Biomechanical Analysis of a World Record Javelin Throw: A Case Study

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As part of an ongoing project to evaluate elite track and field throwers in the United States, the javelin competition was filmed during the 1983 Pepsi Invitational Track Meet. A high-speed video camera (Spin Physics SP2000) was positioned orthogonal to the javelin runway to record the release of all throws. During this competition, Tom Petranoff's world record (99.72 m) was filmed at 200 fields per second. Subsequent frame-by-frame digitization yielded results consistent with reports in the literature. Release velocity was 32.3 m/s and represents one of the highest values ever reported. Angle of release was .57r, javelin attitude at release was .64r, and angle of attack was .07r. While optimum values for these release parameters, in light of published results, remain open to discussion, the results presented here represent unique information on a world record performance and can serve as a basis of comparison for future performances.

Biomechanical data on elite performances are rare and, in general, not well documented in the literature. While qualitative results on selected aspects of performance are prevalent, and certainly important to the coach and athlete, this type of information provides a limited basis for sound mechanical comparisons.

Throwing, a popular but complex motor activity, has limited scientific documentation (Ariel, 1973). Some qualitative components discussed in the literature concern relative timing of body segments and body position at release. Quantitative parameters such as release velocity, angles of release, linear and angular acceleration, mechanical energy transfer, and net moments of force about a joint are also important. With more emphasis

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placed on data collection during competition, there will be useful scientific documentation of throwing performances which will then serve as a quantitative data base for future comparisons (Rich, Whiting, McCoy, Gregor, & Ward, in press).

As part of the Elite Athlete Project sponsored by the United States Olympic Committee, national and world-class American javelin throwers have been studied, biomechanically, for the past 3 years (Rich et al., in press). The purpose of the current project was to collect video records of all javelin throwers during the UCLA-Pepsi Invitational Track Meet (May 15, 1983). During this competition, a world-record javelin throw by Tom Petranoff (99.72 m) was recorded. The results of a biomechanical analysis of this throw are described below. This information affords a unique opportunity to evaluate a rare athletic achievement and can serve as a comparison for other elite throwers.

**Methods**

**Subject**

The information presented here represents a case study of Tom Petranoff's world-record javelin throw (99.72 m). Tom was 1.88 m tall and weighed 965 N at the time of the throw. He was 25 years old and had 6 years of javelin throwing experience. His previous best record throw was 90.5 m, but unofficially he had thrown 94 m in clinics. The aerodynamic javelin used for his record throw was a Dick Held Custom III.

**Data Collection**

A high-speed video camera (Spin Physics SP-2000) was set up orthogonal to the javelin runway to record the release of all throws. The SP-2000 system consists of specially designed video cameras controlled by a central microprocessor. The sensor used in each camera is a solid state MOS-photo capacitor array consisting of 192 x 240 charge-accumulation cells. Image data is transferred to the control unit, FM modulated, and copied to 0.5 inch high-density magnetic tape. Thirty-two separate demodulators are then used to reproduce the recorded information on playback.

A high-speed analog to digital converter scans the 32 demodulated signals and converts them into binary numbers which are transferred to digital buffer memory where they remain until updated by the next frame of information. A digital to analog converter processes the output from the digital buffer memory to a TV monitor, forming a composite video signal that is mixed with the synchronization and timing signals needed to produce a standard TV picture. The SP-2000 has high-speed recording rates ranging from 60 to 2000 full pictures (or fields) per second (fps). Two hundred fps were used in this investigation.

**Data Analysis**

Single frame advance was utilized during data reduction. As each frame was viewed, a reticle, integral to the video screen, estimated 13 segment endpoints on the thrower and three points on the javelin. The points on the javelin were the front edge of the grip and two other points on its long axis estimating the nodal points. The x and y coordinates of
these 16 points were displayed numerically on the video screen. A linear multiplier filmed in the field of view permitted quantification of these data points. Specific parameters analyzed in this investigation were (1) lead foot to foul line distance, (2) height of release, (3) release velocity, (4) angle of release, (5) attitude angle, (6) angle of attack, and (7) stride length (Figure 1). Release velocity was determined by averaging instantaneous velocities over a 15ms period of time immediately following release.

Analysis Limitations

Prior to any discussion regarding ideal conditions, Miller and Munro (1983) point to discrepancies in the literature regarding terminology. By strict definition, the angle of attack is the angle formed between the long axis of the javelin and the relative air flow vector with the latter being a function of both wind and release velocities (Miller & Munro, 1983). Since it is virtually impossible to monitor precise wind conditions in the space surrounding the javelin at release, we have chosen to define the angle of attack as stated in Figure 1. Miller and Munro (1983) called this angle the "uncorrected angle of attack."

Throwing motions do not occur in a single plane. Three-dimensional analysis requires two phase-locked high-speed cameras capable of recording movement in a relatively

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**Figure 1** — Leadfoot/Foul Line Distance (1) Horizontal distance from the toe of the plant (lead) foot to the foul or scratch line; Height of Release (2) Vertical distance from the front edge of the grip to the ground at release; Release Velocity (3) The magnitude of the velocity vector of the front edge of the grip at the last instant of release; Release Angle (4) The angle between velocity vector and a horizontal reference at release; Attitude Angle (5) The angle formed by a line drawn between the two nodal points of the javelin and a horizontal reference at release; Angle of Attack (6) The difference between release and attitude angles; Stride Length (7) The distance between right and left foot at the heel strike of the left (lead) foot.
large calibrated space. While we were fortunate to obtain quantitative information on this world-record performance, the limitations of a planar analysis were recognized. Additionally, segment endpoint markers were not placed on the performer.

Regarding the accuracy with which these measurements were made, some comment is needed on the resolution of the SP-2000. Time and distance were the only two measures extracted directly from the video screen, and the time base, or scan rate, is considered to have less than 1% variability (Hyzer, 1981). Therefore, there can be up to 1% uncertainty in velocity, even if all other errors are zero. At a scan rate of 200, the variability in the time base was 0.05 ms.

During the data reduction phase, each pixel on the video screen represented 0.02 m in real life. Within and between rater reliability in determining release was excellent ($r = 0.99$). However, if this event were consistently different by one complete frame (5 ms), at 32 m/s the actual position of the javelin at release would be off by .16 m. This is the distance the javelin would travel in 5 ms at a velocity of 32 m/s. Using several points before and after release, calculations of release velocity varied within 1 m/s, and release angle varied to a maximum of .07 r. Angular velocity ($\omega$) of the javelin at release was not measured, and it is felt that the vibration of the javelin during release contributed to the variability in release and attitude angle measurements.

Results and Discussion

Quantitative results and graphic representation of Tom Petranoff’s world-record throw are presented in Figure 1. There is good agreement among performance analysts that the magnitude of release velocity is the most significant factor affecting the distance traveled by the javelin. Petranoff’s release velocity of 32.3 m/s is one of the highest ever recorded in this event. Terauds (1975b) reported a correlation of 0.72 between release velocity and distance thrown, with approximate velocity magnitudes of 30 m/s for world-class throws. Miller and Munro (1983) point out that previous studies fail to consider the thrower’s distance from the foul line at release. They reported distances ranging from 1.1 to 3.9 m ($M = 2.46$ m) for throws ranging from 66 to 80 m with release velocities between 25 and 30 m/s. Correcting for this distance from the foul line, correlations between distance thrown and release velocity ranged from $r = 0.84$ to $r = 0.94$. A thrower’s distance from the foul line at release will vary and the thrower, hopefully, will take into account his approach velocity, braking capabilities of lead (plant) leg, type of runway surface, and specific form during follow-through. Petranoff’s distance from the foul line was 2.33 m during this throw, which was less than the mean reported by Miller and Munro (1983) for throws of shorter distance. The fact he could release closer to the foul line resulted in less distance being subtracted from his actual throw.

A second major concern to the thrower focuses on the various javelin angles at release. Angle of release has been reported in the literature to vary between .35 r and .72 r (Miller & Munro, 1983). Petranoff’s release angle was .57 r, which is in the lower part of the range reported by Nigg, Rothein, and Wartenweiler (1974), of .52 to .68 r, and in the upper part of the range reported by Terauds (1975b) of .35 to .61 r. The attitude of the javelin at release was .64 r. By our definition, this results in a .07 r angle of attack. Both Terauds (1975b) and Nigg et al. (1974) report small differences between release and attitude angles. The implication is that a zero radian angle of attack is optimum. In contrast to this, data reported on Nemeth’s world-record throw (Teraud, 1975b)
show a $-0.11$ angle of attack (attitude angle of $0.61$, release angle of $0.72$). While Petranoff consistently had a small positive angle of attack, optimum values for this parameter, in light of published results, remain open to discussion.

Additionally, while stride length and release height will be influenced to some degree by the thrower’s size, Tom’s release height of $2.09$ m agrees well with the $2.08$ m mean value reported by Miller and Munro (1983) for good throwers.

Comparing actual calculations with optimal simulations is important in determining variables critical to successful performance. Regarding the data presented on Petranoff’s world-record throw, we can make such a comparison. Hubbard (in press) reports a set of optimal initial conditions for a javelin throw with a release velocity of $31$ m/s. Table 1 summarizes our calculations with respect to his optimal simulation, and the similarities are pronounced. While all values are within $0.05$ $r$, differences are felt to be due, in part, to the differences in release velocities.

In summary, it would appear that the data presented on selected parameters obtained during the release phase of Tom Petranoff’s world-class javelin throw agree with the information and ideas presented in the literature on elite throwers.

### References


