The Biomechanics of Elite Javelin Throwing Technique

Calvin Morriss, Roger Bartlett, Enrique Navarro and Jukka Viitasalo

Introduction

In the men's javelin went recent publications have typically focused on two particular aspects, the aerodynamics of the javelin and its behaviour in the initial stages of flight, and the technique of the thrower during the latter stages of the run-up and delivery. The present study concentrates on the latter. Using existing three-dimensional cinematographic procedures an analysis of the techniques of elite throwers was conducted. Kinetic energy transfer calculations were also performed to give further insight into the complex movements of these athletes. The specific aims of the study were two-fold. Firstly, to establish fundamental aspects of elite javelin throwing technique that are of use to coaches and practitioners of the event at all levels. Secondly, to identify differences in throwing style between athletes that would have implications for their physical training requirements.

Methods

Two cameras were used to film every throw of the men's javelin final at the 1994 European Championships in Helsinki. The first, a high speed NAC video camera, operating at 200 Hz was placed approximately orthogonal to the javelin runway and zoomed so that the thrower's movements incorporating the end of the last cross-over stride, the delivery stride and the first few metres of the javelin's flight were in view. The second camera, a Magnavox camcorder, operating at 60 Hz, was placed to the rear of the runway and was prepared with a similar zoom setting.

The throwing area was calibrated before and after the event using six extendible poles placed at intervals along each side of the runway comprising a volume of approximately 25 m^3 (2.5 m x 4 m x 2.5 m). Spherical markers were connected to the top and the base of each pole serving as reference points for the calibration system. The xyz coordinates of each point were calculated using an Elta tachymeter.

The best throw of each athlete was then subjected to coordinate digitisation using an M-Image video capture board interfaced with an Acorn Archimedes 440 microcomputer. Event synchronisation was achieved by observation of the instant of right foot strike to begin the delivery stride. Every frame in the 60 Hz sequence, beginning at the point selected for event synchronisation, through to 3 or 4 frames after release was digitised. Every other frame from the 200 Hz sequence was also digitised to cover the same time period and the data resulting from this interpolated to represent a 60 Hz sampling frequency. The

3-dimensional object-space coordinates of eighteen points, defining a fourteen segment performer model, plus the tip, grip and tail of the javelin were then reconstructed from the two sets of image coordinates using a DLT algorithm, correcting for linear lens distortion. After computation of the thrower's mass centre coordinates and body angles required for biomechanical analysis, the data were smoothed and velocities and accelerations calculated using cross-validated quintic splines.

Translational kinetic energies of the body segments were calculated using the mass of each segment and its linear velocity. A local reference system was then fitted to the centre of mass of each segment and its rotational kinetic energy calculated using the values for the segment moment of inertia (Whitsett, 1963) and its angular velocity about the centre of mass.

Results

Certain aspects of body position at the instant of final foot strike (ffs) were similar for all athletes. This body posture could be described as one where the hips were approximately perpendicular to the throw direction (horizontal angle of 90") and the shoulders rotated 50" further back. The 'carry' position of the javelin was high (approximately 5 cm vertically below the throwing shoulder).

Energy flow analysis conducted upon each athlete revealed a correct pattern for each athlete. Peak kinetic energy levels were reached earlier for larger, more proximal, body segments and later for the smaller, more distal, segments. As expected, energy was seen to flow appropriately through the kinematic chain to the javelin for all throwers.

Differences in technique between athletes were evident. It was found that athletes who were able to reduce the horizontal velocity of their body centre of mass by the greatest amount during the period between ffs and release (ffs-rel) threw the furthest ($r = 0.60$, $p = 0.039$). A further significant inverse relationship was found between the degree of lead leg knee flexion during ffs-rel and the distance thrown ($r = -0.59$, $p = 0.044$).

Athletes varied in their ability to maintain an extended throwing arm up to the instant of ffs. The throwing arm elbow angle at this instant ranged from 149° to 118° for the 12 athletes.

The path of the javelin through the delivery was also found to vary greatly between throwers. The lateral displacement of the grip during the delivery ranged from 0.25 m to 0.62 m and were for the gold and bronze medal throwers, respectively. Estimated lateral forces based on the lateral acceleration of the grip were 58 N and 148 N for these throws. This would have had consequences for the aerodynamic drag forces experienced by the javelin in flight owing to flutter.

Discussion

The impulse generated by the thrower to commence the delivery of the javelin is generally accepted to begin at the instant of ffs. The following delivery phase lasts approximately 0.12 s in which there is practically no way for the athlete's movements to be coached. Instead, attention is better spent on the events leading up to it. The similarity of aspects of each thrower's body position at ffs for the 12 athletes in this study lends itself to the coaching of fundamental aspects of the throwing technique. The shoulder axis should be approaching a position parallel to the throw direction and the hips more 'open'. The javelin should be carried in a high position. Momss and Bartlett (1994) found that athletes adopting a high carry at ffs attained smaller yaw angles at release and a lower lateral displacement of the javelin during the delivery than throwers who used low carry positions. As the throws in this study were longer than many of those in the Morriss and Bartlett (1994) study, it may be that a high carry is characteristic of elite throwers who, by a process of trial and error, have found this position to be favourable in producing an appropriate release with the new-rules unroughened javelin.

The significant relationship found between the reduction in the horizontal velocity of the thrower centre of mass during ffs-rel and the distance thrown, has often been explained as a lack of strength in the quadriceps muscles of the lead leg of the less successful throwers. This is supported by the significant inverse correlation between the degree of lead leg knee flexion during ffs-rel and the distance thrown. The function of the block at ffs is to accelerate the larger body segments to begin the delivery. Joris et al. (1985) suggested that acceleration of heavy proximal segments is used to facilitate eccentric contraction of the involved muscles of the distal segments immediately prior to their concentric contractions. Thus it might be that the less successful throwers in this study who blocked less effectively, were not lacking in strength of the quadriceps muscles. Rather, the strength and flexibility of the upper body segments which would undergo large eccentric forces as the result of a strong block may have been a limiting factor.

Maintenance of an extended throwing arm elbow angle up to the instant of ffs should provide the athlete with a longer path over which to accelerate the javelin. The elbow angle of 149" at ffs for the gold medallist compared to the 118° measured for the eighth placed athlete, would mean that each athlete lost approximately 4 % and 15 % of the acceleration path available to him. However, some throwers who arrived at ffs with a relatively flexed elbow reduced the kinetic energy of the javelin for a few moments following this instant. Study of the angular displacement data for this joint showed a small degree of elbow joint extension immediately following ffs. The reason for this could be to enhance the eccentric contraction of the muscles involved in the delivery action. Nevertheless, the flexed position of the elbow of the throwing arm at ffs could be misleading to coaches and practitioners should careful attention not be paid to its movements in the short duration following this instant.

The different delivery styles of the gold and bronze medallists will have consequences for both the aerodynamic drag forces experienced by the javelin after release and the stresses placed on the upper body during the delivery phase. Based on the **maximum** horizontal lateral acceleration of the javelin grip for these two throws, estimates for the lateral forces applied to the javelin were 58 N (gold) and 148 N (bronze). Owing to the elasticity of the javelin these lateral forces are responsible for the vibration of the javelin at release. It is likely that an increase in javelin flutter will increase the aerodynamic drag acting during flight, hence, the more lateral, round-arm style of the bronze medallist may be detrimental to performance as opposed to a more linear style because of the vibration induced in the javelin.

The round arm style of throwing has also been reported to place great stress on the medial collateral ligament of the elbow (Williams, 1980), where as the linear style of delivery used by the gold medallist places great stress on the shoulder musculature. The maximum angular velocities of the elbow joint, in extension, for the gold and bronze medallists were; 4.8 $rad.s^{-1}$, 29 $rad.s^{1}$ and, for the shoulder joint, 17.4 $rad.s^{-1}$, 15.0 $rad.s^{-1}$. As the minimum elbow angle for the gold medallist during the delivery was 133" the emphasis on the musculature crossing the shoulder joint to accelerate the javelin is clear. Such large differences in the natural throwing styles of these athletes implies that the specific physical training each conducts should cater for their different needs. A more detailed analysis of the coordination patterns and exact movements, predominantly of the upper body, would be required to design a very specific training mode or programme for each athlete. However, an emphasis on training of the shoulder musculature for the gold medallist and that surrounding the elbow for the third place athlete would seem approriate.

References

Joris, H.J.J., Edwards van Muyen, A.J., van Ingen Schenau & Kemper, H.C.G. (1985). Force, velocity and energy flow during the overarm throw in female handball players. *Journal of Biomechanics*, **18,** pp. 409-414.

Morriss, C. J. & Bartlett, R M. (1994). Carry height of the javelin and its effect on throwing performance. In J.T. Viitasalo & U. Kujala (Eds.) *Proceedings of the International Conference on Applied Research in Sport "The Way to Win", Helsinki,* pp.133-137.

Whitsett, C.E. (1963). Some dynamic response characteristics of weightless man. AMRL Technical Report 63-18, Wright-Patterson Air Force Base, OH.

Williams, J.G.P. (1980). *Atlas of Injury In Sport.* London, UK.: Wolfe Publications.