THE DYNAMIC ANALYSIS OF THE APPLIED FORCE ON JAVELIN DURING FINAL THRUST BY AN ELITE JAVELIN THROWER

Guo-Hong Gu[1], Yeh-Jung Tsai[2], Chenfu Huang[1]

[1]National Taiwan Normal University, Taipei, Taiwan
[2]National Taipei University of Education, Taipei, Taiwan

According to the javelin rules, a throw is valid only if the tip strikes the ground before any other part of the javelin. So it is important to precisely control the applied force on javelin for further distance and tip-first landing. Two synchronized Redlake high-speed cameras (250 Hz) were used to videotape an elite thrower; a javelin with three fixed non-collinear markers was used in experiment. The aerodynamics and Newton-Euler equation were taken into account in the 3D inverse dynamic analysis. The results showed that the force was mainly on the axial direction as the whole hand gripped the javelin. However, as the portion of hand touching the javelin became lesser, the direction of force was changed from axial to lateral direction. The lateral torque was significantly larger than axial torque during the whole phase, and their maxima were 24.08 and 1.31 Nm, respectively. The results measured by this method were similar to those by force sensor, and it could be suitable for use in further researches.

KEY WORDS: javelin, inverse dynamics, force, torque.

INTRODUCTION: According to the International Amateur Athletic Federation (IAAF) rules, a throw is valid only if the javelin lands tip-first. And acceleration and rotation are products of force and torque. So understanding the force and torque applied to the javelin is important for a successful throwing. If the force applied to the javelin is not proper, it may not only cause the javelin over-rotation but also make it flat landing. Maeda, Shamoto, Moriwaki, and Nomura (1999) also indicated that the measurement of the force could provide important information about the javelin simulations, design and better throwing. In their research, a force sensor was attached to the javelin to measure the force and torque of the three components of local frame. However, that method is more complicated and may change the characteristics of the original javelin. Moreover, the force sensor is connected by a wire, which could interfer the throwing motion. In this study, an IAAF javelin with three non co-linear markers and the 3-D inverse dynamic method were used to calculate the applied force. The purpose of this study was to measure and analyze the javelin dynamics by an easier method.

METHOD: A national record holder (male, best record: 76.18 m) was recruited as the subject, age: 20 yrs, height: 178 cm, weight: 78 kg. Two synchronized Redlake high-speed cameras (sampling rate: 250 Hz, shutter speed: 1250 Hz) were setup on two sides of the runway to record the data. In order to access the local coordinate system, some landmarks needed to be set on the javelin. A total of three non co-linear markers and an IAAF-approved javelin were used in this experiment. The first one (point A) was located on the tip portion. In order to setup another two markers, a wing-like device made of #14 Zn wire was fixed on the tail portion. The wing weighs 7.39 g. The position of the wing is not unchangeable, and it could be adjusted to a proper site for individuals. B and C points were fixed on two sides of the wing (Fig. 1). Whether the tip landed first or not, the position and shape of the wing was checked and adjusted after each throwing.

The position of the wing was determined by the following three principles:

1. No injury to athlete
2. No interference with athlete
3. As close to grip as possible (in order to reduce the error from vibration)

Figure 1: The overview of javelin with three landmarks (left) and magnifying photo of the wing with two markers (right)

The video clips were digitized by Kwon-3D motion analysis system, and the raw data was smoothed by Butterworth 4^{th} -order zero lag with 10 Hz cutoff frequency. Position vectors of the marks defined the local coordinate system. P point was set as the middle of B and C. Vector (the direction of javelin longitudinal axis) was defined as Z-axis. X-axis was defined as $PC \times PA$. Y-axis was defined as $Z \times X$. Two neighbor video frames defined the rotation matrix. The angular kinematics was calculated by Cardan angle method, and the GCVSPL (Woltring, 1986) was used in the first and second derivatives. The aerodynamics of the wind and the Newton-Euler equation were taken into account in 3D inverse dynamic calculation. The sectional and side areas of the shaft were 9.021 and 598.496 cm^2, respectively (measured by myself). The drag coefficients of the tip and shaft were 0.4 and 1.2, respectively. The axial force and torque were the force and torque along the z-vector (longitudinal axis); the lateral force and torque were the resultant force and torque of the other two vectors (x & y). Matlab 6.5 was used in computer programming.

RESULTS AND DISCUSSION: The subject performed three throws, mean flying distance was 61.87 ± 0.99 m. It indicated that the throws are homogenous. The best one (62.91m) was chosen for analysis. Some kinematic parameters of this throw at release are printed in Table 1.

Table 1 Some release parameters of the best throw

Release velocity (m/s)	Angle of release (deg)	Angle of attitude (deg)	Grip height (m)
25.37	41.23	41.33	1.95

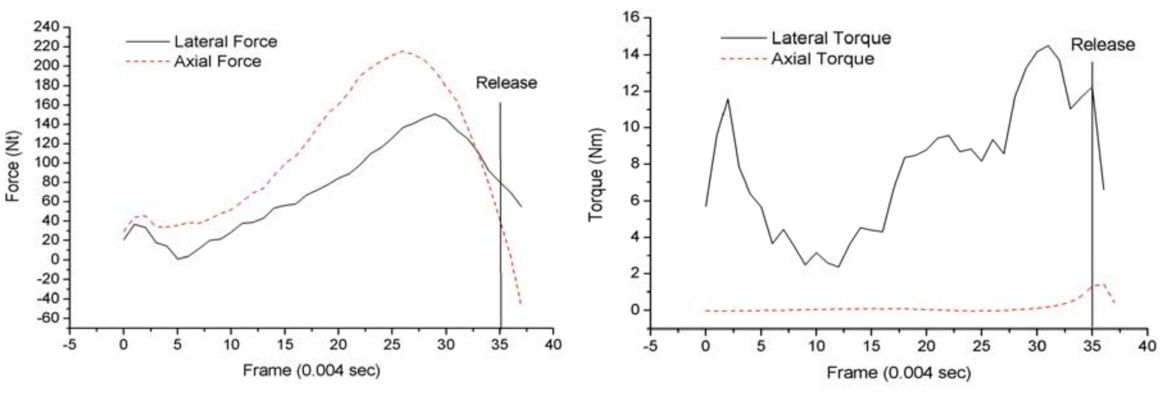

Figure 2: The force and torque applied to the javelin during throwing

During the frames 0 to 5, from about the final right heel landing to shoulder starting internal rotation, while the right arm was still outward stretched and with full-extended elbow. Fig 2 shows a small decrease in both axial and lateral force curves, which means that there was a short-time relax in the arm before starting to accelerate the javelin. This may not only help the arm storing more energy before acceleration but also improve coordination of muscle recruitment. The frames 5 to 35 represent the phase from shoulder starting internal rotation through elbow flexion and extension to javelin release. Figure 2 shows that both the axial and lateral forces significantly increased to maximum, then decreased. The acceleration phase lasted for approximately 0.12 seconds; these forces accelerated the javelin for the maximum release speed. The axial force reached its peak 215.58 Nt 0.0036 sec before release, following the lateral force reach its peak 150.75 Nt (about 0.024 sec before release). After peak, the part of the hand that controlled the javelin become less and less, so both forces applied to javelin decreased. For this athlete one thing is noteworthy: the axial force was always larger than lateral force until frame 32 (about 0.01 sec before release). Then the lateral force becomes larger. The switch point is at about the time the javelin is going to be controlled by a few distal parts of index finger, middle finger and ring finger. This indicates that when the whole hand gripped the javelin, the direction of the applied force by arm was mainly focused on axial direction. When the javelin was to be released and controlled just by the distal parts of ring and middle fingers, the main distribution of the applied force was changed from axial to lateral direction. So the lateral force becomes larger than axial force near release; this showed the that function of the distal portion of fingers was mainly contributed to the lateral movement and vibration (Hubbard & Laporte, 1997), or to adjust the proper release angle.

For torques, lateral torque significantly differs from the axial torque. The curve pattern of the lateral torque is more like that of the applied force than axial torque (Fig 2). Initially the lateral torque decreased, then increased to peak 14.51 Nm, 0.024 sec before release. Compared to the lateral torque, the value of axial torque was relatively small all the time. It reached the peak 1.31 Nm shortly before release. The function of lateral torque was mainly on making the javelin lateral rotation, which may make some contribution to tip-first landing. The axial torque can make the javelin rotate along the longitudinal axis, and that could make the javelin move through the air more stably. In this throw the angular velocity along the longitudinal axis at release was 6940.6 deg/s (19.27 rps), and this value is in the range reported by some Internet related articles. Figure 2 shows that the thrower made more effort to control the rotation along lateral axis than longitudinal axial. The thrower should apply proper lateral torque on javelin. If the lateral torque is more than needed, this may cause an over-rotation of the javelin and then induce large wind resistance. On the contrary, if it is deficient, this may cause the tip go upward and make the javelin flat land.

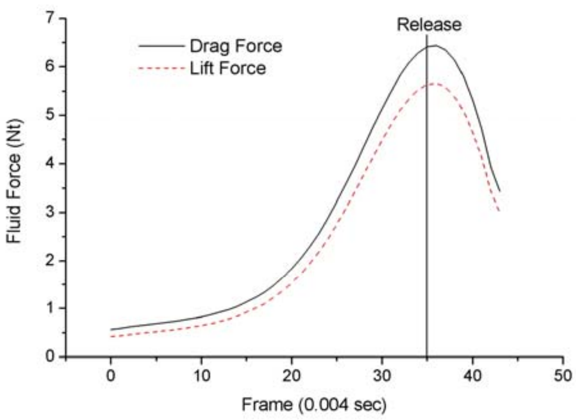

Figure 3 The drag and lift force caused by the wind during throwing

Here, the aerodynamic forces of the wind were presented on the global coordinate system (the ground system), not on local coordinate system (the javelin system). The lift force was the total components of force on the javelin perpendicular to the ground. The drag was the total components of force parallel to both the ground and the javelin runway. Aerodynamics are very important not only for the flying phase but also for the final thrust phase. Figure 3 showed that the drag force was always larger than the lift force. The maximum of drag and lift forces were 6.41 Nt and 5.64 Nt, respectively, and both occurred almost at release. It indicated that the effect of the wind was to make the javelin move toward the opposite direction of the runway rather than upward direction. According to our calculation, if aerodynamics of the wind were neglected in inverse dynamic calculation, there would be a large error in the axial force, it's peak becomes 210.74 Nt, and this is less about 5 Nt (2.24%) than the original one (215.58 Nt).

CONCLUSION: For this athlete, the results showed that the direction the most applied force concentrates on is not always the same; it varies during throwing. Analyzing the force and torque applied to the javelin may improve the understanding of how an elite javelin thrower achieves success and how to perform effective throwing technique. This study calculates the kinetic variables of the javelin by inverse dynamics, and the result was similar with that measured by force sensor (Maeda, Shamoto, Moriwaki, and Nomura, 1999). However, this method is easier and makes little change on the characteristics of the javelin. Moreover, it has no interference of connecting wire. So it could be suitable for use in further javelin researches.

REFERENCES:

Maeda, M., Shamoto, E., Moriwaki, T., & Nomura, H. (1999). Measure of applied force and deflection in the javelin throw. Journal of Applied Biomechanics, 15(4), pp. 429-442.

Woltring, H. J. (1986). A Fortran package for generalized cross-validatory spline smoothing and differentiation. Advances in Engineering Software, 8, pp. 104 -147.

Hubbard, M., & Laporte, S. (1997). Damping of javelin vibrations in flight. Journal of Applied Biomechanics, 13, pp.269-286.