Lake Louis, Canada
Technological Contributions to Sports Analysis
From Mexico City 1968 to Beijing 2008

By
Gideon Ariel
IACSS 2007

6th International Symposium on Computer Science in Sports
Featured Speakers and Workshop Leaders To Date

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**Topic:** Technologies Contribution to Sports Analysis from Mexico City 1968 to Beijing 2008
[abstract](#), [bio](#)

Prof. Arnold Baca
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**Topic:** Computer Science in Sport - History Research Areas and Fields of Application
[abstract](#), [bio](#)

Kristin Collins
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**Topic:** The role of Performance Technology within Elite Level Coaching
[abstract](#), [bio](#)

Dr. Richard W. DeVaul
President & Senior Scientist, AWare Technologies,
Cambridge, Massachusetts, USA
**Topic:** Towards Real-time Athletic Form Classification and Corrective Feedback Using Body-worn Sensors, Analytics, and Transducers
[abstract](#), [bio](#)
Gait Analysis
Markless Digitizing
Tokyo Olympics - 1964
Future Coach (1972)
Considerations in designing Sports Analysis System

- System must be non-invasive (No sensors on the body)
- Measurements must be done in 3D
- Data must be collected in real performance condition
- All environmental condition must be constant
- Minimum of 10 trials must be analyzed
- Athlete should not be aware of data collection
- Data analysis must be minimally filtered
- Markers cannot be used as joint centers
- Markers sets are not reliable and cumbersome
- Data analysis and reporting must be done in 24 hours or less
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 René Descartes had made significant contributions.
In Biomechanics we owe the same sentence to the following:

**Pythagoras of Samos**
- 596 – 475 B.C.E.
- World’s first pure mathematician
- Founded a philosophical and religious school in southern Italy

**Hippocrates**
- 460 – 370 B.C.E.
- Applied a scientific approach to medical conditions
- Principle of causality
  "...that chance does not exist, for everything that occurs will be found to do so for a reason" (Sarton, 1953).

**Plato**
- 427 – 347 B.C.E.
- Ideas represented the only reality
- Knowledge could not be obtained from observation
- Emphasized the use of mathematics

**Aristotle**
- 384 – 322 B.C.E.
- Son of a physician
- Studied at Plato’s academy
- Considered by some to be the first biomechanician
- “De Motu Animalium” – On the Movement of Animals (gait analysis text)
Archimedes of Syracuse

- 287 – 212 B.C.E., Syracuse, Sicily
- Method of integration for areas, volumes and surface area

Archimedes Principle

On Floating Bodies

- A body immersed in water is buoyed up with a force equal to the weight of the water displaced.

Leonardo da Vinci

- 1452 – 1519
- Artist, civil engineer and anatomist
- Inventions: parachute, helicopter, water skis

Applied mechanical concepts to studying human movement

- Dissection studies
- Described the ball and socket joint for circumduction
- Hip joint – “Polo dell’omo”
- Muscles as threads

Andreae Vesalius

- 1514 – 1564
- Anatomist
- Medical training: University of Padua, magna cum laude, 1537
- De Humani Corporis Fabrica Libri Septem (On the Fabric of the Human Body)
Galileo Galilei

- Feb 15 1564 – Jan 8 1642
- Studies mathematics and medicine
- Professor of Mathematics of the University of Padua (1592)
- 1586 – *La Balancitta* (The Little Balance)
- Projectile path

Rene Descartes

- 1596 – 1650
- Established a mechanical approach to the study of nature
- 1637
- *Discours de la méthode pour bien conduire sa raison et chercher la vérité dans les sciences* (Discourse on the Method of Reasoning Well and Seeking Truth in the Sciences)
- Appendix: *La géométrie*

Giovanni Borelli

- 1608-1679, Naples, Italy
- Born as Giovanni Francesco Antonio Alfonso
- Degrees in mathematics and medicine
- Professor of Mathematics at the Universities of Messina, Pisa and Florence

Gottfried Wilhelm von Leibniz

- July 1 1646 – November 14 1716
- Entered University of Leipzig (1661)
- Bachelor's degree in law
- Doctorate in law (University of Altdorf, 1667)

- 1671, *Hypothesis Physica Nova* (New Physical Hypothesis)

Considered to be the “Father of Biomechanics”

Applied mechanical principles (levers, forces, moments) to the study of human movement
Etienne Jules Marey

- 1838 – 1904
- Physician and physiologist
- First to quantify human locomotion
- Station Physiologique (funded by the French Ministry of War and the Ministry of Public Education)
- Cinematography

Station Physiologique

- 500 m circular track
- Research assistants: Demeny and One Lieutenant Andriveau

Projects:
- Walking and running in soldiers
- Athletic activities
Giovanni Alfonso Borelli (1608–1679)

On the Movement of Animals

Springer-Verlag
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. Therefore¹, 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.
On the Centre of Gravity of the Human Body
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.
Early Mechanical Analysis of Human Movement

Brune and Fischer
Edweard Muybridge

- 1830 – 1904
- Photographic analysis of animal and human locomotion
- Stanford University
One of the first book related sports to mechanical principles
Fig. 2-17
Glass top tracing table. This equipment is used when the paper must be moved for each frame because of camera movement or in recording a body motion relative to a moving object (i.e., rowing, bicycling).
Fig. 4-15
Jump from stool (a) and jump up after jump from stool (b).
Tennis service — Rod Laver.

Segment is a combination of trunk flexion, extension and shoulder rotation.
Three-Segment Motion

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:

\[ F_{y_3} = -WT_2 + m_3 R_{a1} \cos \theta_3 + m_3 \bar{\omega}^2 \sin \theta_3 - m_3 R_{a1} \cos \phi_3 + m_3 \bar{\omega}^2 \sin \phi_3 \]

\[ F_{z_3} = -m_3 R_{a1} \sin \theta_3 + m_3 R_{a1} \cos \phi_3 + m_3 R_{a1} \sin \phi_3 \]

\[ M_{\theta_3} - WT_2 \cos \theta_3 + m_3 \bar{\omega}^2 \sin (\phi_3 - \theta_3) r_3 - m_3 R_{a1} \cos (\phi_3 - \theta_3) r_3 + m_3 \bar{\omega}^2 \sin (\phi_3 - \theta_3) r_3 = 0 \]

Segment 2

\[ F_{y_2} = -WT_2 + m_2 R_{a1} \cos (180^\circ - \theta_2) + m_2 \bar{\omega}^2 \sin (180^\circ - \theta_2) \]

\[ F_{z_2} = +m_2 R_{a1} \sin (180^\circ - \theta_2) - m_2 \bar{\omega}^2 \cos (180^\circ - \theta_2) + m_2 R_{a1} \sin \phi_3 \]

\[ M_{\theta_2} - WT_2 \cos (180^\circ - \theta_2) r_2 - m_2 \bar{\omega}^2 \sin (\theta_2 - \phi_3) r_2 \]

\[ -m_2 R_{a1} \cos (\theta_2 - \phi_3) r_2 + F_y r_3 \cos (180^\circ - \theta_2) + F_{z_2} (\sin 180^\circ - \theta_2) - M_{\theta_2} = 0 \]
MUSCLE FUNCTION CHANGE DUE TO 25 LBS. ON SHOULDERS

![Diagram showing muscle function calculations](image)

- \( M_1 = -109,316 \text{ g cm} \)
- \( M_2 = 183,060 \text{ g cm} \)
- \( M_3 = -107,825 \text{ g cm} \)

For hip extension:
- \( M_1 = -109,316 \text{ g cm} \)
- \( M_2 = 183,060 \text{ g cm} \)
- \( M_3 = 107,825 \text{ g cm} \)

For knee extension:
- \( M_1 = -109,316 \text{ g cm} \)
- \( M_2 = 183,060 \text{ g cm} \)
- \( M_3 = -107,825 \text{ g cm} \)

For knee flexion:
- \( M_1 = -321,205 \text{ g cm} \)
- \( M_2 = 106,690 \text{ g cm} \)
- \( M_3 = 533,450 \text{ g cm} \)
| C | (1) COMPUTE THE M + 1 VALUES OF XBAR(1), WHERE M IS THE DEGREE |
| C | (2) NORMALIZE THE INITIAL VALUES OF X(1) TO THE INTERVAL (-1,1). |
| C | (3) PERFORM THE LAGRANGIAN INTERPOLATION TO OBTAIN M + 1 VALUES OF |
| C | YBAR(I) WHICH CORRESPOND TO THE M + 1 VALUES OF THE XBAR(I). |
| C | (4) COMPUTE THE COEFFICIENTS C(I). |
| C | (5) CONVERT THE CHEBYSHEV SERIES FOR Y(M) TO ITS EQUIVALENT POWER |
| C | SERIES. |
| C | (6) CONVERT THE POWER SERIES FROM THE INTERVAL (-1,1) TO THE |
| C | INTERVAL (A,B). |
| C | (7) PUNCH THE COEFFICIENTS OF THE FINAL SERIES EXPANSION. |
| C | M = DEGREE OF THE POLYNOMIAL Y(M) DESIRED. |
| C | XMIN = FIRST VALUE OF X (SMALLEST VALUE OF ORIGINAL X-COORDINATES). |
| C | DELTX = INCREMENT BETWEEN VALUES OF X; THAT IS, X(1) = X(1) - 1. |
| C | Y(1) = VALUE OF THE ORIGINAL Y CORRESPONDING TO THE JTH VALUE OF X. |
| C | R(I) = THE ITH ROOT, OR XBAR(I). |
| C | V(I) = THE ITH VALUE OF XP(I), OR NORMALIZED X(I). |
| C | C(I) = THE ITH COEFFICIENT OF THE CHEBYSHEV SERIES IN (-1,1). |
| C | E(I) = THE INTERMEDIATE STORAGE USED IN COMPUTING INTERPOLATED |
| C | YBAR(I) IN COMPUTING C(I) @S AND IN CONVERTING C(I) @S TO FINAL |
| C | POWER-SERIES COEFFICIENTS IN (A,B). THE FINAL COEFFICIENTS ARE |
| C | STORED IN Y(J). |
| C | CHEBYSHEV POLYNOMIAL APPROXIMATION = EQUIDISTANT DATA |
| C | DIMENSION YI(9C), DATB(8,S0), DATV(B,50), DAT(50), NFBO(8,50) |
| C | DIMENSION 0.20, Y(920), C(20), F(20), DATV(B,50), DATL(50) |
| C | DIMENSION YGRAP(4), C(1), DATV(8,50), DATR(B,50), DATV(B,50) |
| C | DIMENSION W(9), XL(9), R(I), A(8), B(8), Z(9,2) |
| C | DIMENSION PCTR(9), PCKT(B), EN(8), NFU(B), CX(8), CXL(B), DATM(8,50) |
| C | DIMENSION DUW(B), DURM(B), DUMK(B), WHOA100, WHOB100, MP(8), YMAX(8) |
| C | 1.OMEGA(B), ALPHA(8), OMEG(A), ALPH(A), FXA(8), FYA(8), XOMT(8) |
| C | 2.FXA(8), FYA(8), AMOMT(8), XK(8), IZ(I), DFX(8,50) |
| C | 3.FXI(B), FYE(8,50), XFI(8), XFA(8), YFI(8), YFA(8), MI(8), MA(8) |
| C | 4.DFY(B,50), RE(8,50), RR(8,50), AA(8,50), THE(8), STORE(5,50,8) |
| C | COMMON PI, CONST, XL, XK, R, A, B, XMAX, CGZ , OMEGA, ALPHA, OMEGA, ALPH |
| C | 0NSG, IT, DX, FYE, NPOS, RE, RR, AA, THE, EQUIVALENCE (YGRAPH(1), X1), (YGRAPH(2), X2), (YGRAPH(3), X3) |
| C | 1 READ 300, WHOA |
| C | IF (EOF. 60) 9999, 9999 |
| C | 9998 READ 300, WHOB |
| C | 320 FORMAT (10AB) |
| C | PRINT 301, WHOA, WHOB |
| C | 301 FORMAT (* //1X, 10AB /1X, 10AB) |
| C | PRINT 302 |
| C | 302 FORMAT (* ANG.. DEG.. VEL.. DEG. PER SEC.. ACC.. DEG. PER SEC.. SQ** |
| C | 1) |
| C | READ S, NSEG, NPOS, XMIN, DELTX |
| C | FORMAT (/14//2F10.5) |
| C | READ 104, NTRK, TRNKNL, KIP, NSPEC, NSPEC1 |
| C | 104 FORMAT (1I, 1F10.3, 3I1) |
| C | READ 101, (PCTR(1), PCKT(1), 1=1, NSEG) |
| C | READ 101, (EN(I), 1=1, NSEG) |
| C | 101 FORMAT (7F10.3, 1I1) |
| C | READ 136, COR |
| C | 136 FORMAT (1I3) |
| C | READ 101, (W(I), 1=1, NSEG) |
| C | READ 303, (MP(ID), 1=1, NSEG) |
| C | 303 FORMAT (7I1) |
| C | READ 101, (YMAX(I), ID=1, NSEG) |
| C | DO 3000 I=1, NSEG |
| C | 3000 READ 3010, XFI(I), XFA(I), YFI(I), YFA(I), MI(I), MA(I), IZ(I) |
| C | 3010 FORMAT (6E6, 1A2) |
Mexico City Olympics 1968
Mexico City 1968 Olympics

THE PERFECT JUMP
Analysis of Long Jump
BOB BEAMON (8.90m) VS CARL LEWIS (8.71m)

The purpose of this analysis is to compare the kinematic characteristics of Bob Beamons jump (1968 Olympics in Mexico City) of 8.90 meters (29'2.5") to Carl Lewis jumps (1982 TAC meet). Lewis first jump was unofficially measured to be 8.71 meters (28'3.7") and the distance was 8.71 meters (28'3.7"). Lewis fouled on the second jump (by as much as 1.5") the distance measured was 9.92 meters (31'11.3"). It is important to note that Beamons 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 taken during the competition. The camera speed was 30 frames per second; the camera was panned, but not zoomed. A special technique was used to digitize the performance. A fixed point in 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 panning speed was parceled out in order to attain the true velocity of the various body segments and the center of gravity. The distance jumped was measured using two known scale factors in the plane of the motion. The first scale factor was a one meter horizontal distance between two marks along the pit (this scale measure was available only for Lewis jumps). The second scale factor was the distance from the landing mark to the end of the pit (12 meters from the edge of the take-off board). In Lewis' legal jump the one meter scale was 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 it was used as the 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></th>
<th>Bob Beamon</th>
<th>Carl Lewis</th>
<th>Carl Lewis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance (Meters)</td>
<td>5.80</td>
<td>6.71</td>
<td>6.02</td>
</tr>
<tr>
<td>Distance (Feet)</td>
<td>19'7.5&quot;</td>
<td>21'11&quot;</td>
<td>20'11'</td>
</tr>
<tr>
<td>Year</td>
<td>1983</td>
<td>1985</td>
<td>1985</td>
</tr>
<tr>
<td>Distance measured from the landing mark to the end of the pit</td>
<td>3.16m</td>
<td>3.28m</td>
<td>3.16m</td>
</tr>
<tr>
<td>Distance digitized from the landing mark to the end of the pit</td>
<td>60.2cm</td>
<td>26.0cm</td>
<td>51.4cm</td>
</tr>
<tr>
<td>Scale measure digitized on the screen</td>
<td>shank = 4.62&quot;</td>
<td>shank = 4.77&quot;</td>
<td>shank = 4.08&quot;</td>
</tr>
<tr>
<td>True length of the scale measures</td>
<td>shank = 53.5cm</td>
<td>shank = 51.0cm</td>
<td>shank = 51.0cm</td>
</tr>
<tr>
<td>The digitized distance between the feet landing mark and the box</td>
<td>****</td>
<td>****</td>
<td>7.6cm</td>
</tr>
<tr>
<td>The true distance between the feet landing marks</td>
<td>****</td>
<td>****</td>
<td>35.0cm</td>
</tr>
<tr>
<td>Velocities of the Center of Gravity at take-off, . . .</td>
<td>11.76m - 38.65°</td>
<td>12.97m - 45.2°</td>
<td>12.58m - 41.25°</td>
</tr>
<tr>
<td>X-Horizontal</td>
<td>2.68m - 9.8&quot;</td>
<td>2.35m - 7.6°</td>
<td>2.49m - 8.7°</td>
</tr>
<tr>
<td>Y-Vertical</td>
<td>11.45m - 37.4°</td>
<td>11.65m - 38.2°</td>
<td>11.08m - 38.3°</td>
</tr>
<tr>
<td>Angle to the horizontal</td>
<td>13.5 degrees</td>
<td>11.5 degrees</td>
<td>13 degrees</td>
</tr>
<tr>
<td>Velocities of the Center of Gravity at take-off, . . .</td>
<td>11.79m - 38.66°</td>
<td>13.00m - 42.92°</td>
<td>11.73m - 38.9°</td>
</tr>
<tr>
<td>X-Horizontal</td>
<td>3.90m - 12.85°</td>
<td>4.00m - 13.11°</td>
<td>2.96m - 9.71°</td>
</tr>
<tr>
<td>Y-Vertical</td>
<td>11.17m - 36.5°</td>
<td>10.20m - 33.4°</td>
<td>9.84m - 30.9°</td>
</tr>
<tr>
<td>Angle to the horizontal</td>
<td>20.5 degrees</td>
<td>23 degrees</td>
<td>19 degrees</td>
</tr>
<tr>
<td>The velocity height of the C.G. at take-off</td>
<td>1.085 meters</td>
<td>0.982 meters</td>
<td>0.904 meters</td>
</tr>
<tr>
<td>The calculated (*) horizontal distance of the C.G.</td>
<td>12.00m</td>
<td>13.18m</td>
<td>9.93m</td>
</tr>
<tr>
<td>0.45°</td>
<td>39.45°</td>
<td>43.40°</td>
<td>30.40°</td>
</tr>
</tbody>
</table>

* X=Vx(Vx+sqrt(Vy**2+2gY)))g
Velocity of the Center of Mass

Mike Powell 8.95m - World Record
Change of the Height of CM

Last strides of the approach

\[ M \]

\[ TD_{12} \quad TO_{24} \quad TD_{36} \quad TO_{46} \quad TD_{57} \]

\[ TD_{13} \quad TO_{25} \quad TD_{37} \quad TO_{49} \quad TD_{58} \]

\[ TO_{66} \quad TO_{68} \]

\[ \Delta = \text{CM vert.disp. Powell} \quad \nabla = \text{CM vert.disp. Lewis} \]

Fr#
# Comparative Kinematic Characteristics

<table>
<thead>
<tr>
<th>Parameters of the Long Jump</th>
<th>M. Powell</th>
<th>C. Lewis</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>General Information</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Official Distance [m]</td>
<td>8.95</td>
<td>8.91</td>
</tr>
<tr>
<td>Effective Distance [m]</td>
<td>8.98</td>
<td>8.91</td>
</tr>
<tr>
<td>Favorable Wind Velocity [m/s]</td>
<td>0.3</td>
<td>2.9</td>
</tr>
<tr>
<td><strong>The Approach</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Speed: 11-6m to the Board [m/s]</td>
<td>10.79</td>
<td>11.23</td>
</tr>
<tr>
<td>Average Speed: 6-1m to the Board [m/s]</td>
<td>10.94</td>
<td>11.26</td>
</tr>
<tr>
<td>The Length of the Third-Last Stride [m]</td>
<td>2.4</td>
<td>2.23</td>
</tr>
<tr>
<td>The Length of the Second-Last Stride [m]</td>
<td>2.47</td>
<td>2.7</td>
</tr>
<tr>
<td>The Length of the Last Stride [m]</td>
<td>2.28</td>
<td>1.88</td>
</tr>
<tr>
<td><strong>The Take-Off</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CM Horizontal Velocity [m/s]</td>
<td>9.27</td>
<td>9.11</td>
</tr>
<tr>
<td>CM Vertical Velocity [m/s]</td>
<td>4.21</td>
<td>3.37</td>
</tr>
<tr>
<td>Angle of Projection [deg]</td>
<td>24.1</td>
<td>20.3</td>
</tr>
<tr>
<td>Angle of body Lean at Touch-Down [deg]</td>
<td>71.8</td>
<td>77</td>
</tr>
<tr>
<td>Angle of body Lean at Take-Off [deg]</td>
<td>73.9</td>
<td>67.5</td>
</tr>
</tbody>
</table>
Computerized Biomechanical Analysis of Track and Field Athletics
Utilized by the Olympic Training Camp
For Throwing Events
Gideon Ariel
Assistant Coach
University of Massachusetts

This past summer (1971) at the Olympic Training Camp conducted at Dartmouth College, a computerized biomechanical analysis was done on the performance of each weight event man in attendance. The results were vividly noticeable by coaches and athletes. Several athletes were able to affect immediate improvement in their performance by making changes as warranted by their computer analysis. Others were able to return to their respective colleges armed with the scientific data and knowledge necessary for an intelligent approach to develop their own personal program for improvements. Events and Athletes: Discus—Michael Hoffman, Larry Kennedy, Stanley McDonald, Hammer—Robert Narcisse, Steve DeAutremont, Lawrence Hart, and Alfred Pallivoda, Shot—Put—Samuel Walker, Bruce Wilhelm and Erich Hardaway; Javelin—William Schmidt, Michael Lyngstad and James Stites. All found the program very beneficial. For instance, Hoffman's analysis revealed a flaw, and he immediately uncorked throws 10 feet better than ever before.

This biomechanical analysis provides a new approach to track and field athletics which was made possible by the collective efforts of many scholars and the technological advances of the past decade. Slow motion cinematography is used to record any desired motion and then special tracing equipment enables data to be processed directly by a high speed computer. The appropriate programming results in a segmental breakdown of information of the whole motion. Data obtained includes the total body center of gravity, segment velocities and accelerations, and joint forces and moments of force. A unique feature allows the interpretation of the data to show the significance of contribution of each body segment to the whole motion. Other available information shows 1) the positions of maximum velocities and accelerations, 2) the magnitude of the muscle action at each joint, 3) the vertical and horizontal forces at all joints and at the ground contact points, 4) the timing or coordination of motion between the body segments, and 5) the differences due to body builds. The combination of the moments of force, the interrelated patterns of the body segments, and the task performed give a measure of the efficiency of the motion.

This information may be useful in any track and field event to improve performance and to aid in finding optimization of performance.

The scientific principles underlying the analytic technique:

The segments of the human body form a link system. The laws of physics apply to any link system in motion regardless of whether the system is a human or machine. The different segments of this link system in the human body are the foot, shank, thigh, trunk, shoulders, upper-arm, forearm and the hand.

When the link system is in motion such as in any track and field event, there are specific forces acting upon each segment of the total link system. For example, if we analyze the forces which acted on a swinging forearm, the following forces would be obtained: (Fig. 1)

These three forces would act upon any segment in motion whether in the human body or another object.

1. The force of gravity.  
   Upper-arm ---

2. Centrifugal force due to the motion of the segment.  
   Forearm --------------------- Centrifugal force

3. Tangential force applied perpendicular to the segment motion.  
   --- Centrifugal force

   Tangential force --- Force due to Weight
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 con-
tribution 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 seconds
intervals of Seagren's 18' - feet, 9\1/4" inches world
record performance.

Figures 2 and 3 summarize the computer output
for the moments of force and percent con-
tribution 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 coun-
terclockwise 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
swinging phase, the moment changed direction
again indicating a clockwise moment. From
positions 21 to 40 (19/64 of a second), the con-
tribution 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
contribution 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 con-
tributing 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,
swinging) 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-bank 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 con-
tribution 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 con-
tributors. In the swing phase the trunk con-
tributed 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.
Biomechanical Analysis of the Hammer Throw*

Gideon B. Ariel, Ph.D. R. Michael Walls M. Ann Penny, Ph.D.

INTRODUCTION

In the past most field events, including the hammer throw, were dominated by American throwers. More recently, however, Americans have failed to produce distances comparable to those of their Soviet and Eastern European counterparts. In fact, in 1964 the Americans exceeded the qualifying standard of 226 feet at the Moscow Olympic games and more than twenty-five Russian athletes surpassed that distance.

One reason for this improvement involves the use of scientific applicability by the USSR. Application of Newtonian physics underlies the remarkable performances attained by modern Eastern and Russian sport groups. Advancement in computer technology in the U.S. has facilitated the development of similar biomechanical analysis and utilization of biomechanics permits quantification of motion as well as optimization for excellence.

The purposes of the present study were

1. to quantify the performance of outstanding hammer throwers as well as throws by American athletes
2. to compare the different techniques of the separate groups

In order to suggest methods for improved hammer throwing performances, the specific movements and the essential parameters of motion must be discerned so that subsequent technique alterations can be based on objective, quantified evidence rather than on quesswork and untested hypotheses.

METHOD

Two groups of hammer throwers were analyzed in the present study. One group consisted of six 1964 Olympic medalists and the second group was American throwers competing at the 1978 Houston throwing clinic. The Olympic athletes analyzed in order of finishing, beginning with the gold medalist, were:

Syedikham
Spiridonov
Bendarchuk
Riehm
Schmidt
Sachse

In August of 1978, a group of national class American throwers were invited to Houston, Texas by the U.S. Olympic Committee for a hammer throwing clinic. Attending the clinic were some of the best American throwers currently competing in this event:

Arcaro
Rice
Berry
Perkins
Bessette
Satchwell
McArdle
Silvario
McKenzie

Biomechanical analyses were performed on these throwers to afford comparison of the performances of the American athletes with those throwers by the competitors in the Montreal Olympic Games. The heights and weights of the analyzed competitors are listed in Table 1.

<table>
<thead>
<tr>
<th>Athlete</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arcaro</td>
<td>195</td>
<td>105</td>
</tr>
<tr>
<td>Rice</td>
<td>192</td>
<td>101</td>
</tr>
<tr>
<td>Berry</td>
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<td>99</td>
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<tr>
<td>Bessette</td>
<td>190</td>
<td>100</td>
</tr>
<tr>
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<td>102</td>
</tr>
<tr>
<td>McArdle</td>
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<tr>
<td>Silvario</td>
<td>195</td>
<td>106</td>
</tr>
<tr>
<td>McKenzie</td>
<td>194</td>
<td>105</td>
</tr>
</tbody>
</table>

High speed motion pictures, using a 50 lens set at an angle of 90 degrees to the sagittal plane of each thrower, were secured for all athletes. The clinic throwers were filmed at 200 frames per second and the Olympic athletes recorded at 100 frames per second. Each throw was filmed from the moment of release of the hammer. The films were interpreted through several analytic techniques:

1. visual observation
2. frame counting
3. computerized biomechanical analysis.

Tables and graphs were generated to determine patterns of motion to characterize the throwing performances.

The frame count analysis is a straightforward method for obtaining useful information concerning speed of motion. The time lapse between each frame of film is inversely related to the frame speed. For example, film taken at 100 frames per second has an interval of one hundredth of a second between frames. To time a motion, the between-frame interval is multiplied by the number of frames used to film the sequence. The procedure was used in this study for determination of turning time, i.e., the time required for a 360 degree rotation of the hammer head. Timing began at the low point of the hammer path following the preliminary wind. The next low point completed the first turn and began the second, etc. The low point following the third turn marked initiation of the delivery phase which terminated at release. By using the equation:

\[
\frac{\Delta V}{\Delta T} = \text{change in angular velocity of hammer} \\
\frac{\text{time full turn}}{\text{time of full turn}}
\]

the average acceleration of the hammer head, in each of the turns, was calculated.

Frame counts were also used to determine the amount of time the handle had one or both feet on the ground and are referred to as the single and double support phases, respectively. Following the preliminary winds, the low point was used to determine the initiation of the double support phase of the first turn. In subsequent turns, the relationship of the foot to the ground was used to determine whether the thrower was in a single or double support stance. Hammer release was taken as termination of the double support phase during delivery.

For computer analysis, the films were projected upon a transparent 36 x 36 inch glass screen. The digitizing process involved touching the body joint centers of the projected image with a sonic stylus. The emitted sound waves were converted into X-Y coordinates and stored in the computer. As each frame was digitized, joint centers simultaneously appeared on a graphic display screen and were connected by lines to form stick figures. The complete movement could then be recreated in stick figure animation on the screen. Following the digitization phase, motion analysis programs were executed.

The research proceeded in three separate technical areas:

1. The first study directed attention at the single support phases of the third turn and release. For this portion of the study, digitization began as the right (non-fixed) foot broke contact with the throwing surface to start the single support phase of the third turn.
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, Krueger, Laut, Marks, Pyka, Schmick, Stone, Summers, Vincent, Walker, and Weeks. Comparison of the throws of these athletes was made with those of the top six finishers in the 1976 Olympiad. The American athletes who were analyzed were: Beyer, Mironov, Barasnikov, Alan Feuerbach, Gies, and Capps.

A high speed motion picture camera with 50 mm lens recorded the performances of each thrower at an angle of 90 degrees to the athlete's sagittal plane. Films were taken of three throws for each of the clinic athletes and of the single best performance of each Olympic competitor. Each throw was filmed from the beginning of the glide through the release of the shot. The interface, pushoff, and push-off phases were particularly analyzed as well as the analytic techniques: visual observation, frame counting, and computerized biomechanical analysis. Following the computations, tables and graphs were generated to generate patterns of motion which characterize championship performances.

For the computer analysis, the films were projected upon a translucent 36 x 36 inch glass screen. The film was digitized with a sonic stylus and the X-Y coordinates recorded into the computer's memory bank. As each frame was digitized, joint centers were projected onto a graphic display screen and connected by lines to form stick figures. The complete movement was recreated in stick figure form on the screen where examination and corrections, if needed, were made. Figure 1 illustrates a computer graphic output of one digitized sequence. After the digitizing was completed, special kinematic programs were executed to calculate the amount of power or technique will result in a shorter throw. In throws longer than 69 feet, 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 during all the previous phases of the throw. To produce a start can be as detrimental to producing an optimal velocity as a low initial beginning.

In November, 1978, Alan Feuerbach, who finished fourth in the 1976 Games, was invited to the laboratory of Computed Biomechanical Analysis, Inc. to examine his style cinematographically and to obtain direct kinetic measurement of the forces produced during shot put. The latter information was obtained when Feuerbach put the shot from a modified throwing circle with two force platforms embedded within it. The force platforms were arranged in various configurations within the throwing circle so that direct measurements could be obtained as the athlete was throwing. The force platform permits measurements of the forces on the ground at various phases of the throw and yields invaluable data relating to the contribution of each leg to the throw.

Computerized Biomechanical Analysis

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 the angle of release. Although some attention must also be given to the release angle, the primary goal of the competitor 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 the distance. 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 pattern of the shot put can be partitioned into five phases which are illustrated in Figure 2 (from Markhold). The first is the starting phase when the athlete accelerates his body and the shot. The rear foot leaves the ground at the start of this phase. The second phase is the glide when the athlete is in the air for a brief amount of time, after which the foot contact the ground at the end of the phase. This phase the athlete should minimize the deceleration of the center of gravity and allow transfer of energy to the push-off phase. These films were for the fourth phase, the most important one. In this phase the front foot touches the ground initially and the shot leaves the hand at the end of the phase. During the push-off phase, the body exerts maximal acceleration of the shot toward the release.

It is this relationship between the transitional phase and the push-off which differentiates the 50- and 70-foot shotputters. In order to optimize this interrelationship, the athlete should acquire certain style characteristics since any deficiency in the amount of power or technique will result in a shorter throw. In throws longer than 69 feet, 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 during all the previous phases of the throw. To produce a start can be as detrimental to producing an optimal velocity as a low initial beginning.

Figures 3 to 6 illustrate the resultant ball velocities of the athletes who attended the Houston clinic. It can be seen that the velocities and the distances are significantly lower than those observed for the Olympic competitors. Among the clinic throws, Bob Feuerbach demonstrated the highest velocity.
TANGENTIAL FORCES

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

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

FIGURE: TANGENTIAL FORCE DIRECTIONS WITH BACK LEG LIFTED AND WITH SEGMENTS DECELERATIONS AT RELEASE.
Zur Diskussion gestellt:

G. Ariel
Die biomechanische Bewegungsanalyse mit Hilfe des Computers

J. Hay
Die Haytechnik: Das Nonplusultra im Hochsprung?
Die biomechanische Bewegungsanalyse mit Hilfe des Computers

Dr. Gideon Ariel ist Dozent am Institut für Leibesübungen der University of Massachusetts in Amherst. Er vertrat Israel in den Olympischen Spielen 1960 und 1964 im Kugelstoßen und Diskuswerfen und baut noch immer die Leistungsdaten der in diesen Disziplinen für ihn trainierten israelischen Nationaltreffen und als Assistent Leichtathletik Coach der University von Massachusetts.

Dr. William Saville ist Dozent am Department of Exercise Science der University von Massachusetts in Amherst. Eine kritische Stellungnahme zu diesem Beitrag wird in den nächsten Nummern erscheinen.


Die wissenschaftlichen Prinzipien der analytischen Technik

Die einzelnen Teile des menschlichen Körpers bilden ein gegliedertes System. Die Gesetze der Physik gelten für ein System mit Gliedern in Bewegung, egal ob es sich dabei um ein menschliches oder um ein maschinelles System handelt. Die einzelnen Teile des Gliedersystems des menschlichen Körpers sind der Fuß, der Unterschenkel, der Oberschenkel, der Rumpf, die Schultern, die Oberarm, der Unterarm und die Hand. Wenn ein solches Gliedersystem in Bewegung ist, wie das in jeder leichtathletischen Übung der Fall ist, wirken spezielle Kräfte auf jedes einzelne dieser Körperteile im Gliedersystem ein. Wenn wir z. B. die Kräfte analysieren, die auf einem schwingenden Unterarm einwirken, so ergeben sich die folgenden: (Abb. 1)

1. die Schwerkraft,
2. die Zentrifugalkraft aufgrund der Drehbewegung im Gelenk,
3. die Tangentialkraft senkrecht zur Körperteilbewegung.

Diese drei Kräfte würden immer auf Glieder in Bewegung einwirken, egal ob es sich um den
LUSIS

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,
velocities of the body segments and from the velocities it is then possible to calculate segment accelerations. Segment masses are utilized in the calculation of forces and moments of force. Appropriate programming (7) 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; angle of the resultant force application; moments of force, which indicates the magnitude of the muscle action at each joint; the vertical and horizontal forces at the ground contact points; the timing or coordination of motion between the body segments; and the differences due to body build. This combination of the moments of force, the interrelated patterns of the body segments, and the task performed provides a quantitative measure of the motion and allows for perfection or optimization of the activity.

A kinetic analysis of a world-record javelin throw by Luis illustrates the present technique. Figure 2 shows the cinematographical data obtained from the film at a speed of 64 frames per second. The joint centers, which are marked by points, were traced by the digitizer to obtain the relative position of each joint center at each position. This data when processed yielded the velocity and acceleration curves which are presented in Figures 3 and 4. The relationship between maximum velocities and accelerations is important in performance technique and gait analysis.

**FIGURE I.** Schematic representation of Graf-Pen operation.
FIGURE 4. Schematic representation of Graf-Pen operation.
First Digitizer in the World interface to the first Time Sharing in the World for Biomechanical Analysis
Figure 2. Contractile Force Apparatus for Isometric Contraction
Isometric muscular effort under study in the Motor Integration Laboratory.
Figure 1. Leg Press: Total Muscular Involvement (in percent)

- □ = Leg Press on Variable Resistance Machine (Centurion)
- △ = Leg Press with Exercise Apparatus
- ▼ = Squat with Convention Barbell

Lowering Bar

Raising Bar

Positions 1/8 sec
Understanding the Scientific Bases behind our...

Universal® Centurion

Universal's® Dynamic Variable Resistance

The ultimate builder of larger, stronger, faster and more capable athletes.

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First Variable Resistance Machine in the World - 1972
Biomechanical analysis of the knee joint during deep knee bends with heavy load

B. G. Ariel
University of Massachusetts, Amherst

The knee joint, the largest and most complex synovial joint in the human body, is an anatomical region subject to injuries from activities in various fields including athletics, industry, and recreation. Because this joint is between the longest bones in the body, the femur and the tibia, the forces and moments of force around this joint produce torques of such magnitude that injuries ensue. In athletics, various injuries may occur by overloading the knee joint (Nicholas, 1970; Peterson, 1970). In several studies (Kennedy and Fowler, 1971; Marshall and Olsson, 1971; Newman, 1969; Slocum and Larson, 1968), it was found that the instability of the knee joint was the result of the application of excessive external rotation and abduction forces to a flexed, weight-bearing knee.

The knee joint, described as a hinge joint, is much more complex. It consists of three articulations, the surfaces of which are not mutually adapted to each other, so that movement is not simply gliding (Gray, 1954; Lockhart, Hamilton, and Fyfe, 1959). The quadriceps femoris muscle group is responsible for extension of the knee joint. The four muscles of this group pull through a common tendon and insert via the ligamentum patella, which continues from the patella to the tuberosity of the tibia. The movements of the knee joint are primarily flexion and extension and, in certain positions of the joint, internal and external rotation (Dick, 1969).

The purpose of the present study was to investigate the forces and moments of force acting about the knee joint during a deep knee bend exercise with a heavy load.

METHODS

Twelve experienced weightlifters, ranging in age from 21 to 25 years, served as subjects. Their mean height was 181.5 cm and their mean weight was 90.5
TRACING OF SAMPLE X-RAY USED TO DETERMINE KNEE JOINT MODEL

\[ F_1 = F_2 \]
\[ \text{MOMENT} = F \times X \]

- \( K \): Knee joint angle
- \( L \): Angle between tibia and ligamentum patella
- \( e \): Distance from joint center to the tuberosity of tibia (4.4 cm)
- \( d \): Distance from mechanical axis of tibia to the tuberosity of tibia (3.2 cm)
- \( b \): Distance of the bi-sector of the knee joint angle to the apex of the patella (5.7 cm)
- \( X \): Perpendicular distance from knee joint center to the ligamentum patella line of force \( (F_1) \)
Table 1. Knee joint angle, forces, and moments of force for selected subjects in the deep knee bend with heavy load

<table>
<thead>
<tr>
<th>Position</th>
<th>Knee angle (degrees)</th>
<th>Moment (kg/m)</th>
<th>Horizontal force (kg)</th>
<th>Vertical force (kg)</th>
<th>Bone-on-bone force (kg)</th>
<th>Shear force (kg)</th>
<th>Compression force (kg)</th>
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<td>Subject 1</td>
<td>1</td>
<td>150.1</td>
<td>10.7</td>
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(continued on next page).
Photogrammetric Physical Parameters

Graphical representation showing the relationship between different frames of reference:

- Laboratory Reference Frame
- Projection Reference Frame
- Camera Reference Frame

Key points and vectors:

- Object Point of interest
- Projection of Object Point
- Image Projection Plane

Vectors and points labeled with subscripts for clarity.
one advantage of running with long strides is the reduction in the number of strides. But biomechanical analysis indicated that each running stride is associated with a braking force which stops the forward motion of the athlete. The larger the stride the greater the braking force. Ariel calculated that the optimum stride length occurred when the braking force was at a minimum. He reckons that the calculation of the precise relationship between stride and braking force could increase the individual's running efficiency by as much as 20 per cent. Leaning forward at the hip also contributes marginally to running efficiency, as does landing on the ball of the foot rather than the heel.

But although guidelines and techniques can be posted, there is no perfect formula for any given activity. Every individual has his own specific centre of gravity and type of body-build, and perfection lies in the individual's ability to make use of the findings of his own personal analysis.

Another Ariel creation—designed to accommodate each individual's need—is the Ariel-Wilson 4000 Exercise Computer. Initially used as a training device by the Dallas Cowboys American Football team, the unit monitors hydraulic lifts. These function like barbells, but their pressure can be specifically tuned to match needs and so maximize each player's work-out efficiency. Each Dallas Cowboy had his own physical profile cassette—a floppy disc capable of storing up to a million pieces of information about

Above A three-dimensional analysis of football place kicking. The stick figures show four different views of the same action. From such data it is possible to work out all the forces and angles at work, and to improve the player's technique.

American footballers have improved their kicking technique by filming dead-ball kicks (left) from different angles. This provides positional data that can be processed by a digitizer which inputs the relevant information for computer analysis.

Right A highly sensitive force mat is able to chart readings of four kinds of pressure: sideways, forward, vertical or twisting to an oscilloscope. Dr Ariel has charted the forces of footstrike at every point of contact in different shoes to check their ability to absorb shock. Results show that heel design is not as important as was once thought by shoe manufacturers.
Rear Projection Digitizing

Sports Illustrated. August 1977

“Faith” is a fine invention
When Gentlemen can see—
But Microscopes are prudent
In an Emergency.
—EMILY DICKINSON

It took Ariel more than 10,000 hours to program his computer to analyze an athlete’s motions.

Digitizing, Ariel uses his sonic pen to determine the coordinates of javelin thrower Bill Schmidt.
Tennis pro Vic Braden, hooked to a computer by electrodes, demonstrates how movement and muscle response can be tested to improve play.
MD aims to improve nation’s health using Olympic athletes as ‘walking fitness labs’

When Irving Dardik, MD, was a college kid in the mid Fifties, he was not only captain of the track team at the U. of Pennsylvania, but also a top-notch sprinter.

He almost made it to the 1956 Olympics in Melbourne in the 400-meter dash, and planned to try again the next time around, at the 1960 Rome Games.

But in 1958 he entered medical school, and that ended his dream of competing in the Olympics. “In those days, you couldn’t just leave medical school for something like that,” he says.

So instead of achieving fame as a quarter-miler, he achieved fame as a vascular surgeon. With his brother Herbert and Ibrahim Ibrahim, MD, he developed a coronary bypass graft technique using human umbilical cords.

That procedure has helped a lot of arteriosclerosis patients lead more active lives, but Dr. Dardik shrugs it off as “only palliative.” He would rather prevent heart disease than treat it.

ALL OF WHICH explains what he’s doing in Squaw Valley, Calif., helping to train young athletes for the 1980 Olympics. He’s not just interested in helping the United States win more medals at the 1980 Moscow Games—he sees the young athletes as walking, talking laboratories of physical fitness who could help improve the nation’s health.

The U.S. Olympic Committee appointed Dr. Dardik to set up the first of several Olympic Sports Medicine Institutes, on the grounds of the newly-opened Olympic Training Center in Squaw Valley, with two goals in mind: to help Olympic-caliber athletes learn more about their bodies and improve the physical fitness of the nation.

“People ask me, why do you do this thing? As a vascular surgeon, how do you fit? An orthopedist, yes, but a vascular surgeon?

“I treat people with coronary disease, and I work with bypass patients, which is sort of seeing the end of the spectrum of physical fitness. And here are these athletes, who are the best physiological specimens we can produce in this country, and I think somehow we can evaluate the process in physical fitness and use it to our advantage.

“THESE OLYMPIC athletes, these are ordinary people. Ordinary people who have talent. And they need to train and learn to live with that talent. We can learn so much from them.”

Housed in the ghost town of dormitories and offices left over from the 1960 Winter Olympics at Squaw Valley, the Olympic Training Center is a busy and intense place, though it only opened for business two months ago, and all the equipment and facilities have not yet arrived and been set up.

An average of 200 Olympic-quality athletes and coaches (by invitation only) a day train in the center, some staying for only a few days, some for a few weeks. They represent an assortment of sports, from basketball to swimming to kayaking, and the atmosphere at the center, snugly in one end of a bowl-shaped Squaw Valley, 15 miles from Lake Tahoe, is that of a cross between a college campus and a Y.M.C.A.

Sports medicine—sports science, as Dr. Dardik and others at the training center speak of it—has suddenly become a great deal more sophisticated, as have training methods.
MAN BEHIND THE
The Computer of the U.S. Olympic Sports Medicine Committee
PERSON TO PERSON

SC: How did you get involved in the field of computerized biomechanical analysis?
ARIEL: I was born in Israel and competed in two Olympics (1960 and 1964) as a discus thrower. I came to the U.S. on an athletic scholarship to the U. of Wyoming. After graduating with honors, I moved to the U. of Massachusetts for my M.D. and PhD in exercise science. I then jumped into the PhD program in computer science. I was teaching in the computer science dept. when I decided to start my own company—the Coto Research Center in California. It is a co-venture with Penn Central. Our $5-million complex in Coto de Caza is probably the most sophisticated sports research center in the world.

SC: What specific projects are you working on at the moment?
ARIEL: We’re working with the U.S. Olympic Committee in analyzing our top athletes in the throwing events and we have a permanent training center for the women’s Olympic volleyball team. We’re also working on various designs and inventions such as tennis rackets and shoes.

SC: You have said that your theories are based on Newtonian physics. Could you elaborate a little on that?
ARIEL: Anything that moves obviously has to observe Newtonian physics, which means force equals mass times acceleration. That’s basic, something you learn in high school. Now, when athletes try to throw a baseball faster or kick a soccer ball harder, they have to obey the same principle because basically they’re trying to overcome gravity and create inertial forces in their body systems.

To do that, they need internal mechanisms—muscles and other physiological aspects. Say an athlete wants to throw a javelin farther. The javelin had better leave his hand at a certain velocity and a certain angle. We can calculate these velocities and angles and see which are the most efficient to get the most distance. That’s the point—to get the most distance. They don’t measure how beautiful you look, but how far you throw.

On the other hand, we are also working with gymnasts and other aesthetic athletes, such as divers and figure skaters. We want to quantify the feedback that the judge is looking for so that he will say the performance is 9.6 and not 9.2.

SC: But how can a judge be that accurate?
ARIEL: We try to define the factors that affect judgment. For example, in figure skating we found that the wobbling effect of the trunk is extremely important. In other words, the skater can go up and do a double axel, but if his trunk is wobbling a bit, he’ll usually wind up with a low score. It’s not so much how straight the leg is or how beautiful the fingers are in the air, it’s mostly the massive parts of the body that are sending the message to the judges.

SC: How about a non-gravity event, such as swimming?
ARIEL: We try to measure what kind of interaction between the body surface and the water will produce the greatest propelling force. Sometimes it’s not necessarily what makes sense. For example, it used to be thought that if you stretch your arm as fast as possible and pull it as fast as possible through the water—the classic Johnny Weismuller style—you

Gideon Ariel, the guru of computer science, tells us what he’s doing with our athletes
INTRODUCING THE REAL AMERICA'S TEAM

The USA National Women's Volleyball Team is the first permanent amateur sports team ever formed in America, and this year they intend to prove they've earned that support by challenging for the Olympic gold.

By Barry Tarshis

Top row, left to right: Michael Orenduff (asst. coach), Arie Selinger (coach), Denise Corlett, Tauna Vandeveeghe, Flo Hyman, Julie Vollersten, Sherry Moore, John Corbetti (asst. coach), Marion Sano (asst. coach). Middle row: Susan Varga (manager), Laurie Flachmeier, Rose Magers, Sue Woekstra, Linda Chisholm, Robert McCarthy (public relations). Bottom row: Paula Weishoff, Carolyn Becker, Debbie Green, Rita Crockett. Not shown: Jeanne Beaufreys, Kim Ruddins.
frame-by-frame, body-segment-by-body-segment analysis, allows Ariel to capture the stance and posture of Hyman's body during the spiking motion.

had to rely on their eyes to tell them what is going on. But the human eye cannot quantify movement.

"The most important things in athletic pattern in the best throws. Instead of continuing the throw with a follow through motion, we said he should decelerate the heavy parts of the body, stop and then reaccelerate for the spike."

Dr. Gideon Ariel's computer exercise machine looks like something out of Star Wars.
BIOMECHANICAL ANALYSIS SYSTEM
BY KISTLER

Complete Movement Analysis Software/Hardware System Using Kistler Force Plates and Other Instrumentation

* Fully Exploits High Accuracy & Sensitivity of Kistler Force Plates
* Unique Easy to Learn and Use; Menu and Mouse Driven
* On-Line Tutorial and Help Screens
* Includes Complete Array of Force, Moment, and COP Outputs
* Powerful Integrated EMG Analysis Package
* System Part of Larger Synchronized Film/Video Analysis System
NEW HORIZONS OF HUMAN MOVEMENT OPEN UP WITH BASK, YOUR KEY TO ALL
BIOMECHANICAL ANALYSES USING KISTLER FORCE PLATES -
AND OTHER INSTRUMENTATION.

ONLY THE KISTLER BASK COMBINES THESE UNIQUE FEATURES:

Software available for IBM-AT or compatible.
Extremely user friendly menu-driven operation.
Full on-screen tutorial and help screens through single key stroke.
Two monitors driven simultaneously by single mouse or keyboard;
monochrome screen for menu operation and high resolution color
display for immediate viewing of results.
One to four Kistler force plates supported with total sampling rate
of up to 40,000 measurements/second

Powerful processing of EMG, accelerometer or other analog signal
devices; synchronized with force plate and film/video data.
Direct interactive access of data to numerous standard off-the-shelf
software such as spreadsheet, data base, publishing, graphics and
statistics packages.
User access through modem to innovative on-line kinematic/kinetic
data base of more than 15 years.

Open to any software and hardware extension such as offered by the
Ariel Performance Analysis System or other leading movement
analysis systems.
Possibility for diagnosis and trouble shooting through modem.
Unequalled price-to-performance ratio.
KISTLER BASK - The software system sets no limits to the use of Kistler's high accuracy force plates with quartz sensors.

FLOW CHART OF SYSTEM INTEGRATION WITH OPTIONAL EXTENSIONS:

- SUBJECT (Lift, Run, Walk, Stand, Jump)
- KISTLER FORCE PLATE(S), EMG, ACCELEROMETER, PRESSURE SENSOR
- FILM, VIDEO ANALYSIS
- BASK APAS
- DATA BASE, WORKSHEET, STATISTICS DESKTOP PUBLISHING, GRAPHICS
- COLOR DISPLAY PLOTTER PRINTER

SYSTEM DESCRIPTION:

For clinicians and researchers, BASK provides a unique system that enables fast and accurate analysis of movement, using Kistler multi-component piezoelectric force plates and other instrumentation. For over two decades Kistler force plates have been internationally recognized as the leading instrument for measuring ground reaction forces in biomechanics. To fully exploit the exceptional characteristics of our force plates, Kistler offers a powerful and unique software package(1), running on an enhanced AT-compatible.

Integrated Hardware/Software System Includes:
- IBM PC/AT 100% Compatible
- 70MB Hard Disk
- 640 KB Memory
- EGA(2) & Monochrome Monitors
- Logitech R Serial Mouse with SW
- 40KHz A/D Board
- 80287 Math Coprocessor
- Modem with SW
- Fully Formatted and Software Installed
- Various Printers & Plotters Supported (Ink Jet Printer Provided)

1. The Software Used in the BASK is Part of the Ariel Performance Analysis System (APAS); Trabuco Canyon, CA 92679.
2. NEC Multisynch II R is Required for Use with Kinematic Package.
Running sequence on treadmill zero-G
ALL APPLICATIONS UTILIZED SIMILAR QUANTIFICATION TECHNIQUES
Hi Speed Camera at 120 Hz
Capture videos using several cameras simultaneously and save the clips directly as AVI files to your hard disk. This allows you to connect multiple digital video cameras to your computer and to start capturing with one mouse click.
Portable performance analysis system:

- force plate
- EMG
- video cameras
- notebook computer
- portable VCR
- portable printer
- optional A/D devices
Video Capturing System
Software Integration

- Capturing
- Digitizing
  - Locally
  - Net Digitizing
- Transformation
- Filtering
- Kinematic Results Display
- Kinetic Results Display
In the Laboratory
Software Integration
Analysis of Performance Require:

**Video Recording**

**Digitizing the Data**

*Manual*

**Automatic**

**Transformation of the Data**

*2D - Two Dimensional*

*3D - Three Dimensional*
Technological advances have made it possible to integrate, synchronize, and simultaneously display video records, kinematic, kinetic, EMG, and force plate data of human movement.
Hardware

- **Main Computer System**
- **Workstations**
- **Capture Card**
- **Network**
  - **Intranet**
  - **Internet**
    - **Renderer**
    - **Presentations**
Display and Analysis
Program Integration and Synchronization
TECHNIQUE COMPARISONS USING VIDEO DISPLAY
Discus Throwing Analysis Using Video Viewing Option

Video View--The video viewing function permits the biomechanist to observe a sport or functional movement from multiple perspectives, simultaneously. This allows the coach or clinical to perform sport or clinical evaluations at sampling rates that may be 2-10 times faster than visual observations depending on the video cameras transport rate.
Gymnastics Techniques Comparison of Backhand Spring & Flic-Flac Using Synchronized Views

Sync View--The synchronization function provides the capability of performing a comparative study of two separate trials or different movement techniques in a side–by–side analysis format.
The e-Golf Reports (or e-Reports) will be one of the most important technical factors of the system. With these reports, users should be able to understand their mistakes. Users will be able to improve their skills by interacting with e-Coaches, keeping records of progress, get online update recommendations for training, design training programs, obtain third party intervention, track progress and learn online through real-time interaction.
F2 - Hide Info...
Refreshrate 35.7 fps
Time = 0.57 seconds [49%]

Speed - Ball: 7.74 m/s
Speed - Racket: 8.63 m/s
Right Wrist Angle: 31.63 degree

Event: Start Activity - ...
COMPUTERIZED EXERCISE EQUIPMENT
Fig. 1. The programmable variable resistance exerciser flow chart.
Gideon Ariel is a single-minded problem-solver, calling on the disciplines of exercise science (in which he received his doctorate at the University of Massachusetts), computer science, mechanics, and engineering to provide solutions for the problems of athletic performance. As biomechanics and computer science chairman for the US Olympic Committee he recently helped the women's volleyball team at Squaw Valley, who weren't jumping high enough. Using computer analysis of their movements, he and colleagues found that the volleyballers didn't have sufficient weight and strength in their arms, as compared with their legs, for the work of leaping. "They worked on it for six weeks," recalls the biomechanist, "increased their arm strength, and increased their jumping capacity quite a bit."

Dr. Ariel gets to the heart of challenges like these by using the data-gobbling, data-juggling talents of the computer, which if properly programmed, can analyze and manipulate data concerning the complex motions and interactions of human-body segments and athletic gear. Originally he labored to reduce limb and trunk movements to stick-figure representations from motion-picture photographs superimposed on each other. Finding the conventional ways tedious and time-consuming, he experimented with shortcuts. Now he feeds coordinates of points on a body into computers by several methods.

In one of them, a scanning device glances over a photographic image projected on a screen, responding to its light and dark areas. A computer connected to the scanner then plots the positions of joints to produce stick-figure tracings. Two other gadgets depend on sound rather than light to position body segments on a cathode-ray tube or paper printout. In one technique, Dr. Ariel touches a "sonic pen" to a photographic image displayed over a kind of grid with tiny microphones around the edges. The microphones pick up sound impulses and measure how far away the source is; the computer converts the coordinates to visual images. From this, says Dr. Ariel, he can calculate the forces, velocities, and accelerations, if given the segment weights and distribution of body mass.

Restless and curious, Dr. Ariel has explored a broad spectrum of athletic activities—running, field events, diving, golf, basketball, football, ice skating, and tennis—at Computerized Biomechanical Analysis, Inc (CBA), his private company.

Although still an adjunct professor of computer science at the University of Massachusetts, he presently has little to do with pure research, having made a conscious decision in 1971 to steer a commercial course. CBA has taken on a number of projects for manufacturers so Dr. Ariel can recover his investment in facilities. "The money has to come from somewhere," he laments. Although he's been consulted by professional teams in the past, he's not currently active in such work. He is, however, busy dealing with tennis rackets, golf clubs, and football helmets and jackets newly conceived to prevent injuries. Furthermore, he's absorbed in developing new, large exercise devices—he has contributed to the Universal, Nautilus, and Paramount equipment—perhaps even for home use. Someday, he speculates, the exercise machine's computer will describe how to work out to be a better tennis player, bowler, or orienteerer, and in addition, tell the athlete what to eat and how much.  

David Whieldon
Biomechanics of Sports and Kinanthropometry

Biomécanique du sport et kinanthropométrie

Compiled and edited by

FERNAND LANDRY, Ph. D.
WILLIAM A.R. ORBAN, Ph. D.
Computerized Dynamic Resistive Exercise

Gideon Ariel

Introduction

The relationship between resistance exercises and muscle strength has been known for a long time. Muscular strength may be defined as the force a muscle group can exert against a resistance in a maximal effort, and any motion by the human requires muscular involvement. Forty to sixty percent of the human body is composed of contractile tissue forming 437 different voluntary muscles, and the most fundamental function of these muscles is the ability to produce motion by their own contraction. The action of these muscles on the bones, which provides the leverage system, permits man to stand erect, carry out activities of daily living and participate in athletic performances requiring optimal efficiency in muscular contraction and coordination. This motion of the musculoskeletal system is governed by the strength of the muscles and skeletal structure.

In 1948 Delorme [3] adopted the name “progressive resistance exercise” for his method of developing muscular strength through the utilization of counterbalancing the weight of the extremity with a cable and pulley arrangement and, thus, gave load-assisting exercise to muscle groups which would not perform antigravity motions. McQueen [4] distinguished between exercise regimens for producing muscle hypertrophy and for producing muscle power. He concluded that the number of repetitions for each set of exercises determines the different characteristics of the exercise. Based on evidence presented in these early studies, hundreds of investigations have been published relative to muscular development through resistance exercise with various methods being introduced. Techniques for muscular development include isotonic, isometric, isokinetic, eccentric, concentric and many other exercise techniques. Each system has been supported and refuted by numerous investigations.

Gideon Ariel, Computerized Biomechanical Analysis Inc., Amherst, Massachusetts, U.S.A.
With the purchase of the Ariel Computerized Exercise System you join a select group of people:
The National Aeronautic and Space Agency selected the Ariel CES for research in adaptation of exercise to zero gravity. According to the experts at NASA, the Ariel CES is the only programmable modality which can provide the necessary exercise for humans in space to counteract the effects of zero gravity.
In a laboratory at Harvard Medical School, studies are being conducted with the Ariel CES to determine human adaptation to physical stress, lack of sleep, and exercise on various biochemical processes.

The United States Olympic Committee purchased the Ariel CES to assist in research for appropriate alternates to anabolic steroids or other ergogenic aids for athletes.

Hospitals and rehabilitation centers have purchased the Ariel CES to enhance the traditional methods of diagnoses, research, and rehabilitation protocols.

Health and fitness clubs have selected the Ariel CES because it allows both instructors and members to assess performance levels, follow changes, as well as tailoring special exercise regimens.
CAN COMPUTERS

High-tech machines may provide the ultimate individual training.
The ARIEL Edge computerized exercise system drives physical conditioning, sports training, rehabilitation and research to a whole new playing field.

KEY ADVANTAGES

- Provides training modes including fatigue, work, pyramiding, and isometric sticking-point challenges. Combines cardiovascular conditioning and resistance training.

- The ARIEL Edge adjusts to you. Analyzes the velocity, acceleration, position, applied force and resistance 16,000 times per second throughout the entire range of motion and adjusts to match the resistance.

- Intelligent Programming simulates training at the same speed athletes compete. Eliminates the inertia experienced with traditional weight training. Allows for high-speed training of the type II fast twitch muscle fibers.

- Enhances muscular development. The faster the muscles contract, the faster the limbs move. The faster the limbs move, the faster the body can run, jump, hit, throw and all-around functionally perform better.

- No pain, all gain. When using the ARIEL Edge there is no eccentric (negative) resistance applied to the muscle, therefore no muscle tear down, which causes DOMS (Delayed Onset Muscle Soreness).
ACCOMMODATING RESISTANCE CURVE OF A BENCH PRESS PUSHING/PULLING MOVEMENT WITH COMPARISON OF DIFFERENT TRAINING SESSIONS
Force, Position, and EMG of the flexors and extensors of the elbow

---

Force

Position

Biceps

Triceps

Extensors stop motion

Pre-movement EMG
The effect of anabolic steroid upon skeletal muscle contractile force

GIDEON ARIEL, Ph.D.
(from the Department of Exercise Science, University of Massachusetts,
Amherst, Massachusetts, U.S.A.)
up upon the maximal lifts between the training period and the anabolic period and between the control and experimental groups for the same two periods.

RESULTS

Figure 1 presents the changes in contractile force for both control and experimental groups for the training and anabolic periods. Data is reported for the bench, military and sitting presses and the squat exercises. Also, total contractile force gain in all four exercises is reported.

A comparison of regression lines between the training and the anabolic periods and a comparison between the control and experimental groups is reported in Table 1.

Considering the differences between the training and the anabolic steroid periods, a comparison of regression lines yields the following results. No differences were found between the training period and the anabolic steroid period for the control group (Table 1; 1-5). Significant differences between the slopes of the regression lines were found in the bench press, seated press, and the squat exercises, for the experimental group between the training period and the anabolic steroid period (Table 1; 6, 8, 9). A significant difference was found when all exercises were combined for the experimental group (Table 1; 10).

When comparing the slopes of the control group to the experimental group, no significant difference was found in the training period in the bench press and seated press exercises (Table 1; 11, 12). However, significant differences were

![Diagram](image.png)

**Fig. 1.—** The effect of anabolic steroid (Dianabol) upon the muscular contractile force.
The effect of anabolic steroids on reflex components

ABSTRACT. The purpose of this study was to investigate the effect of anabolic steroid upon the nervous system by measuring the various reflex components of the knee jerk reflex. A double blind technique was used in this study. The anabolic steroid (Dianabol) had a significant effect upon the reflex components of 6 male subjects. Significantly faster Motor Times and significantly slower Latencies were obtained. From these results it can be concluded that the anabolic steroid acted upon the central nervous system and the biochemical processes involved in the reflex.

The work of Kochakian and Murlin (3) provides the basis for the use of anabolic steroids. The pharmacological properties of these steroids have proved of clinical value in the treatment of conditions where protein synthesis and reduced nitrogen loss is desired. Their use has been extended by “power event” athletes who have attempted to develop increased muscular contractile force. The use of anabolic steroids for this purpose is reported to be widespread (2).

The effects of anabolic steroids upon the nervous system are still unclear. The purpose of this study was to investigate the effect of an anabolic steroid (Methandrostenebolone) upon the nervous system by measuring the knee jerk reflex. This reflex arc, which is initiated by striking the patellar ligament has been subdivided into three components: the reflex latency, the motor time, and the total reflex time, in accordance with the nomenclature of Weiss (6). In general, the subdivisions used by Weiss (6), and Botwinick and Thompson (1), to fractionate reaction time were used in the present study to fractionate reflex time. Therefore, the reflex latency is the time from mechanical stimulation of the patellar ligament to the appearance of an action potential at the motor point of the rectus femoris muscle. The motor time is the period from the appearance of an action potential at the motor point to the mechanical movement of the leg by the muscle. The total reflex time is the time from the mechanical stimulation of the tendon to the mechanical movement of the leg. Kroll (4) has postulated the relative independence of these components. This independence suggests different mechanisms. The effect of anabolic steroids upon the afferent- efferent nervous pathway and the electro-biochemical exchange period was examined to add to present knowledge which is already aware of consistent changes in the biochemical parameters.

METHODS

Six male university students, aged 18-22 years, served as subjects in this study. Their height averaged 182 cm and their weight 87 kg. The experiments were conducted weekly on two successive days during an eight-week period. In order to minimize the effect of diurnal variation, testing was done between 8 p.m. and 10 p.m.

All subjects were varsity athletes who had experienced two years of weight training. For a period of four months prior to the beginning of the experimental period all the subjects trained for five days and performed test trials on the sixth and seventh days. This procedure was followed for the 8 weeks study period. During the second, third, and fourth weeks of the study all subjects were given placebo pills daily with the information they contained 10 mg of Dianabol (Methandrostenebolone), an oral anabolic steroid. From the fourth to the eighth weeks a double blind technique was used. Three of the subjects received 10 mg of the oral anabolic steroid and the remaining three subjects continued to receive the placebo. The oral anabolic steroid and the placebo...
were assigned to the subjects by code by the University Health Service and the investigators were not informed what the subject actually received until after the 8 weeks testing period.

Total patellar reflex time and reflex latency were obtained on the right limb. A Lafayette knee reflex apparatus was used with an adjustable hammer to deliver a strike to the patellar ligament. The hammer was released at a 90 degree angle. The subject was comfortably seated with his heel held relaxed against an adjustable plate depressing a microswitch. The recording was started when a microswitch in the hammer was activated by the strike. This microswitch closed the circuit, causing an electric Hunter clock counter to start when contact was made by the hammer head with the patellar ligament. As soon as the reflex arc was completed, a mechanical movement of the limb caused the subject’s heel to lose contact with the heel plate which again opened the circuit and stopped the electric clock. The time elapsing is the total reflex time.

Electrodes for recording the EMG were placed directly over the rectus femoris motor point which was located by the standard procedures indicated in the TECA Operator’s manual (5) for the variable pulse generator and chronaximeter model GH3. The electrodes were connected to the TECA Electromyograph model B2 oscilloscope. At the time when the hammer struck the patellar ligament, a beam swept across the oscilloscope, and as the nerve impulse reached the motor point electrodes, a spike potential was displayed on the oscilloscope. This time interval was the latency. Ten reflex trials were taken consecutively on each subject at each testing session.

Data are reported for the control (placebo) and the experimental groups (Dianabol), and comparisons between the training period (1st four weeks) and the anabolic steroid period (last four weeks) have been statistically tested.

RESULTS

Figure 1 presents the relative percentages of each reflex component in the training and anabolic steroid periods for both the control and the experimental groups. Only slight changes are seen between the percentages of the different components for the control group. However, the effect of the anabolic steroid on the experimental group is marked. The reflex latency of 11.21 percent changed to 19.74 percent during the anabolic steroid period; the motor time component decreased from 88.79 percent to 80.26 percent of the total reflex time during the same period. These changes in the motor time produced a greatly reduced total reflex time. The mean motor time of 108.39 ms was reduced to 60.33 ms for the experimental group. Figure 2 presents the changes in the reflex components for both control and experimental groups for the same two periods. There was an increase in the length of the reflex latency component of the experimental group during the anabolic steroid period. This lengthening of the latency component was statistically significant despite the small mean difference. The faster motor time and its effect upon the total reflex time are clearly seen to be more marked for the experimental group who received the anabolic steroid during this period.

A comparison of regression lines between the training and the anabolic steroid periods yields the following results (Table 1). The control and the experimental groups demonstrated significant differences between the slopes of the regression lines for latencies (Table 1, A5). The regression slopes were significantly different between the training and the anabolic steroid periods in the motor and total reflex times for the experimental group (Table 1, B5 and C5).
Biomechanics of athletic shoe design

G. B. Ariel
University of Massachusetts, Amherst

In all athletic performances, whether team games such as football, soccer, basketball, volleyball, or in individual sports such as running, jumping, throwing, or cycling, where gravitational forces play a major role, the shoes on which the weight bearing athlete plays are probably one of the most important contributing factors in the execution of efficient human performance. The interaction between the uniqueness of each specific activity and the athlete is influenced by factors such as the force of impact, the weight of the athlete, the surface upon which the activity is performed, the individual’s stride and gait, etc. Athletic footwear cannot be evaluated separately from the “athlete in the shoe.” Therefore, biomechanical factors of the athletic performance must be considered when designing shoes.

For a number of years, repeated attempts have been made by the writer to determine the scientific methods used by various shoe companies in the United States, Germany, Finland, and other countries in the development of their athletic shoes. However, it is evident that shoe design and safety have been the province of both the shoe designer and safety engineer. The engineer has been concerned with the physical components of the shoe such as the coefficient of friction and durability factors influencing the shoe. Often esthetic features receive the greatest consideration. However, it is contended that athletic performance cannot be thoroughly researched without taking into account “the athlete in the shoe.” Unfortunately, the shoe designers have overlooked the fact that shoe efficiency, safety, and performance are inextricably tied to the biomechanics of the particular activity and the style of whoever is under scrutiny.
not return to zero in time for the beginning cycle of the first curve of the next cycle.

**RESULTS**

The present experiment resulted in two types of data. The first results were the biomechanical behavior of the athlete. The second results were the data obtained from the various athletic shoes based on the dynamic testing of the shoe itself. Figure 1 illustrates the interaction between the surface, shoe, and body joints. A unique approach in this study was that the dynamic characteristics of the shoes were obtained by utilizing the biomechanical data from the athlete as he performed rather than the common trial and error method of observation alone.

**Anatomical Consideration**

Foot movements are important considerations in the design of the athletic shoe. However, because of the numerous articulations, the foot is quite complex. For example, the foot consists of the following joints: (a) the ankle joint, between the tibia and talus; (b) the talocalcaneal joint, between the talus and calcaneus; (c) the mid-tarsal joints, calcaneus to cuboid, and talus to navicular; (d) the tarsometatarsal and

![Figure 1. Force interaction between surface, shoe, and body segments.](image-url)
been attained from a 10-cycle/sec loading. The slope of the curve and the point at which any abrupt changes in the slope take place must be compared to the impact loading of a runner contacting the ground. The force per unit area on the shoe was calculated for different speeds of running. This information, used in conjunction with the hysteresis loops, showed that the shock absorption quality of the foot and ankle was fully used during the time period that the softest part of the shoe (inner sole) was being compressed. The slope of the hysteresis loop changed sharply upward after a loading of approximately 22–33 kg (10 to 15 lb), and neither the shoe, nor the foot, nor a material with a lower slope can absorb any more vertical forces. From the hysteresis loops in Figure 3, it was revealed that a leading cross country shoe (A) showed little shock absorption that might result in the transmission of high forces to the ankle, knee, and hip joints. Shoe (F), which is a leading jogging shoe, had maximum shock absorption when the load was minimal and minimum shock absorption when the load was at a maximum. This phenomenon illustrates energy loss during running. Shoe (C) is a leader among basketball shoes. Its characteristics are opposite to the desired ones. Energy loss is great, which may contribute significantly to the athlete's fatigue, and the shock absorption characteristics are not consistent with those desired in this game.
**DISCUSSION**

Analyses of more than 35 different running shoes revealed that human factors were not taken into consideration when designing these shoes. The dynamic characteristics of these running shoes yielded results which are opposite to the desired ones. The hysteresis loops obtained demonstrated insufficient shock absorption characteristics or too much absorption at the wrong time. In other words, when the loading was at its minimum the greatest shock absorption occurred while at the point of greatest loading, when the shock absorption is needed, the material does not respond properly. None of the shoes in this study demonstrated results that are considered desirable for the given activity.

From the evaluation of the shoe material and its interaction with the shock absorbing qualities of the foot, it was concluded that the heel and the outside edge of a shoe should have a hysteresis slope of about 45 degrees with no abrupt changes in the slope. The section of the shoe at the ball of the foot should have a hysteresis slope of about 75–80 degrees with no abrupt changes so that the runner or thrower can push off from a solid surface.

At the present time, there are no athletic shoes available which consider the “athlete in the shoe.” In fact, some of the shoes may contribute...
Computer helps design shoe that walks on air

By MILTON COLE

AMHERST — Walking on air.

The very thought is so pleasing that the expression is used constantly to describe emotionally inspiring success.

But now a computer and a former Olympic athlete have created a new kind of footwear that makes "walking on air" a reality.

Dr. Gideon Ariel of Belchertown and his Computerized Biomechanical Analysis company in Amherst have designed shoes in which one walks on air.

How efficient the shoe is depends upon the design of the shoe in general, and how can it be made more efficient.

The result of that survey and study could be shoes that have one walking on air.

And if the air shoes are the most unusual of the products of the CBA, they are not the only ones.

For example, there is a new exercise machine that makes it unnecessary for large rooms to house it, and makes it possible to do to all your exercises in half the average-size room.

There is a tennis racket with a pivoting handle that enables a player to absorb the shock of a ball at his feet, and return it with maximum force and accuracy.

And there is a new study being made for the Department of Defense on how to make the foot soldier more efficient as far as equipment and uniform are concerned, and what is the most efficient way to hold and shoot a machine gun.

Yet these are not all of the more unusual studies that have been, or are being made. But there are others, enough others that the business started by Ariel six years ago has now grown into a multi-million-dollar firm that is expanding.

Take the air shoe.

Originally the U.S. Bureau of Standards contracted with CBA several years ago to do a survey on the efficiency of the design of the common shoe.

The study, including filming of people walking and then slowing down the film to analyze frame-by-frame what happens when a person takes a step, showed that the common shoe is not an efficient design.

The preceding heel causes a person to step onto the heel of the foot first, putting the strain of each step on the legs, and then complicating it by the strain up through the leg into the lower back.

"It showed that the way we walk and the kind of shoes we wear can cause a great deal of trouble as well as the cause of foot and leg problems," Ariel said.

The computer showed that the most efficient way to walk is the way we walk barefoot, with a rolling motion so that the weight is distributed more evenly throughout the body.

How to utilize knowledge

After the report was sent to the federal agency, Gideon and his compatriots at CBA worked on putting theory into reality.

One shoe was designed, aimed at providing the rolling motion, but still sending some of the jarring motion up the legs. Then came the idea of using that jarring action to provide forward motion.

The air shoe was born. The prototype is designed for athletes, and has been used successfully in practice by the members of the U.S. women's volleyball team.

They have found that they jump higher, and they end up with fewer leg problems, muscle pull, etc., as a result of landing on their feet after a jump.

The next step was to design a shoe that would allow players to experiment with it, along with runners.

The shoe is a regular nylon-bodied running shoe, with the rubberized toe box and a molded plastic sole.

The rubberized toe box is made with a molded rubberized insert running the entire length of the shoe.

A rubberized toe box is inserted into the valve and the insert is filled with air, like filling an auto or bicycle tire for ball or basketball.

"You put it on, lace and tie it. And when one walks on it, he or she is literally and actually walking on air," Ariel said.

Each step forces the air from one spot to the next, in an alternating pattern of the computer-designed valves, and the result is a cushioned step whether walking or running, and a jarring one when one walks.

"They should end problems with leg muscles, shin splints, bone spurs, etc. And they should cut foot fatigue for runners," Ariel said.

Right now the design has been acquired by the Pony Shoe Company, which makes footwear for all kinds of sporting activities.

Ariel believes that the shoe will be used in athletic and other national and international competition. He believes it will find a place in sports, particularly basketball, and perhaps football as well.

But it also should find use in regular shoes worn by the general public, and could have the nation, if not the world, walking on air, and being healthier for it. If Ariel and his computers are correct.

"I imagine how great this would be for paratroopers or others jumping from considerable heights," enthused Ariel.

The large but husky University of Massachusetts doctoral graduate also is enthusiastic about the exercise machine he has designed.

Originally used weights

Originally he designed one for the Universal firm, one of the top sports companies in the U.S., using the established method of actual weights attached to pullies and handles.

It was different and easier to operate than others on the market at the time, but still quite bulky and time-consuming.

The latest design, made possible by the omniscient and omnipresent computer, is a simple cylinder connected to a variety of bars or pedals or overhead handles.

The computer is hooked up on a shelf as part of the system.

You press a button, and the computer asks if you want to exercise.

You press buttons that indicate you want to do weight lifting, and how much force or pounding you want to lift.

The computer then sets the valves that control the hydraulic fluid in the cylinder and thus the amount of force necessary to lift the piston in the cylinder.

It eliminates the need for the actual weights to be there.

One of the people involved with Ariel in his other enterprises is former U.S. Treasury Secretary William Simon. He is interested in forming their own manufacturing firm to turn out the new tennis rackets that CBA has designed.

Doing research on tennis racket efficiency and how the airfoil, "tennis elbow," occurs, CBA and Dr. Ariel found that the impact of a ball on the racket sends a jarring force through the racket handle up the arm and into the elbow joint.

The computer suggested a rotating handle that would use the airfoil effect to twist the handle, making it so the face of the racket is directly against the ball each time it hits the racket.

This not only eliminated the jarring force going into the elbow joint, but provided the opportunity for a perfect return shot.

Using that racket, which Ariel says will be produced by someone within a year, either their own firm or one of the several sporting goods manufacturers, with the tennis balls CBA designed for Spalding, could make for much improved tennis.
PUMPING UP the sole prepares the new “air shoe” for use. It was designed by Computerized Biomechanical Analysis in Amherst, and CBA president Dr. Gideon Ariel is getting the shoes ready. (Richard Carpenter Photo).
First Computerized Shoe invented by Dr. Gideon Ariel 1974
Computerized Footwear
How one man's mind is thrusting athletic footwear design into areas which border on science fiction, but which are based on science fact.

by Steve Lloyd

Dr. Gideon Ariel, director of Computerized Biomechanical Analysis, Inc., and a consultant to the U.S. Olympic Committee, has been called the "Leonardo Da Vinci of sports." But while Da Vinci's studies of the human body were never fully appreciated by his contemporaries, Dr. Ariel is finding an increasing receptive audience for his computerized analysis of human motion.

A pioneer at tying the science of motion into physical skills necessary to perform athletic feats, Dr. Ariel's studies are helping athletes perform by revealing to them heretofore undeterminable deterrents to optimum performance.

But Dr. Ariel's work isn't limited to helping athletes discover motion efficiency. His computer has been and can be applied to the improvement through redesign of athletic equipment, including, but not limited to, shoes, racquets, clubs, bats and balls, and jerseys. Perhaps most important, it's providing preventive and rehabilitative articles and research in sports medicine.

The 39-year-old native of Israel combines the esoterica of computer science with the old athletic standby: high speed, slow-motion and stop-action photography applied with the century old principles of Newtonian physics.

"By analyzing high speed films (as fast as 10,000 frames per second) frame-by-frame, using equipment interfaced with our computer, we calculate velocity, acceleration, direction and angle of forces on all body joints. From that a whole new dimension of data becomes available to us," Ariel says.

Ariel combined science with sport following his own late-blooming career as a discus thrower on the Israeli team at the 1960 and 1964 Olympics. During his remaining eight-hour training sessions he heard one coaching theory after another. During his undergraduate years at the University of Wyoming and at Israel's Weizmann Institute of Science, a physical education major, his skepticism of countless — and contradictory — coaching theories grew. When he enrolled for master's courses at the newly-established School of Exercise Science at the University of Massachusetts, Ariel not only put his own thoughts to work there as the track coach, but also plunged himself into the study of calculus, cybernetics, physics, kinetics, medicine and computer technology.

It was at the suggestion of the head of computer sciences at U-Mass that Ariel first toyed with the idea of combining computer analysis with athletics. When he discovered the method of transferring data into computer banks via electronic pen ("source plates"), Ariel installed a keyboard terminal in his home and refined his aims. By 1971, he founded Computerized Biomechanical Analysis, Inc. and secured his first contracts for testing athletic equipment. It wasn't long afterward that athletes themselves came to Ariel for advice.

Ariel is by no means limited to giving advice on improving technique. Through biomechanics he has prescribed means of rehabilitation for a broad spectrum of sports. He continues his association with the University of Massachusetts by further opening his computer banks to the study of animal behavior. He even talks of applying biomechanics to treatment for diabetics and weight watchers, or studies of concert musicians.

While Dr. Ariel uniquely brought together two sciences — biomechanics and computer sciences — it is important to state that his ability to do this was made possible by the collective efforts of many scholars and the technological advances of the past decade in the computer science.

Testimony to the tremendous potential of Ariel's work has been lauded by athletes including Mac Wilkins, Terry Albritton and Bill Schmid professional teams such as the Dallas Cowboys and the Seattle Super Sonics; the U.S. Olympic Committee, and the head of its medical staff.

Ariel's studies of the athlete in action have revealed that shoe designers unfortunately have overlooked the fact that shoe efficiency, safety and performance are inextricably tied to the biomechanics of the activity for which they are used. Too often, the one concept receives over-emphasis beyond that given the functional features of shoes.

In essence, says Ariel, "all footwear, athletic specifically can be evaluated separately from the 'athlete in the shoe.' Yet, this apparently is what has happened not only in shoe design, but in non-partisan evaluation and ranking of performance in a major scientific publication."

Because Pony wanted a shoe for the runner, male and female, competitive racer or a recreational jogger, he was chosen to design the first anatomically, biomechanically designed and scientifically tested running shoe.

This shoe, in essence, is a radical departure from the norm in athletic shoe production. "In essence, the shoe's function underlies its appearance and quality. However, Pony, a young and energetic sports shoe company, has sought out that fit. This shoe, unlike any other on the market, says Thom Gravelle, executive vice president of Pony."

With this shoe, Pony, through Dr. Ariel's Massachusetts-based laboratory, has begun a directional change of sports shoe production forever. How they did it is a fascinating story.
A SIX STEP SYSTEM

4 The Development: With this information, Pony’s design and production engineers knew the structural requirements and materials critical to the creation of a running shoe which would most sufficiently provide the two qualities Ariel determined were absolutely necessary in an athletic shoe: shock absorption and return of energy. Ariel explains: “You see pictures of runners, it looks like they’re landing on their heels, but they are not. The good ones don’t. They flick the foot down flat at the last instant. Too many companies were making wonderful heels and the best runners weren’t coming down on them.” What Ariel knew from his studies was the slight, but powerful, rotation of the foot which occurred during each contact with the ground in an athlete’s stride. Different areas of the sole were performing different functions, yet nearly all athletic footwear, including Pony’s original Runner, had uniform soles with some type of grid pattern or nipple affect. Pony designers, working with Ariel, slowly developed a sole with two distinct features, each conceived to provide the shock absorption and the return of energy deemed invaluable for high performance. They changed the shoe’s construction by using two sole materials, realigned the nipple pattern on most of the contact surface and added a “traction grid” on the inside of the sole, where motion study showed the runner used his power during each stride.

5 The finished product: With the addition of a lightweight, durable upper and the familiar Pony chevron symbol, the company has what they feel is the most sophisticated racing shoe on the market. The heart of these shoes, though, is that Ariel-conceived sole. There are two versions of the shoe, the training model (shown) and the racing model. The trainer is slightly heavier and more durable than the racer, because it will be needed for those long, grueling practice sessions. The racer is expected to be used for exactly that — racing. The VSD sole (patent pending) is, by the way, endorsed by Jim Bush, the head track and field coach of the University of California at Los Angeles (UCLA). All of the research, presumably, cost money, but Thom Gravelle, executive vice-president of Pony, is adamant that athletic footwear prices will not skyrocket because of it. He said at the beginning of the year: “Our strategy is to market the finest athletic footwear at prices that will give the retailer a decent profit margin for a change, and yet give the consumer quality products at prices which are not outrageous.” The Racer, he thinks, will fill that hope and then some. Reaction to the shoe has been favorable, but it will have to prove itself in the future.

6 The future: While Pony and other companies struggle to keep their product at reasonable prices, the research and development continues. But where will it lead? What future refinements will athletic footwear undergo as producers scramble to come out with the most “modern” shoe? Well, the quest for the perfect sneaker may one day be over. Ariel, in his continuing work for Pony, is developing — are you ready? — an inflatable running shoe. Someday, an athlete will simply slip the limp casing of the shoe over each foot, fill it up with air and, presto, a perfect fit. He may not even have shoelaces to tie. More important, Pony points out, the shoe will be good for his feet, absorbing shock better and reducing the likelihood of shin splints and blisters. The research for this shoe has been going on for more than a year now, and company officials expect another year-and-a-half before they will be ready to take orders for the shoe. The inflatable shoe will be lighter than the conventional model and may only come in four sizes — small, medium, large and extra large — because the shoe will mold itself to the foot. Ariel envisions the shoe as having a valve that will accept the nozzle of a can of compressed air, and can be released to deflate the shoe. Laces will be replaced by an elastic band. If the shoe works, and sells, what will be the next step in footwear development? Ariel just might have some secret ideas on that subject — but he’s not telling.

Canadian Footwear Journal — August, 1978
BODY IMAGES:
LEANER MEN
STRONGER WOMEN
Mass meets machine—the computer tells all

FUTURE SHOE

BY JAMES C. G. CONNIFF

At as much speed as I can generate in such close quarters, I pound up the wooden ramp onto the rectangular-shaped force plate and across its hard white surface. By then, I am moving fast enough to crash into the laboratory wall, but Gideon Ariel reaches out and grabs me. We are conducting some experiments in the forces the body develops in motion. This lab is one of the most sophisticated anywhere for capturing, computerizing, analyzing and storing the data that emerge from what Ariel calls a “rapidly applied dynamic load.”

Right now, I am the rapidly applied dynamic load under investigation. As running enters the 1980s, laboratories supervised by exercise scientists such as Gideon Ariel will be able to determine exactly what happens to runners’ feet, their legs, their bodies and their running shoes when they run. A decade ago this...
THE IVORY TRAIL
From Africa to Asia, a story of greed and slaughter
TEACHING TENNIS TO TOADS

VIC BRADEN, coach extraordinaire, uses humor and physics to show nonstars how to improve their moves on the courts and ski slopes.

Braden's Tennis for the Future, has sold 200,000 copies. Still, Braden has his detractors. While quick to praise able coaches, he is disliked, and as he admits, "even hated" by many others. They resent his criticism, his intrusion into what they think is their turf, and his systematic discrediting of some of their most cherished teaching methods.

But Braden has never met a sport he didn't like. He runs a ski college in Aspen, and has made volleyball and badminton instructional videotapes. Using high-speed cameras and computers, he has analyzed and critiqued the techniques of such star athletes as baseball's Reggie Jackson, pro-football quarterback Steve Grogan and Olympic stars Al Oerter (discus throw) and Edwin Moses (hurdles). In tennis, his coaching helped launch the careers of Tracy Austin, Eliot Teltscher and Jim Pugh (a mixed-doubles winner at Wimbledon this year).

Despite his success with the athletic elite, Braden is more concerned about the masses. "People have been pushed out of sports," he says. "What we've done in this society is to build huge stadiums to let 22 people play on the grass." Most Americans, he feels, participate largely by watching sports on television. "People think that's all that's left for them," he complains. Statistics seem to bear him out. The number of active tennis players, for example, has declined dramatically. He still predicts, however, U.S. participation in Olympic sports will increase.

BY LEON JAROFF
The United States Olympic Committee is pleased to present this Certificate of Appreciation to Dr. Gideon Ariel in carrying out the highest traditions of Olympism as a USOC Sports Medicine Research Site.
Biomechanical Analysis of Discus Throwing at Olympic Games
PROJECT CHALLENGES
METHODS

The Track & Field project involved collecting video records of the preliminaries and final performances of various events for the immediate development of digital movies to be uploaded on the Internet.
There Were 18 Throwers During the Qualifying Round and the Best 8 Athletes Competed for the Gold Medal in the Final Round.
Video Cameras Were Placed in Several Locations to Maximize the Data Obtained for the Event
There Were 18 Throwers During the Qualifying Round and the Best 8 Athletes Competed for the Gold Medal in the Final Round.
## Washington Throwing Kinematics

<table>
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<th>Attempt</th>
<th>Distance (m)</th>
<th>Velocity (cm/sec)</th>
<th>Projection Angle (rad/deg)</th>
<th>Release HT (cm)</th>
<th>Move Time (sec)</th>
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<tr>
<td>Best Throw</td>
<td>65.4</td>
<td>2541V_r 2134 V_x</td>
<td>.52 (29.9)</td>
<td>120</td>
<td>1.2</td>
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<tr>
<td>Worst Throw</td>
<td>61.3</td>
<td>2441 V_r 1222 V_x</td>
<td>1.05 (59.9)</td>
<td>140</td>
<td>1.4</td>
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<tr>
<td>% Change</td>
<td>-6.3%</td>
<td>-4.0% V_r -43.0% V_x</td>
<td>+100%</td>
<td>+17%</td>
<td>+12%</td>
</tr>
</tbody>
</table>
DISCUS THROW DISTANCE  m.

COMPETITOR
THROW DIST   m.
69.4
66.6
65.8
65.4

Riedel
Dubrov
Kap
Wash

THROW DIST m.

COMPETITOR
Calculating the Velocities of the lower limb revealed acceleration and deceleration patterns in a unique sequence.
DISCUS RELEASE ANGLE  deg

COMPETITOR

PROJ ANGLE  deg

21.9
29.1
37.3
29.9
0
10
20
30
40

Riedel
Dubrov
Kap
Wash
DISCUS MOVEMENT TIME  sec.

<table>
<thead>
<tr>
<th>COMPETITOR</th>
<th>MOVE TIME  sec.</th>
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<tbody>
<tr>
<td>Riedel</td>
<td>3.0</td>
</tr>
<tr>
<td>Dubrov</td>
<td>2.3</td>
</tr>
<tr>
<td>Kap</td>
<td>1.9</td>
</tr>
<tr>
<td>Wash</td>
<td>1.6</td>
</tr>
</tbody>
</table>

The bar chart shows the movement times for different competitors in seconds.

- Riedel: 3.0 sec
- Dubrov: 2.3 sec
- Kap: 1.9 sec
- Wash: 1.6 sec
## Throwing Kinematics for Top Four Discus Performers at 1996 Atlanta Olympics

<table>
<thead>
<tr>
<th>Place</th>
<th>Performer</th>
<th>Dist</th>
<th>M Vel</th>
<th>Rel C</th>
<th>Proj ang</th>
<th>Rel Ht</th>
<th>Mov T</th>
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<tr>
<td>1</td>
<td>Riedel (Ger)</td>
<td>69.4</td>
<td>3080.1</td>
<td>21.9</td>
<td>1.5</td>
<td>3.0</td>
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<tr>
<td>2</td>
<td>Dubrovschchik (Blr)</td>
<td>66.6</td>
<td>2718.5</td>
<td>29.1</td>
<td>1.8</td>
<td>2.3</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Kaptyukh (Blr)</td>
<td>65.8</td>
<td>2599.0</td>
<td>37.3</td>
<td>1.6</td>
<td>1.9</td>
<td></td>
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<tr>
<td>4</td>
<td>Washington (USA)</td>
<td>65.4</td>
<td>2498.0</td>
<td>29.9</td>
<td>1.2</td>
<td>1.6</td>
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</tbody>
</table>
The Internet has opened a new frontier for research and international cooperation on multifaceted studies.
BIOMECHANICAL APPLICATIONS IN CYBERSPACE

Gideon B. Ariel and M. Ann Penny
University of California, Irvine
Trabuco Canyon, California USA

INTRODUCTION:

The Internet provides access to a worldwide collection of information resources and services as a window on the ever-expanding world of on-line information. The new communication links afforded by rapid satellite/computer exchanges will enable the field of Biomechanics to advance into a new age of technology, resources, research, data base development, as well as interaction among scientists. Utilizing the tools available in Cyberspace, the Biomechanist can retrieve and display data as well as documents from virtually anywhere on the planet. Studies can be conducted at multiple locations and data rapidly exchanged among these sites. Application of multiple media sources within Cyberspace is referred to as "hypermedia". Thus, with the Internet’s hypermedia-based interface, documents can include color images, text, sounds, and animation. As a hypermedia technology designed for searching and retrieving, Internet provides a unified interface to the diverse protocols, data formats, and information archives appropriate for biomechanical endeavors. Most of the documents are "hypertext" which are papers containing links to other texts, media, and/or locations. Using electronic links, known as Hyperlinks, specified information can be incorporate within a document by embedding full-color images, sounds, graphs, bibliographies, supplementary resources, data bases, etc. located within that text or at some distant site. This interface allows information located around the world to be interconnected in an environment that permits users to access the information super-highway by clicking on "hyperlinks". Similarly, complex biomechanical research segments at different research sites can be "tethered" through these "hyperlink" phases. Biomechanical research and subsequent reports become virtually three-dimensional with this multiple level access.

METHODS:

The present study was designed to test the efficacy of acquiring data at a "host" site with simultaneous on-line interaction with a second location. The following Internet tools were selected as appropriate for the study: (1) FTP (File Transfer Protocol) - to transfer large video and document files from site to site; (2) Gopher - To retrieve and post research finding and progress documents; (3) WWW (World Wide Web) - To hyperlink documents with video images and sound; (4) HTML (Hyper Text Mark-up Language) - To create the Hyper-link documents.
The Future – The Virtual Coach

• Virtual Biomechanic Desk

  • Locate and download your favorite Biomechanical Data from one convenient, easy-to-use interface.

  • Software that allows users to share Biomechanical libraries with each other no matter where they are located. Coach_virtual provides a search capability for videos, 3D/2D Files capability for users to communicate in forums of like interest.

  • Each Coach is a download/upload source

  • Each User Computer, when it is on, it becomes a shared directory

• For more information:  http://www.arielnet.com
The Future

- A user records and stores Video file in a specific folder on his or her hard disk.
- A central directory maintained by Coach.com keeps track of which users are logged on, cataloging by title and researcher/biomechanist the activity in each user’s special folder.
- A user searches through the Coach.com directory for a desired activity or sports. Once the activity is downloaded it can be used for further analysis or observation. This file can also be sent to another person as e-mail or attachment.
- Any user folder can be shared with the rest of the World.
- Coach.com monitor and publish the catalogue of activities and sports worldwide.
The Wireless APAS and on Hand Held Computers
Biomechanical Analysis of the Shot-Put Event at the 2004 Athens Olympic Games

By

Gideon Ariel, Ann Penny, John Probe, Rudolf Buijs, Erik Simonsen, Alfred Finch, and Larry Judge

ISBS 2005 Beijing China
Introduction

The Shot Put competition at the 2004 Athens Olympiad was held in the Ancient Olympia stadium. This was the site of the ancient Games of the Olympiad, 2,800 years ago. Despite skepticism from the rest of the world, the organizers of the Athens games did so many things right and nothing exemplified this more than holding the shot put competition at Olympia. In a games already steeped in history, the organizers thoughtfully connected the ancient and modern Olympics in a serene setting that was so unusual that it will probably be remembered as one of the highlights of these games whenever they are recalled.
Purpose of the Study

The purpose of this study was to analyze the best shot put performances in the Athens 2004 Olympic Games. Multiple high speed digital video cameras were placed in specific locations on the field at proper angles in order to capture the performance of the athletes in the preliminaries and finals. Two stationary cameras were placed at 45 degrees to each other. In addition 3 more cameras used by the NBC broadcasting were used to assist the other 2 cameras. Temporal and kinematics variables were calculated from the videos records and were analyzed yielding three-dimensional biomechanical results. Patterns of the segmental movements were used rather then absolute values, to assist the athletes and the coaches in the analysis of the performances. Kinematics parameters for the best 3 final performers were presented in this study.
The Biomechanical Wizard
www.sportsci.com/wizard
Release Velocity Cm/sec.

Belonog: 1385 cm/sec.
Nelson: 1395 cm/sec.
Olson: 1360 cm/sec.
# Selected Kinematic Performance Parameters of the Top Three Throwers

<table>
<thead>
<tr>
<th>Performer</th>
<th>Place</th>
<th>Distance m</th>
<th>Release Height m</th>
<th>Shot Velocity m·s⁻¹</th>
<th>Release Angle Rad (deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yuriy Belonog</td>
<td>Gold (1)</td>
<td>21.16</td>
<td>2.55</td>
<td>13.85</td>
<td>.58 (33)</td>
</tr>
<tr>
<td>Adam Nelson</td>
<td>Silver (2)</td>
<td>21.16</td>
<td>2.33</td>
<td>13.95</td>
<td>.58 (33)</td>
</tr>
<tr>
<td>Joachim Olsen</td>
<td>Bronze (3)</td>
<td>21.07</td>
<td>2.31</td>
<td>13.60</td>
<td>.72 (41)</td>
</tr>
</tbody>
</table>
What is wrong in this movement?

What caused the fall?
You cannot shoot a cannon out of a canoe
Ariel was the first company to create a biomechanical system for scientific, educational, and commercial applications. (1968)

Ariel invent and build the first "Air Shoe" (1971)

Ariel was the first to connect a force platform to a computer AND to write the software to control it. (1972)

Ariel invent and develop the first "Variable Resistance Exercise" Equipment. (1972)

Ariel provided the first hardware-software controlled interface for other input signals such as EMG integrated with the movement analysis system. (1972)

Ariel supply to Kistler Force Plate producer the first direct interface to the computer and A/D converter on Data General Mini Computer. (1973)

Ariel establish the first organized Olympic Training Analysis in the United States at the Olympic Training Center at Colorado Spring. The APAS system is used at the Olympic Training Center. (1976)

Ariel was the first to grab video images and store them on the hard disk for subsequent processing. (1980)

Ariel introduced the first "online" digitizing system on the Internet. (NetDigi) (1993)

Ariel establish the "Net Society of Biomechanics" - NSB to allow biomechanists and others to share data on line and exchange data in real time. (1999)

Ariel introduce the first affordable high speed camera at 240 Hz to be used with direct capturing to hard disk and up to one hour of continuous recording. (2000)

The first Virtual Biomechanical desk top World Wide. (2000)

Full Biomechanical Analysis on Wireless Cellular Phone, August, 2000.

SwingWatch Inc. The first Wireless Biomechanic Company.
• The USB APAS Mobile Revolution
THANK YOU