Performance Analysis System

Ariel Dynamics
On February 5, 1676, Isaac Newton penned a letter to his bitter enemy, Robert Hooke, which contained the sentence, “If I have seen farther, it is by standing on the shoulders of giants.” Often described as Newton’s nod to the scientific discoveries of Copernicus, Galileo, and Kepler before him, it has become one of the most famous quotes in the history of science. Indeed, Newton did recognize the contributions of those men, some publicly and others in private writings. But in his letter to Hooke, Newton was referring to optical theories, specifically the study of the phenomena of thin plates, to which Hooke and Renè Descartes had made significant contributions.
Proposition CXXXVIII

Determination of the magnitude of the forces exerted by each of the feet when man stands erect.
Tab. X, Fig. 13.

The centre of gravity of the human body $R$ is $A$. The body $R$ is supported by the two oblique columns of the legs $BA$ and $CA$. The line of gravity is $ADH$. A segment $AG$ is taken on $AC$ such that the ratio $BA/AG$ is equal to the ratio of the force exerted by the strut $BA$ to that exerted by the strut $AC$. $GI$ is drawn parallel to the horizontal $BC$. The lines $BA$, $CA$ are prolonged and intersect $FHE$ parallel to $CB$. I claim that the ratio of the weight $R$ to the force exerted by the strut of the leg $AB$ is equal to $(DA + AI)/AB$; the ratio of the force exerted by the strut $AB$ to the force exerted by the strut $AC$ is equal to $AB/AG$. The weight $R$ is carried by the struts $BA$ and $CA$ with the same force as if it was suspended by the ropes $AE$ and $AF$ inclined as are $BA$ and $CA$. The ratio of the forces exerted by the ropes $EA/FA$ or the ratio of the forces exerted by the struts $BA/CA$ thus is equal to $BA/AG$. Therefore, the force exerted by the strut $BA$ is measured by the length of the line $BA$ and the force exerted by the strut $AC$ is measured by the length of the segment $AG$. The weight $R$ of the whole body is measured by the sum of the lines $AD + AI$. Consequently, if the weight of the body is known, the magnitude of the force exerted by each leg is known.
Proposition CXL

When the line of gravity of the human body is outside the plantar sole of the one supporting foot or outside the quadrangle delineated by the two supporting feet, no muscle can prevent the body from falling. Tab. X, Fig. 15.

The human body R stands on the ground ST with all the plantar sole BC. The angle ABC formed by the leg and the ground is obtuse so that the perpendicular AV falls outside the plantar sole. I claim that no effort of muscles can prevent the body from falling. The body R can be prevented from falling towards V only by inclining the lever AB towards S or, in other words, by closing the angle ABS. The angle B being decreased and made acute by the muscles of the leg, the foot CB must be brought closer to the leg AB. This occurs by dorsiflexing the foot CB to BD. But the weight of the whole body R acting at A cannot yield to the small weight of the foot CB which is not attached to the ground ST but is only in contact with it. In such an instance, the whole machine RABD is supported by the heel B and the total weight tips from A towards V.

Secondly, if the perpendicular line of gravity AV lies in front of the acute angle ABC beyond the tip C of the foot, falling also follows inescapably. Falling cannot be prevented without the plantar flexor muscles of the foot opening the angle B. This brings the support to the tip of the foot C and thus the line of support AC is still inclined to the subjacent horizontal plane. Consequently, the weight R falls towards the perpendicular through V.
Fig. 12. Shooting attitude without regulation equipment, side view. • Projection of the centres of the joints; ○ projection of the centres of gravity of the head, hands and rifle; □ S projection of the centre of gravity of the whole body with rifle
fig. 4. Projection of the 31 phases on the plane of gait with the partial centres of gravity (red), the centres of gravity of different systems (blue) and the total centre of gravity of the body (C).
another by the same athlete.

For a resultant to be found, the direction of each separate turn must also be known. Conventionally, positive direction is that which makes the turning look clockwise and, therefore, each axis is looked along so that this is so (Fig. 84), and arrow-heads are then added to point accordingly (Fig. 85).

By using the parallelogram method (already described in connection with velocity and forces, pages 17 and 35) the magnitude and direction of the total angular momentum and the position of the axis of momentum can then be established. The latter, in the case of
Tennis service — Rod Laver.
Three-Segment Motion

Two and Three-Segment Motions

\[ F_{x_1} = -WT_1 - m_1\omega_{11} \sin \theta_1 + m_1\omega_1^2 \sin \theta_1 + F_{y_1} \]
\[ F_{x_2} = +m_2\omega_{21} \sin \theta_1 + m_2\omega_2^2 \cos \theta_1 + F_{z_2} \]
\[ M_{\alpha_1} = -WT_1 \cos \theta_1 - m_1\alpha_1 + F_{y_1}(\cos \theta_1) + F_{z_1}(\sin \theta_1) - M_{\alpha_1} = 0 \]

A three-segment motion analysis and the use of the computer programs should be reserved for graduate students. The undergraduate should be aware of the numerous forces due to motion and the complexity of the calculations without being responsible for determining force magnitudes and directions. When the study of three-segment motion is completed, students realize fully that muscle action is totally unpredictable from observation of movements alone.

Figure 5-5 shows a three-segment motion with segment 1 rotating about a fixed point, and segments 2 and 3 rotating about a moving axis. (Note segments 2 and 3 have a minus angular acceleration.) The free body diagram for each segment, showing inertial forces and weight, is presented in Fig. 5-6, and Fig. 5-7 gives a breakdown of the forces to aid in writing the force formulas. The force and moment formulas are as follows:

Segment 3

\[ F_{y_3} = -WT_3 + m_3\omega_{31} \cos \theta_3 + m_3\omega_3^2 \sin \theta_3 - m_3R_{31} \cos \phi_1 + m_3R_{31} \sin \phi_1 \]
\[ + m_3R_{31} \cos (180^\circ - \phi_2) + m_3R_{31} \sin (180^\circ - \phi_2) \]
\[ + m_3(2\omega_1 V_1 + 2\omega_2 V_2 + 2\omega_3 V_3) \sin \theta_3 - m_32\omega_3 V_3 \sin \theta_3 \]
\[ F_{z_3} = -m_3\omega_{31} \sin \theta_3 + m_3\omega_3^2 \cos \theta_3 + m_3R_{31} \sin \phi_1 + m_3R_{31} \cos \phi_1 \]
\[ + m_3R_{31} \cos (180^\circ - \phi_2) - m_3R_{31} \sin (180^\circ - \phi_2) \]
\[ + m_3(2\omega_1 V_1 + 2\omega_2 V_2 + 2\omega_3 V_3) \cos \theta_3 - m_32\omega_3 V_3 \cos \theta_3 \]
\[ M_{\alpha_3} = -WT_3 \cos \theta_3 + m_3\omega_{31} \sin (\phi_1 - \theta_3) - m_3R_{31} \cos (\phi_1 - \theta_3) \]
\[ + m_3\omega_3^2 \sin (\phi_1 - \theta_3) - m_3R_{31} \cos (\phi_1 - \theta_3) = 0 \]

Segment 2

\[ F_{y_2} = -WT_2 + m_2\omega_{21} \cos (180^\circ - \theta_2) + m_2\omega_2^2 \sin (180^\circ - \theta_2) \]
\[ - m_2R_{21} \cos \phi_1 + m_2R_{21} \sin \phi_1 - m_2V_{21} \sin (180^\circ - \theta_2) + F_{y_2} \]
\[ F_{z_2} = +m_2\omega_{21} \sin (180^\circ - \theta_2) - m_2\omega_2^2 \cos (180^\circ - \theta_2) + m_2R_{21} \sin \phi_1 \]
\[ + m_2R_{21} \cos \phi_1 + m_2V_{21} \cos (180^\circ - \theta_2) + F_{z_2} \]
\[ M_{\alpha_2} = +WT_2 \cos (180^\circ - \theta_2) - m_2\omega_{21} \sin (\phi_1 - \theta_2) \]
\[ - m_2R_{21} \cos (\phi_1 - \theta_2) + F_{y_2}(\cos 180^\circ - \theta_2) \]
\[ + F_{z_2}(\sin 180^\circ - \theta_2) - M_{\alpha_2} = 0 \]
MUSCLE FUNCTION CHANGE DUE TO 25 LBS. ON SHOULDERS

\[ M_1 = 109.316 \text{ g.cm} \]
\[ M_2 = 183.060 \text{ g.cm} \]
\[ M_3 = 107.825 \text{ g.cm} \]

- HIP EXTENSION
  \[ M_3 = 533.450 \text{ g.cm} \]

- KNEE EXTENSION
  \[ M_2 = 183.060 \text{ g.cm} \]

- ANKLE EXTENSION
  \[ M_1 = 109.316 \text{ g.cm} \]
  \[ M_2 = 183.060 \text{ g.cm} \]
  \[ M_3 = 107.825 \text{ g.cm} \]

- HIP FLEXION
  \[ M_3 = 533.450 \text{ g.cm} \]

- KNEE FLEXION
  \[ M_2 = 106.690 \text{ g.cm} \]

- ANKLE EXTENSION
  \[ M_1 = 321.205 \text{ g.cm} \]
  \[ M_2 = 106.690 \text{ g.cm} \]
  \[ M_3 = 533.450 \text{ g.cm} \]
Table B-3  Computer Program

(1) COMPUTE THE M + 1 VALUES OF XBAR(I), WHERE M IS THE DEGREE
(2) NORMALIZE THE INITIAL VALUES OF X(I) TO THE INTERVAL (-1,1).
(3) PERFORM THE LAGRANGIAN INTERPOLATION TO OBTAIN M + 1 VALUES OF YBAR(I) WHICH CORRESPOND TO THE M + 1 VALUES OF THE XBAR(I).
(4) COMPUTE THE COEFFICIENTS C(I).
(5) CONVERT THE CHEBYSHEV SERIES FOR Y(M) TO ITS EQUIVALENT POWER SERIES.
(6) CONVERT THE POWER SERIES FROM THE INTERVAL (-1,1) TO THE INTERVAL (A,B).
(7) PUNCH THE COEFFICIENTS OF THE FINAL SERIES EXPANSION.

C = DEGREE OF THE POLYNOMIAL Y(M) DESIRED.
XMIN = FIRST VALUE OF X (SMALLEST VALUE OF ORIGINAL X-COORDINATES).
DELT X = INCREMENT BETWEEN VALUES OF X; THAT IS, (X(I) - X(I-1)).
Y(J) = VALUE OF THE ORIGINAL Y CORRESPONDING TO THE JTH VALUE OF X.
R(I) = THE ITH ROOT, OR XBAR(I).
V(I) = THE ITH VALUE OF XP(I), OR NORMALIZED X(I).
C(I) = THE ITH COEFFICIENT OF THE CHEBYSHEV SERIES IN (-1,1).
F(I) = THE INTERMEDIATE STORAGE USED IN COMPUTING INTERPOLATED YBAR(I) IN COMPUTING C(I)S TO FINAL POWER-SERIES COEFFICIENTS IN (A,B). THE FINAL COEFFICIENTS ARE STORED IN Y(J).

C = CHEBYSHEV POLYNOMIAL APPROXIMATION - EQUIDISTANT DATA
DIMENSION Y1(90), Y2(850), Y(50), DATA(850), NFBD(850)
DIMENSION 5(20), V(50), Y(90), C(20), F(20), DATY(850), DATX(850)
DIMENSION W(8), X(50), R(8), A(8), B(8), X(50), Y(50), S(8)
DIMENSION PCTR(8), PCTK(8), EN(8), NFU(8), CTS(8), CXL(8), DATM(850)
DIMENSION DUMW(8), DUMR(8), DUMK(8), WHOA(10), WHOB(10), MP(8), YMAX(8)
OEGA(8), OMEGA(8), ALPHA(8), OMEGA(8), ALPHA(8), OMEGA(8), ALPHA(8)
FXA(8), FYA(8), AMOMT(8), X(8), IZ(8), DFX(850)
FXE(850), FYE(850), XFI(8), XFA(8), YFI(8), YFA(8), MI(8), MA(8)
DFY(850), RE(850), RR(850), AA(8), B, X(8), X(8), H(8), T(8), STORE(850)

1 READ 300, WHOA
IF (EOF, 300) 9999, 9998
9998 READ 300, WHOB
300 FORMAT (10A8)
PRINT 301, WHOA, WHOB
301 FORMAT (/*/1X, 10A8, 1X, 10A8)
PRINT 302
302 FORMAT (* ANG., DEG., VEL., DEG., PER SEC., ACC., DEG., PER SEC., SQ.*
5 READ 5*NSEG, NPOS, XMIN, DELTX
5 FORMAT (11/14/2F10.5)
READ 104, NTRK, TRNKLK, KIP, NSPEC, NSPEC1
104 FORMAT (11/14/3, I1)
READ 101, (PCTR(I), PCTK(I), I=1, NSEG)
101 FORMAT (17F10.5)
READ 136, COR
136 FORMAT (13)
READ 101, (W(I), I=1, NSEG)
READ 303, (MP(I), ID=1, NSEG)
303 FORMAT (11I1)
READ 101, (YMAX(I), ID=1, NSEG)
DO 3000 I=1, NSEG
3000 READ 3010, (XI(I), YFI(I), YFA(I), MI(I), MA(I), IZ(I))
3010 FORMAT (6E6, 1X)

### Analysis of Long Jump

**Bob Beamont (8.90m) vs Carl Lewis (8.71m)**

Gideon Ariel

The purpose of this analysis is to compare the kinematic characteristics of Bob Beamont's jump (1985 Olympics in Mexico City) of 8.90 meters (29'2.5") to Carl Lewis' jumps (1982 and 1985). Lewis' first jump was officially measured at 8.90 meters, while the distance was recorded at 8.71 meters (28'7") for Beamont. Lewis fouled on the second jump (by as much as 1.6") the distance measured was 8.70 meters (28'3") for Beamont. It is important to note that Beamont's jump took place at an altitude of approximately 6000 feet. Carl Lewis jumped at an altitude closer to sea level.

The film on the jumps was actually taken from a video recording during the competition. The camera speed was 30 frames per second; the film was timed and analyzed. A special camera was used to perform the analysis. A fixed point on the field, in the same plane of the athlete's movement, was digitized. Later on all the displacement and velocity data were plotted relative to the "moving" fixed point. In this manner the resulting data was partitioned out in order to obtain the true velocity of the various body segments and the center of gravity. The distance jumped was measured from the center of the pit to the point of take-off. The second scale factor was an altitude scale used to determine the distance between the landing mark and the end of the pit. Lewis legal jump was one meter upper scale used to verify the distance between the landing mark and the end of the pit, and vice versa.

After the calculations of the multiplier from the known scale factors, the length of the shank of the athlete was measured and calculated and then was used as scale factor for all the digitized frames in the sequence. All the information related to the scale measures and kinematic data are presented in Table 1.

#### Table 1

<table>
<thead>
<tr>
<th>Distance measured</th>
<th>Bob Beamont</th>
<th>Carl Lewis</th>
<th>Carl Lewis</th>
</tr>
</thead>
<tbody>
<tr>
<td>from the landing mark</td>
<td>3.10m</td>
<td>3.29m</td>
<td>3.19m</td>
</tr>
<tr>
<td>to the end of the pit</td>
<td>10'7&quot;</td>
<td>10'7&quot;</td>
<td>10'7&quot;</td>
</tr>
<tr>
<td>Distance digitized</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>from the landing mark</td>
<td>60.3cm</td>
<td>26.8cm</td>
<td>57.4cm</td>
</tr>
<tr>
<td>to the end of the pit</td>
<td>25'7&quot;</td>
<td>11'25&quot;</td>
<td>20'25&quot;</td>
</tr>
<tr>
<td>Scale measure digitized on</td>
<td>shank = 4.02&quot;</td>
<td>shank = 2.17&quot;</td>
<td>shank = 4.08&quot;</td>
</tr>
<tr>
<td>the screen</td>
<td>1 meter  = 4.20&quot;</td>
<td>1 meter  = 4&quot;</td>
<td></td>
</tr>
<tr>
<td>True length of the</td>
<td>shank = 52.5cm</td>
<td>shank = 51.8cm</td>
<td>shank = 51.0cm</td>
</tr>
<tr>
<td>scale measures</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Digitized distance</td>
<td>***</td>
<td>***</td>
<td>7.5m</td>
</tr>
<tr>
<td>between the front landing</td>
<td>***</td>
<td>***</td>
<td>3&quot;</td>
</tr>
<tr>
<td>mark and the back most</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>landing mark</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>True distance</td>
<td>***</td>
<td>***</td>
<td>35.2m</td>
</tr>
<tr>
<td>between the feet landing</td>
<td>***</td>
<td>***</td>
<td>13.75&quot;</td>
</tr>
<tr>
<td>marks</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Velocities of the Center of Gravity at Breaking Point...:

| X-Horizontal               | 11.76m - 38.55° | 12.97m - 42.52° | 12.58m - 41.25° |
| Y-Vertical                 | 2.68m - 8.8"    | 2.33m - 7.3"    | 2.49m - 8.17"   |
| R-Resistant                | 11.45m - 37.64° | 11.68m - 38.23° | 11.08m - 36.36° |
| Angle to the horizontal    | 11.5 degrees    | 11.5 degrees    | 11.5 degrees    |

#### Velocities of the Center of Gravity at Take-off...:

| X-Horizontal               | 11.79m - 38.86° | 13.00m - 42.52° | 11.73m - 38.50° |
| Y-Vertical                 | 3.92m - 12.85°  | 4.00m - 13.11"  | 2.96m - 9.71"   |
| R-Resistant                | 11.13m - 39.50" | 10.20m - 33.44" | 9.04m - 39.64"  |
| Angle to the horizontal    | 20.5 degrees    | 23 degrees      | 13 degrees      |

- The calculated (\(X=V_1(V_0+\text{SORT}(V_0**2+y^2))/g\))
- \(X=10.55\) meters
- \(Y=6.982\) meters
- \(Z=1.004\) meters
- Horizontal distance of the C.G. = 39.45°
THE CONTRIBUTION OF THE POLE TO THE VAULT

Gideon Ariel
Department of Exercise Science
University of Massachusetts

In the past, the kinematic and kinetic analysis of the human body has been lacking in analysis of forces and moment of forces. Today, with the use of high speed photography, anatomical data, and knowledge of mechanics, forces and moments of force about each body joint may be calculated for any instantaneous position. With the advent of computerization, the analysis of human motion becomes much less laborious, and the results more readily interpretable.

The purpose of this study was to find the contribution of the fiberglass pole to the vault by analyzing the world record performance in the pole-vault using engineering dynamics while utilizing a special computer program to obtain the results. A complete analysis was performed; however, the scope of this paper permits only a discussion of the contribution of the pole to the vault.

The Contribution of the Fiberglass Pole to the Vault: Figure 1 presents 105 frames 1/64 second intervals of Seagren's 18' - 0" at 5/4 inches world record performance.

Figures 2 and 3 summarize the computer output for the moments of force and percent contribution of the fiberglass pole to the total moment and the vertical and horizontal forces created by the pole. The units for the moments are in Kg.M. and the units for the forces are in Kg.

In Figure 2, it can be observed that five phases occur as revealed by the changes in the direction of the moment of force. In the take-off, the moment of force was in the clockwise direction (same direction as the run). The positive percent contribution reveals that the pole, in this phase, hindered the motion. At the instance when the pole vaulter left the ground with his take-off leg, the moment changed direction to a counterclockwise direction (direction of the bend in the pole). In this phase, the pole also had a hindering effect. Just prior to the end of the swing phase, the moment changed direction again indicating a clockwise moment. From positions 21 to 40 (19/64 of a second), the contribution of the pole to the total moment ranged from a value of 166 percent in position 22 to 15 percent in position 40. This phase, the moment contributing phase, is the critical phase for successful pole-vaulting. Seagren in his attempt at 16'9" demonstrated a shorter contributing phase as indicated by (b) in Figure 2. Other pole vaulters at 16' demonstrated smaller contributing phase as indicated at (a) in Figure 2. The contributing phase appears to begin in the rock-back phase and continues until the beginning of the turn-phase. This "loading" effect of the pole (sum of run, plant, take-off, swing) contributes to the vertical force which is the main goal in the pole-vault.

Figure 3 indicates that the pole contributes to the vertical force between positions 32 to 49 (17-64 sec.). This vertical force is the result of the sum of the moment of force which was created by the good run, plant and take-off, as well as the flexible pole in the rock-back phase.

It was found that the fiberglass pole had its effect on the horizontal force in the rock-back phase (Figure 3). In order to clear the bar, horizontal force is needed; however, the timing between the horizontal and the vertical forces is critical for a successful vault. The average pole vaulter (16') overlaps the two forces in the rock-over and turn phases. Seagren successfully differentiated these two forces which resulted in a greater vertical force leading to a World Record.

Relationship of the Fiberglass Pole to the Other Body Segments: Figure 4 illustrates the contribution to the vertical force by the pole and the other body segments throughout the vault. From positions 1 to 6 the shank and foot, and the thigh and the trunk were the main contributors to the vertical force. From positions 6 to 10 the upper-arm and the forearms were the main contributors. In the swing phase the trunk contributed to a positive vertical force which acts downward. The fiberglass pole had its effect from positions 32 to 50 in the rock-back and the turn phases.

Analysis of pole vault performances yielded important evidence relative to the critical period of contribution of the pole to the vertical phase. Expansion of the moment contribution phase which may be the most critical in achieving greater vertical force, could result in even greater heights. Theoretically, designing a pole with variable flexibility according to the weight of the athlete and his horizontal velocity in the run could yield jumps of 20-feet or higher.

TANGENTIAL FORCES

F1 = BACK SHANK SEGMENT
F2 = BACK THIGH SEGMENT
F3 = TRUNK SEGMENT
F4 = SHOULDERS SEGMENT
F5 = FRONT SHANK
F6 = FRONT THIGH

TANGENTIAL FORCE DIRECTIONS WITH DOUBLE CONTACT AND SEGMENT ACCELERATIONS AT RELEASE.

TANGENTIAL FORCE DIRECTIONS WITH BACK LEG LIFTED AND WITH SEGMENTS DECELERATIONS AT RELEASE.
Biomechanical Analysis of Shotputting

Gideon B. Ariel, Ph.D.

INTRODUCTION

In recent years American shotputters have failed to duplicate the advances demonstrated by their Eastern European counterparts. In fact, at the 1976 Olympic Games, it was perhaps the first time that, no American was present on the winners’ stand. The purpose of the analysis presented in this paper was to conduct a biomechanical analysis of selected American shotputters and compare their technique to that of the best six competitors in the Montreal Olympic Games.

METHOD

In August of 1978 a group of national class throwers were invited to Houston, Texas by the U.S. Olympic Committee for a shotputting clinic. Attending the clinic were some of the best American throwers in this event: England, Bob Feuerbach, Klein, Kuehler, Laut, Marks, Pyka, Schneck, Stoner, Summers, Vincent, Walker, and Weeks. Comparison of the throws of these athletes was made with those of the top six finishers in the 1976 Olympic Games. The top six who were analyzed were: Beyer, Mironov, Barinov, Alan Feuerbach, Gou, and Goues.

A high speed motion picture camera with 50 mm lens recorded the performance of each thrower at an angle of 90 degrees to the athlete’s sagittal plane. Films were taken of three or four throws for each of the clinic athletes and of the top six best performances of each Olympic competitor. Each throw was filmed from the beginning of the glide through the release of the ball and the push-off, in turn, for each throw. The resultant images were then analyzed by a computer and the data from the computer was used to determine the patterns of motion and to derive the results of the analysis of the shots. The results of this analysis are illustrated in Figure 2 (from Morhard). The first is the starting phase when the athlete accelerates his body and the shot. The second phase is the glide when the athlete is in the air for a brief amount of time, after which the foot contacts the ground. The third phase is the push-off phase, the most important one. In this phase the athlete should generate the maximum force of the shot toward the release.

RESULTS

Cinematography

The present biomechanical analysis revealed that the most important factor in shotputting is the velocity of the shot at release. This factor is more important than either the angle or the position of the shot. Although some attention must also be given to the release angle, the primary goal of the competition should be to generate the greatest ball velocity at the point of release. Other factors being approximately equal, the faster the ball at the release, the further it will travel. The movement patterns associated with shotputting are directed towards generating the maximum velocity of the shot under given conditions. In order to achieve maximum velocity at the release, there must be a summation of forces from the various phases of the throw and the various body segments.

The movement patterns of the shot put can be partitioned into 5 phases which are illustrated in Figure 2 (from Morhard). The first is the starting phase when the athlete accelerates his body and the shot. The second phase is the glide when the athlete is in the air for a brief amount of time, after which the foot contacts the ground. The third phase is the push-off phase, the most important one. In this phase the athlete should generate the maximum force of the shot toward the release.

It is this relationship between the push-off phase and the push-off phase which differentiates between the 50 and 70-throw shotputters. In order to optimize this relationship, the athlete should acquire certain style characteristics in the amount of power or technique. The velocity calculated for the shot put was found to exceed 45 feet/second. As was previously mentioned, this velocity is the most critical factor in achieving maximum distance. It is important to note that, in order to produce this velocity, it is necessary to achieve specific coordination among the muscles of the shot. For the participants, the push-off phase can be as detrimental to producing an optimal final velocity as a low initial beginning can.

Figure 3 illustrates the resultant shot velocities of the Olympic competitors and reveals remarkable similarities among the athletes. Beyer, the gold medalist, demonstrated the greatest shot velocity; however, Feuerbach, the fourth place finisher, produced a significantly lower shot velocity. In order to throw more than 65 feet, the athlete must release the shot at a speed exceeding 45 feet/second.

Figures 4 to 6 illustrate the resultant ball velocities of the athletes who attended the clinic. It can be seen that the velocities and the distances are significantly lower than those observed for the Olympic competitors. Among the clinic throwers, Bob Feuerbach demonstrated the highest velocity.
Abb. 2  Lusis freies Körperdiagramm

Abb. 3  Geschwindigkeitskurven
COMPUTERIZED BIOMECHANICAL ANALYSIS OF HUMAN PERFORMANCE

Gideon Ariel
University of Massachusetts

ABSTRACT

A kinetic analysis of human motion, one of the greatest advances in the field of biomechanics, has been expanded by the computer-digitizer complex which allows analysis of total body motion through utilization of slow motion cinematography, special tracing equipment to convert the data, and the high-speed computer. Appropriate programming results in a segmental breakdown of information of the whole motion including the total body center of gravity, segment velocities and accelerations, horizontal, vertical, and resultant forces, moments of force, and the timing between the body segments. This analysis provides a quantitative measure of the motion and allows for perfection and optimization of human performance. Applications of biomechanical analyses permit an objective, quantitative assessment of performance replacing the uncertainty of trial and error, eliminating the element of doubt, and provides a realistic opportunity for improved performance.

INTRODUCTION

As early as the fifteenth century Leonardo Da Vinci wrote:

"Mechanical science is the noblest and above all others the most useful, seeing that by means of it, all animated bodies which have movement perform all their actions."

Since that time, biomechanics of human motion developed; however, the kinematic and kinetic analyses of the human body lacked specific force analysis. It was only after the combining of high-speed photography, anatomical data, and the utilization of man as an integral part of a system, that total motion analysis of human performance was realized. The computer-digitizer complex has reduced the long tedious hours of tracing and hand calculations to a matter of minutes and, thus, complex whole body motion analysis can be practically obtained. This analysis provides a quantitative measure of the motion and allows for perfection and optimization of human performance in industry, sport, and human factors in man-product interactions, as well as,