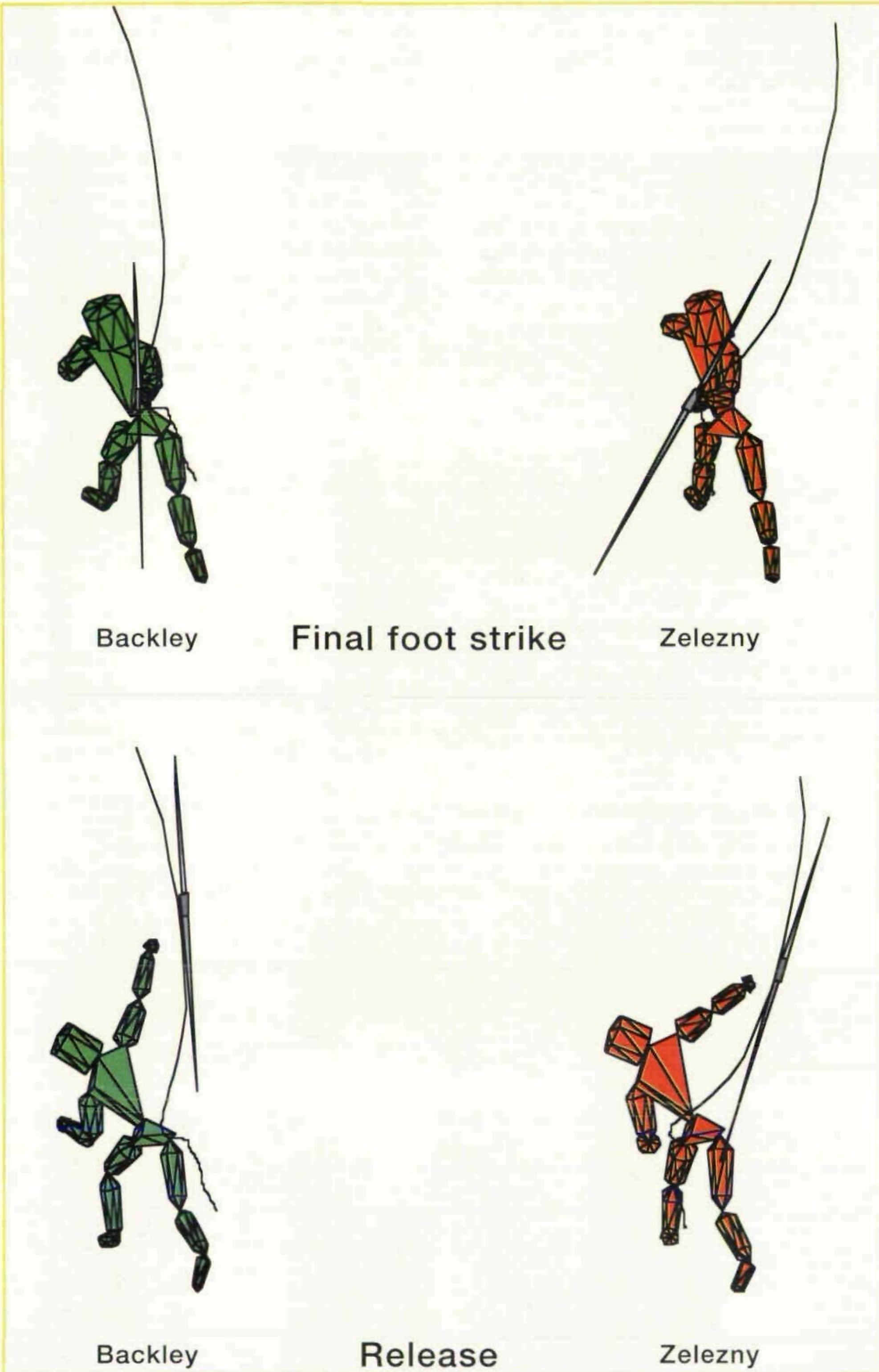

Figure 6: Elevated rear views of Backley and Zelezny at final foot strike and release

the javelin throwing technique of elite athletes. Elements of a good throwing technique include: right foot strike, to begin the delivery stride, with the shoulder and hip axes closed and the left knee extended in preparation for left foot strike; maintaining a mass centre horizontal velocity of $6 m \cdot s^{-1}$ and an extended right elbow through to final foot strike; and decelerating the mass centre at the greatest possible rate by maintaining an extended left knee to transfer momentum to the upper body.

The athletes in this study achieved these body positions and movements to different extents. Notably, the medallists were able to achieve the highest release speeds. This factor was the main contributor to the three throws, all in excess of 86m. Interestingly, each of the athletes had a markedly different way of generating the release speed. Zelezny and Henry appeared to use shoulder medial rotation and elbow extension to provide the force necessary to accelerate the javelin. Backley, however, used rapid shoulder extension and horizontal flexion as primary movements. This suggests that a very good understanding of an athlete's javelin throwing technique is needed to design specific training exercises. Otherwise the muscles that the athlete uses to apply force to the javelin may not receive the appropriate training stresses and, consequently, not aid the thrower's performance.

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