BIOMECHANICAL ANALYSIS OF ELITE SHOTPUTTERS

The purpose of the present study was to analyze the performance of elite American shotputters as part of a series of studies to be conducted for the U.S. Olympic Committee. Some of the people involved with the present study include Dr. Charles Dillman of the U.S. Olympic Committee; Dr. Paul Ward, coordinator of the Elite Athletes Project-Throwers, of the Chicago Health Club organization; and from the Coto Research Center, Dr. M. Ann Penny, Mr. Dany Saar, and the author of the study, Dr. Gideon Ariel. The two organizations involved in the analysis are the U.S. Olympic Training Center and the Coto Research Center.

A review of past studies and a general description of biomchanical analysis of shotputting technique is summarized in the article by Satsiorsky, Lanka and Shamanov. This reveiw is presented in Appendix A. The present study is the most comprehensive study to date relating to shotput technique. For the first time, a complete three dimensional analytic procedure has been utilized to evaluate this athletic performance. When comparing this quantitative method of analysis to previous studies, conducted by the present author, the following differences exist:

1. The measurements have been calculated in the true plane of motion.

2. Movements were recorded and calculated in all three planes of motion.

3. Calibration was performed with over-determined equations which increases the accuracy of the measurements.

4. A combination of Cubic Spline and Digital filter technique were applied to the digitized data which allowed extraction of the best fit for the data.

5. The filming session utilized three cameras --- side, rear, and top views. Tracing of the body joint centers was, thus, facilitated since if a joint was obscured form one view it was visible from another.

6. Three force plates were utilized to assess the contact forces in the horizontal, vertical and lateral, directions.

For this specific study, the following elite athletes were analyzed:

1. Lorna Griffin - currently longest female thrower
2. Dave Laut - 1981 TAC champion
3. Brian Oldfield - American record holder

METHOD

In May, 1982, a group of national class U.S. elite throwers were invited to the Coto Research Center in Coto de Caza, California by the U.S. Olympic Committee for a shotputting clinic. Attending the clinic were some of America's elite throwers in this event: Griffin, Laut, and Oldfield.

The present analysis consisted of three different types of tests. The first test was to evaluate stength and speed through the utilization of the Wilson-Ariel 4000 Computerized Exercise Machine. A description and method for the use of this machine is described in the enclosed Appendix B. The results of this testing are summarized in the enclosed report in Appendix C.

The biomechanical analysis consisted of two different types of tests. The first test consisted of utilizing three force plates within the shotput circle to measure the vertical and horizontal forces as well as the temporal relationships in the throwing sequences. The second test consisted of high speed cinematography utilizing three camera positions --- side, back, and top views --- with the speed set at 100 frames per second. All trials for each athlete were filmed during an official competition. Appendix D is the master log of film data for this competition and filming session. A representative film sequence for each of the throws was then selected for the computerized biomechanical analysis.

The true three-dimensional parameters of motion (displacement, velocity, and acceleration) for each point of interest on the subject were determined using high-speed cinematography. The athlete's performance was filmed by multiple cameras operating simultaneously and placed at different locations. The location of the throw was "calibrated" by filming an object of known dimensions in that same location with the same camera orientations. The film sequence from each camera was then digitized in the following manner. The film was projected, one frame at a time, onto a large rear-projection digitizing screen. For each frame, a trained operator touched the location of each point of interest (in this case the body joints and the shotput) in a predetermined order using an electronic stylus. As the points were touched, their two-dimensional relative coordinates were transmitted to a computer and saved. In addition, at some point in the sequence of frames, for each camera view, the operator digitized the points of the calibrating object. In this study, a large cube with spheres at known locations served as a calibration object and is shown in Figure A.

The next step consisted of a numerical transformation on two or more digitized film sequences which converted from two-dimensional relative coordinates to three-dimensional absolute coordinates. This was done using a method known as direct linear transformation, wherein the two-dimensional coordinates of the known points (calibration object) are used to create a transformation matrix which in turn is applied to the unknown points (data points) yielding three-dimensional coordinates. The result of this transformation was a sequence of three-dimensional "frames" corresponding to the digitized data points from two or more cameras.

These data points were then smoothed to remove "noise" introduced during the filming and digitizing stages of data collection. Smoothing was accomplished using a sophisticated cubic-spline or digital filtering algorithm which has been demonstrated to be superior to algorithms such as polynomial approximation or some digital filters, especially in sequences with high acceleration such as throwing events. The smoothed sequence of frames was then viewed in stick-figure format on a graphic display. In addition, during the smoothing process the velocity and acceleration of each data point, as well as its displacement were computed and these may be displayed as vectors on the graphic display or plotted as a function of time for analysis purposes. Further computation resulted in the parameters of motion of segments (lines connecting pairs of points), and joints (intersection of pairs of segments) in both linear and angular coordinates. Motion parameters of these various types are reported and discussed in this study.

Force Platform Analysis

Three force plates were incorporated in a "circle" constructed specifically for this purpose in order to record the contact forces of the feet with the ground. These forces are very important for determining the efficiency of the thrower. The force platforms used in this study were Kistler model 9261A multicomponent piezoelectric measuring platform and two plates made by Advanced Mechanical Technology, Inc. The plates are used in medical diagnoses and evaluation as well as for assessing athletic performance research. The platforms have high sensitivity levels over a wide frequency range. The electrical outputs of the plates were conditioned by charge amplifiers and amplified to suitable levels for computer sampling (+/- 10 volt peak). These amplified signals were sampled and stored by a dedicated minicomputer at a rate of 40000 samples/second/channel.

Eight channels of force data were sampled with the vertical and horizontal components from each force platform. Because the landing on the middle plate produced a torque, this was also measured.

The athletes started the glide with the right foot on the rear plate, for the linear style, and with their left foot, for the turning style. Then the right foot landed on the plate in the middle of the circle for both styles, and then the front leg (left leg) blocked against the plate located at the front of the circle.

After all trials of throws were recorded and saved in computer memory, the data from each sequence was processed to quantify the various response parameters for each of the throws. The parameters that were measured were peak force, impulse, time of force application, and the time between force applications. In addition, the different temporal phases, such as single and double support, and the airborne phase were measured.

RESULTS

Strength Measurements:

The strength report enclosed in Appendix C illustrates the performance tests for all the participant athletes who were willing to be measured. A comparison to a similar clinic held in March, 1982 is included in Appendix C.

RESULTS

Figures 1 and 2 present examples of the stick figures with the appropriate points and segments that were traced. Figures 3 to 6 present the stick figures for each of the athletes for the three dimensional views. These three views represent the throw from the side view (X-axis); from the rear view (Z-axis); and from the top view (Y-axis). For proper orientation, the viewer looks along the Z-axis to view the side view; along the X-axis to view the rear view; and along the Y-axis to view the top view.

According to the literature (Appendix A), the shotput performance can be divided into various phases. Some of these phases have been arbitrarily assigned by various investigators while others have been functionally determined. In the present study, the various portions of the throw have been based upon the kinematics and kinetics of the performance itself utilizing high speed cinematography and force plates data. Accordingly, the shot-put activity may be divided into the following functional phases:

1. Push-off phase - Push-off of the rear leg in the linear technique, or push-off from the front leg in the spin technique.
2. Airborne phase - The time the athlete is in non-contact phase with the ground after the push off.
3. Single support phase - from the time the rear foot touches

the circle's surface until the moment the front foot touches the ground.

4. Double support phase - From the moment the front foot touches the ground until the time that the rear foot leaves the ground.

5. Second single support phase - from the time the rear foot leaves the ground until the release of the shot or until the front foot leaves the ground before release.

6. Second airborne phase - this phase does not occur with all throwers; however, if it occurs, it is from the point the front foot left the ground until the release.

Figures 7 to 10 illustrate the stick figures of the throwers and show the different division phases. Each of the following figures are divided into these phases which are shown at the top of the figure. Figures 11 to 14 presents kinematic data (unsmoothed vertical displacement) of the thrower's feet used to calculate the time relationships between these phases for the different throwers. Table 1 illustrates the time relationship for the different phases for the different athletes.

The Kinematics of the Shot

The goal of the shotputter is to deliver the shot at maximum speed and at the optimal angle based upon physical and anatomical factors. From a physics point of view, the optimal would be a release at an angle of 45 degrees to the plane of release. The