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Biomechanical Factors Critical for Performance in the Men's Javelin Throw

Calvin Morriss and *Roger Bartlett*

Division of Sport Science, The Manchester Metropolitan University, Alsager, England

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Summary

In the men's javelin event the athlete throws an 800g implement into a 40° sector. The objective is to throw as far as possible. Compared with most other throwing implements, the javelin is relatively aerodynamic. Even so, the most important release parameter is still the release speed. Maximising this parameter gives the athlete the best chance of attaining success in the event.

For an elite thrower, as much as 70% of the release speed of the javelin is developed in the last 0.1 second. As such, the movements of throwers during this period and immediately preceding it have received attention from researchers. It would appear that a thrower's body position at the instant of final foot strike, his ability to transfer momentum between the lower body and the upper body during the delivery, and coordination of the working body segments in the most effective manner are linked to his success in the event. This paper reviews the most important biomechanical research on the men's javelin throw and highlights findings such as these which may improve the understanding of how elite javelin throwers achieve success.

Recent research on javelin throwing has tended to focus on the aerodynamics of the implement or the technique of the thrower. This review concentrates on the latter of these two areas and on male throwers as more research has been conducted on these athletes. Readers interested in the aerodynamics of the javelin should consult Best et al.[1]

In 1986, the specification of the men's javelin was changed so that the distance athletes could throw it was reduced and flat landings were eliminated. This resulted in a new set of optimal release parameters for the javelin and, consequently, some modification to the throwing technique for optimal release.

As for other throwing events, the most important contributor to a long distance thrown is the generation of a large release speed. Bartlett and Best[2] suggested that gains in javelin speed can be optimised by having the force applied to the javelin and the time of force application interacting in such a way that the force impulse is maximised.

The force generating capacity of a thrower can only be altered through physical training. Nevertheless, the force that an athlete applies to the javelin during the course of a throw will be directly affected by the forces generated by his working muscles. Because the javelin throw involves a sequence of complex movements by a multi-jointed performer, the activation pattern of the working muscles will affect the force that is applied to the implement.

To demonstrate that the activation sequence of working muscles will affect the motion of the throwing implement Alexander[3] developed a simple simulation model of an athlete performing a throwing task. The purpose of the model was to identify the correct activation sequence of the muscles within the model such that the speed of the implement was maximised at release. He found there to be an optimum time delay between activation of the muscles that maximised the kinetic energy of the thrown implement at release.

Other related research[4] on the overarm handball throw found that the majority of the work done on the ball (over 70%) was delivered in as little as 50 msec prior to release. This time span is much too short to develop a large force in the working muscles should these be relaxed at the start of this phase.[5] Instead, Joris et al.[4] proposed that 'acceleration of the relatively heavy proximal segments is used to facilitate eccentric contractions of the involved muscles of the distal segments just before their concentric contractions'. This serves 2 purposes; first, it allows the distal muscles to generate their maximum possible forces. Secondly, because of the work done by the proximal muscle groups, the distal muscles will be contracting over joints that have increased kinetic energy. This sequential action allows a large force to be exerted on the implement, even when its speed is already very high. In this way, a large flow of kinetic energy can be delivered to the implement. This research[3,4] established a link between the thrower's technique and the motion of the thrown implement. An effective throwing technique is a critical requirement for an elite athlete.

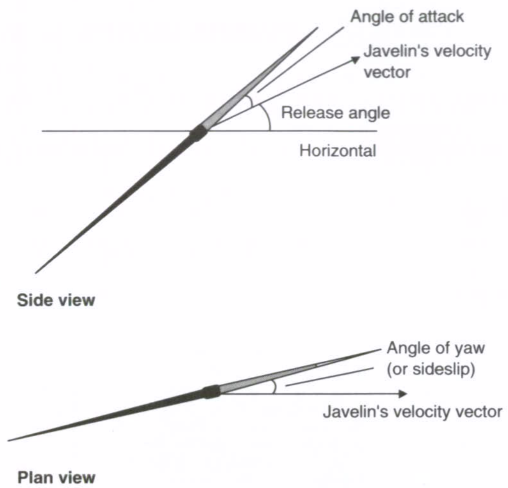

Fig. 1. Angles of the javelin at release: (**top**) side view, (**bottom**) plan view.

This review concentrates on those aspects of the thrower's technique that have been related to the release conditions of the javelin. Of most importance are those that affect the speed of the implement, but other factors have been shown to be related to the angles of the javelin at release (fig. 1) which also affect the range. The factors that are thought to contribute to the release speed of the javelin are summarised in a hierarchical technique model (fig. 2) similar in concept to that proposed by Hay.[6]

To address the technical factors highlighted in figure 2 most effectively, the javelin throw can be separated into 4 phases, each with its own bio-

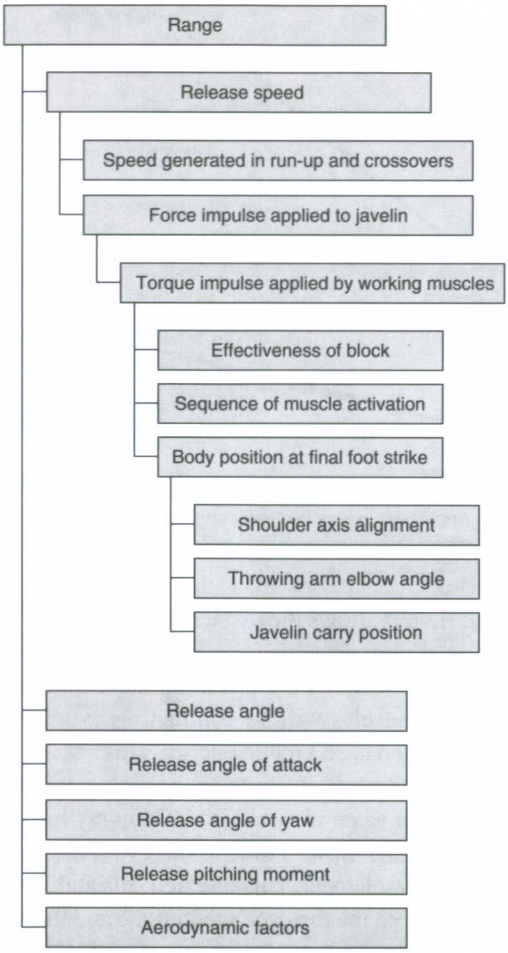

Fig. 2. Basic hierarchical technique model of the factors of an athlete's technique that affect the distance thrown.

mechanical function. These are generally accepted to be the run-up, the crossovers (including the withdrawal), the delivery and the recovery.[2] The remainder of this review will be directed to the research that has been conducted upon each of these phases. In descriptions of the thrower's body position it is assumed that he is right-handed.

1. Run-Up

That athletes can throw further after a run-up than from a standing position follows from Newton's second law of motion which suggests that the javelin should have an initial velocity before its most important phase of acceleration.[2] Initial velocity is given to the javelin during the run-up, but most scientific studies do not cover this phase in their analysis. Typical horizontal velocities for the thrower's centre of mass at instants later in the throw have been reported to range from 5.2 to 7.0 m/sec for elite level athletes.[7-9]

2. Crossovers

The traditional view of the javelin throw saw the run-up as ending with the withdrawal of the javelin (placement of the implement into its delivery position) and a single crossover stride preceding the delivery stride. In modern javelin throwing, a series of crossovers are performed in which the thrower can maintain the velocity generated through the run-up but also put their body and the javelin into a position that will optimise the effectiveness of the delivery. The body position of an athlete during the crossovers is illustrated in figure 3, which shows an elite right-handed thrower at the instant of left foot strike and right foot strike. In both cases the hip and shoulder axes of the athlete can be seen to be approximately parallel to the ground and to the throwing direction. In addition, the javelin is held such that the elbow of the throwing arm is fully extended with the javelin parallel to the ground. This serves to lengthen the distance between the javelin position at the end of the crossovers and its position at release. The ability of the athlete to do mechanical work upon the javelin is positively affected by increasing this distance, often known as the acceleration path. Therefore the kinetic energy gained by the javelin during the period of work will also be increased.

As the delivery phase lasts for approximately 0.12 seconds, it is practically impossible for the sports scientist or coach to train the athlete for this period. Rather, they should concentrate on providing technical advice for the athlete to utilise during the crossover phases. Surprisingly, no scientific research could be found that concentrated on these phases or on the relationship between the technique

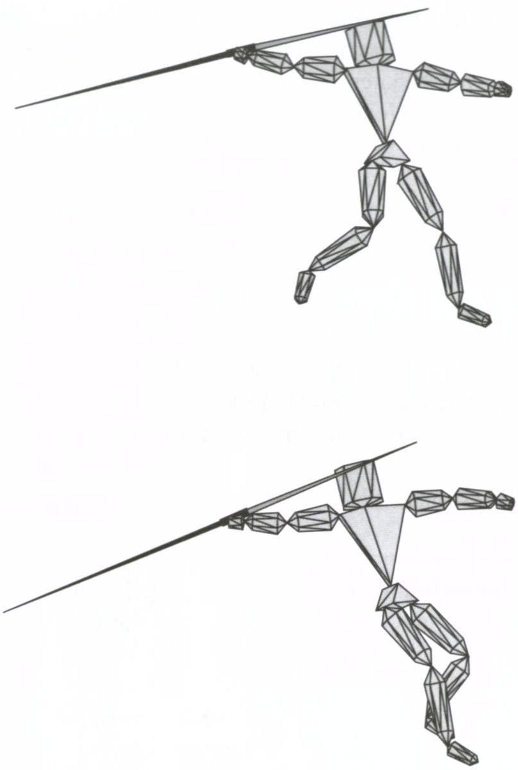

Fig. 3. Side view of an elite thrower at the instant of (**top**) left foot contact to start the last cross-over stride and (**bottom**) right foot contact to start the delivery stride.

of the thrower during the crossovers and in the delivery stride. This area is certainly worthy of attention for future research.

3. Delivery

The delivery stride begins with the thrower's final right foot strike. However, it is at the instant of final left foot strike when the thrower is considered to transfer the horizontal momentum gained in the run-up into a combination of vertical and horizontal momentum of the upper body, which is then the javelin. This instant is also known as final foot plant[8] or final foot contact. The few studies that have reported the forces or pressures acting on the foot at this instant suggest that final foot strike is the most appropriate term, as the forces are several times bodyweight (BW) at around 6.6BW[10] or 2.8BW.[11] At this instant the javelin speed for the elite male athlete will be approximately 8 m/sec.[9] This leaves approximately 20 to 21 m/sec to be generated during the next 0.12 seconds, after which the javelin will be released. The body position of the thrower at this instant is therefore of paramount importance. A body position should be adopted that will allow him to maximise the force that he can apply to the javelin, lengthen the time in contact with the implement, and transfer momentum to the javelin in the most effective manner.

3.1 The 'Block'

At final foot strike the thrower begins the process of transferring momentum from the lower body to the upper body. For a right-handed thrower this is achieved by flexing the hip and extending the knee of the left leg prior to ground contact. This leg is then used as a brace for the upper body to work against at left foot strike. For the transfer of momentum to be most effective it is thought that the athlete should flex the left knee only very slightly between foot strike and release. Indeed, a significant inverse correlation ($r = -0.93$) has been reported between the degree of front leg knee flexion and the distance thrown.[12] This suggested that if the extensor muscles of the left leg could not adequately withstand the impact of final foot strike then the upper body is forced to work over an unstable base of support.[2] This has a detrimental effect on the transfer of momentum to the upper body.

Similar correlations are rarely reported in inter-thrower studies. This is thought to be because of differences in the run-up speeds of the athletes in such studies.[7] The importance of a strong block (maintaining an extended front knee at final foot strike) is, however, seldom questioned in any study. What is also common to most studies is a lack of explanation of the mechanism that links a strong block at final foot strike to the athlete's capacity to accelerate the javelin.

Mero et al.[9] alluded to a series of stretch-shortening cycles in the delivery phase of the javelin throw. Presumably the act of blocking at final foot strike induced strong eccentric then concentric contraction of the quadriceps femoris muscles in the front leg. The act of blocking also facilitates lateral rotation of the shoulder axis (the line joining the 2 shoulder joints) from a parallel position to one that is perpendicular to the javelin runway. Again, it is feasible that eccentric followed by concentric contraction of the abdominal musculature facilitates this process. Similar observations could be made for the musculature of the shoulder, upper arm, forearm and wrist.

Supporting research for this phenomenon[13] has found that in some elite throws as much as 70% of the kinetic energy of the javelin was generated in the last 50 msec prior to release. It has been suggested[4] that such a short time is insufficient for the working muscles to generate high forces. A muscle can begin shortening with a force greater than its maximum isometric level should it be stretched beforehand.[14] Thus, it would seem that a series of stretch-shortening cycles, commencing with the proximal musculature and ending with that more distal, is a feasible mechanism for generating the high forces necessary to throw the javelin a long way. In the interests of the physical training of javelin throwers this area certainly warrants further research. Additional research relating to this topic is considered in section 3.3.

3.2 Shoulder Axis Rotation

At the instant of final foot strike, elite throwers have their shoulder axes aligned approximately parallel to the throwing direction. Values of greater than 140° for the horizontal angle between the shoulder axis and the mid-line of the throwing sector (180° would mean parallel to the sector midline) have been reported for athletes competing in the 1995 World Championships men's javelin final.[13] Adopting such a position is thought to be beneficial to the throwing performance for 2 reasons. First, a 'side-on' shoulder axis position puts the javelin the maximum distance away from its release position so lengthening the acceleration path. Secondly, leftwards lateral rotation of the trunk can be performed to give an initial acceleration to the implement. Morriss[15] reported durations of as little as 0.08 seconds for the time taken for elite throwers to laterally rotate the shoulders into a position parallel with the hips (in the horizontal plane). This gives an idea of the contribution of the abdominal musculature in accelerating the implement. It should be noted that at final foot strike the horizontal plane angle between the hip and shoulder axis was approximately 25°. Thus, the average angular velocity of the trunk during this period was in the region of 5.5 rad/sec. This rapid rotation is probably facilitated by the initial eccentric contraction of the abdominal muscles following the blocking action of the lower body at final foot strike.

3.3 Throwing Arm Elbow Angle

In addition to the orientation of the hip and shoulder axes, throwers seek to lengthen the acceleration path of the javelin by maintaining an extended elbow of the throwing arm until the instant of final foot strike. Bartlett et al.[16] found a significant difference between elite throwers and those of lower skill levels in their capacity to achieve this. Accurate values for the elbow angle at final foot strike necessitate a filming protocol that is 3-dimensional in nature. In studies using 3-dimensional filming, the best throwers reportedly achieve values in excess of 150°.[13]

Using only the angle of elbow flexion at final foot strike to give an indication of the acceleration path of the javelin can be misleading. Some elite athletes, who arrived at final foot strike with a relatively flexed elbow, have been found to perform a small degree of elbow extension immediately following final foot strike.[13] The reason for this could be to enhance the eccentric contraction of the muscles involved in the delivery action prior to concentric contraction. The flexed position of the elbow of the throwing arm at final foot strike could be misleading to coaches and practitioners of the event unless careful attention is paid to its movements in the short duration following this instant.

Although a flexed elbow position at final foot strike may reduce the acceleration path available to the thrower, these negative effects may be outweighed by other, more beneficial factors. Carrying the javelin with a slightly flexed elbow may put the working muscles that cross the shoulder and elbow joints in the optimum position with regard to their force-length-velocity relationship. Voigt et al.[17] investigated the muscular factors which influenced performance in maximal vertical jumping after the muscles received different pre-stretch loads. Results confirmed earlier findings[18] that pre-stretching the muscles did improve performance, but the mechanism responsible for this improvement was not quite as simple as re-utilising stored elastic energy. Voigt et al.[17] explained the improvement in performance as a regulation in the position of the fibres of the working muscles with respect to their own force-length-velocity profile. In other words, the potential of the muscle fibres to contract concentrically was preserved by not over-stretching them during eccentric contraction. Positive work could then be performed by these fibres in concert with the release of strain energy from the tendon. Hence the improved co-ordination of muscle recruitment combined with the appropriate muscle loading optimised the work output from the muscle-tendon complex.

In relation to javelin throwing, a coach's instructions to an athlete would normally advise the maintenance of a relaxed upper body and an extended right elbow through the crossovers until final foot strike. Whether these instructions are the most beneficial to the athlete's performance, or whether they are actually adhered to by the athlete, is open to question.

3.4 Carry Height

The carry position of the javelin has received widespread attention in the literature. It is generally measured as the vertical distance between the throwing shoulder and the grip or as the horizontal distance between the right hip joint and the grip. A lower carry has been reported to significantly correlate with the distance thrown.[19] This suggested that the better throwers tended to carry the javelin lower, which may have been for one of two reasons: to increase the acceleration path of the javelin or to help the thrower in attaining an appropriate angle of release. Not all research is in agreement with these findings, possibly because later studies have been conducted on the throws of athletes competing with new-rules javelins. Morriss and Bartlett[20] studied throwing techniques in 22 men's throws that ranged in distance from 88.14 to 69.40m. They found that the athletes who adopted a higher carry at the start of the delivery seemed to benefit in many ways. The angle of attack and the angle of yaw or sideslip (fig. 1) were lower. This resulted in throws with a 'cleaner' release with smaller drag forces acting on the javelin, but not to the detriment of the release speed or release angle. Furthermore, the maximum lateral displacement of the javelin during the delivery was less for the longer throws which implies that smaller lateral forces were applied to the javelin. This has consequences for the aerodynamics of the implement because the application of forces that are not directed through its long axis will cause it to vibrate when released. Vibration is highly likely to increase the aerodynamic drag acting upon the javelin in flight so shortening its flight time and, consequently, the distance thrown.

3.5 Sequencing of Segmental Movements

Possibly the most important element of any successful overarm throwing activity is the sequential timing of the peak linear speeds of body segments. Proximal segments should reach their peak speeds first followed by those progressively more distal.[21] An orderly progression in peak linear speeds from proximal to distal segments was reported for the 22 finalists in the men's and women's javelin finals of the 1992 Olympic Games.[1] A similar, unsurprising finding has also been reported for other high level athletes.[22] Surprisingly, novice athletes throwing a mean distance of 29.80m have also been found to show a correct pattern of temporal sequencing.[16] The difference of course lies in the peak speed of each joint centre, with elite athletes obviously attaining greater speeds at each joint.

Of much interest to the sports scientist and javelin coach is the contribution to the release speed

Table I. Peak joint speed and time from final foot strike to release[9]

Joint	Silver medallist		Gold medallist	
	speed (m/sec)	time (msec)	speed (m/sec)	time (msec)
Hip	5.2	50	8.4	10
Shoulder	10.0	50	9.6	70
Elbow	17.7	50	16.0	90
Wrist	22.7	80	20.3	110
Hand	24.7	80	21.7	120

of the implement made by the movement of each body segment. The hip, shoulder, elbow, wrist and hand of the throwing side of 2 Olympic athletes are shown in table I.[9] The ways in which each athlete achieved relatively similar javelin release speeds of 29.2 and 29.5 m/sec were markedly different. This must have resulted from the very different movement patterns of the 2 athletes studied.

Supporting data, from an analysis of the men's javelin final at the 1995 World Championships, on the same 2 athletes also showed markedly different movement patterns.[13] For example, the values for the maximum lateral displacement of the javelin during the delivery were calculated to be 0.63 and 0.09m for the 2 throws (fig. 4). For both throwers the frontal plane horizontal displacement of the centre of the hip axis from the centre of the shoulder axis was 0.09m. Hence, the differing paths of the javelin were attributed more to the movements of the throwing arm than to the orientation of the trunk, which has suggested to be the causal factor in such movements.[21] What is more, the peak angular velocities of the shoulder and elbow joints for these 2 throws were 15.6 and 21.8 rad/sec (shoulder angular velocities) and 45.0 and 25.6 rad/sec (elbow angular velocities). The angular velocity of the upper arm at the shoulder joint was produced by a combination of abduction, horizontal flexion and extension, whereas extension was the only action of the forearm about the elbow.

Internal rotation of the humerus (and possibly pronation of the forearm) could contribute greatly to the acceleration of the javelin but these were not measured in this study. Nevertheless, these results suggest that the patterns of muscular activation or the muscles used to accelerate the javelin were different for the 2 athletes. It would therefore seem appropriate that the training programmes of each athlete should be different and designed very specifically to fit their unique movement pattern. Examining the contribution of the upper body musculature to the release speed of the javelin would seem a fruitful area for future research.

4. Recovery

Following release, the javelin is only acted upon by aerodynamic and gravitational forces. Hence, the thrower can do no more to influence the flight path of the javelin, but his task is not yet complete. He must deliver the javelin and then halt his forward momentum such that the foul line is not crossed. The thrower, therefore, has conflicting goals. He will want to deliver the javelin as close as possible to the foul line, but not so close that his forward momentum will carry him across it. This makes the blocking action of the left leg at final foot strike all the more important. For instance, in a recent study of the 1994 European Championships men's javelin final[15] the bronze and silver medal throws were separated by only 0.32m. What is interesting is that the bronze medallist actually threw the javelin 0.10m further than the silver medal winner but attained third position because he released the javelin 0.42m further back from the foul line. Of the 12 athletes studied, the silver medallist blocked most effectively. More specifically, the reduction in the horizontal velocity of his mass centre between the instants of final foot strike and release was 66%, a value at least 18% greater than for any other athlete.

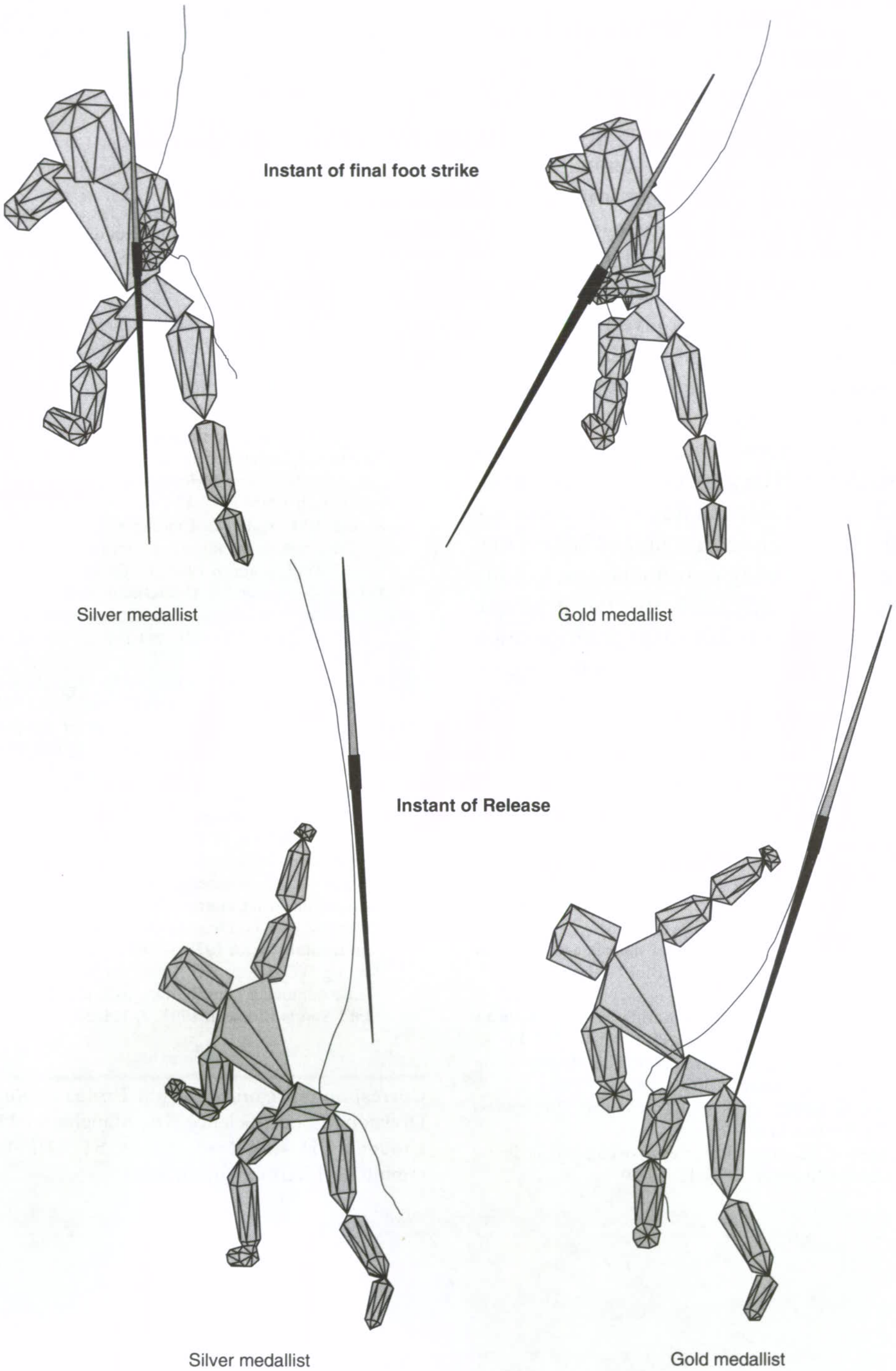

Fig. 4. Elevated rear view of the silver and gold medallists at the instant of final foot strike and release in the 1995 World Championships men's javelin final.

5. Conclusions

The technique of the javelin thrower is crucial to his successful performance which explains the number of investigations concentrating on this aspect of the throw. This review has summarised and reflected on the important findings from such investigations and outlined some areas for future research. Such research should firstly take account of the 3-dimensionality of both the thrower's movements and of the release of the javelin. Secondly, technical analyses of the event should seek to develop, evaluate and modify a technique model of the event such as the example given in figure 2, otherwise the implications for coaches and athletes from such studies will be subjective and less meaningful. Finally, the understanding of the aetiology of javelin throwing injuries has lagged behind that of other overarm throwing movements, such as the baseball pitch. It is highly likely that the technique of the javelin thrower is linked to his predisposition to injury. Research to establish the causative injury mechanisms for javelin throwers, drawing where appropriate on the literature for similar throwing events, is therefore required.

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Correspondence and reprints: Professor *Roger Bartlett*, Division of Sport Science, The Manchester Metropolitan University, Hassall Road, Alsager ST7 2HL, England.
e-mail: R.M.Bartlett@mmu.ac.uk