# History of Sports Analysis

from Mexico 1968 to Beijing 2008

By


Gideon Ariel, Ph.D.


Thailand December, 2007

# APAS

Performance
**Analysis**
System

**APAS** is a **video-based 3D motion analysis** system which provides **objective biomechanical data** the professional may use **in any way** (s)he wants.

Use it for **biomechanics**.
Use it for **motion capture**.
Use it for **sports analysis**.
Use it for **gait analysis**.
Use it for **diagnosis** and **treatment outcome**.

**ACES** uniquely controls, records, evaluates and modifies **functional performance** with user defined parameters.

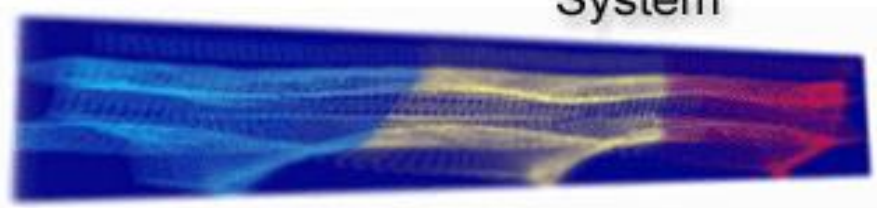
Use it to build **muscular strength** or **muscular endurance**.

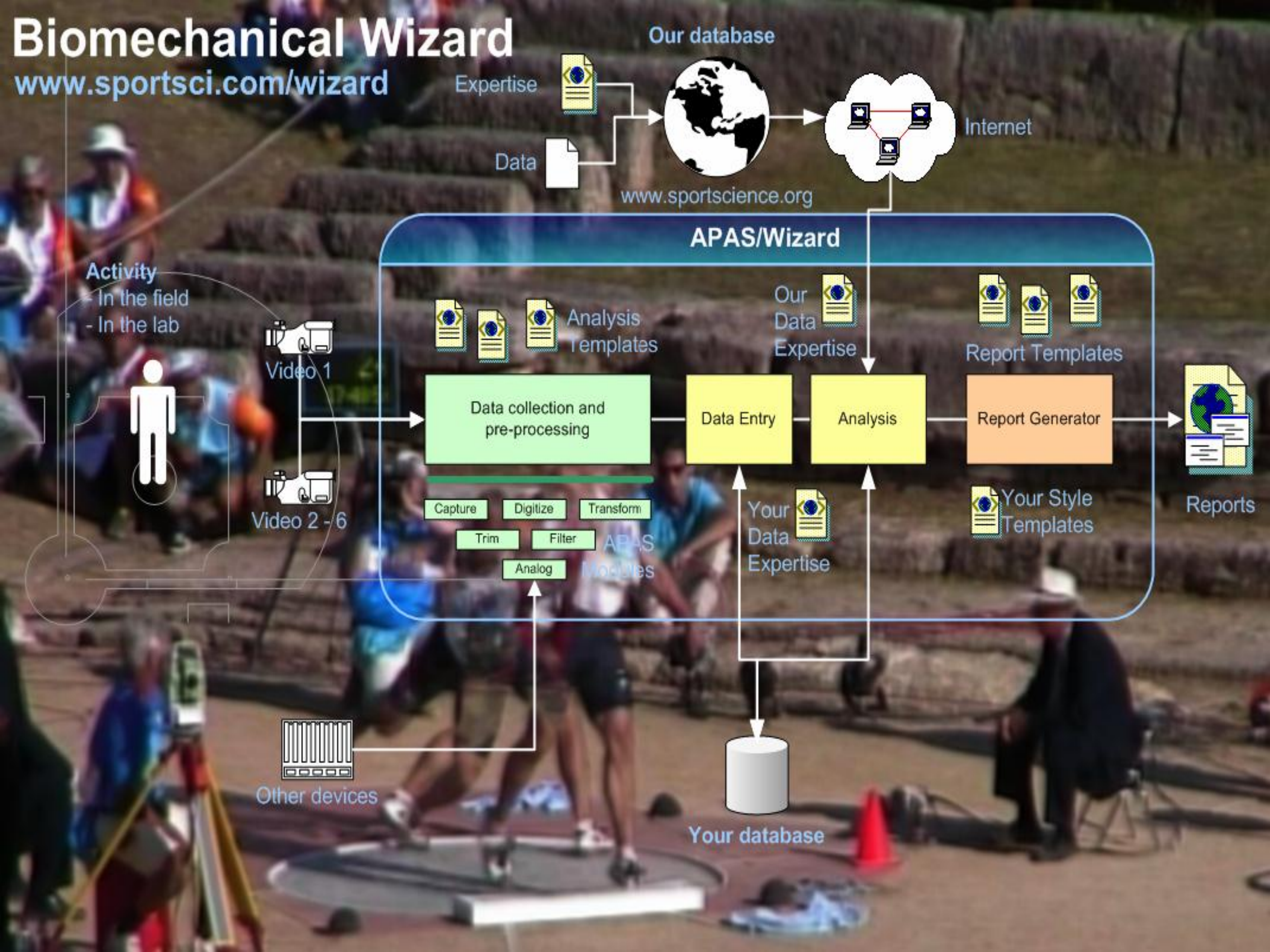
Use it for **isometric**, **isotonic**, **isokinetic** or **muscle overload** training.

Perform any **variable resistance**, **variable velocity**, or **feedback controlled** exercise.

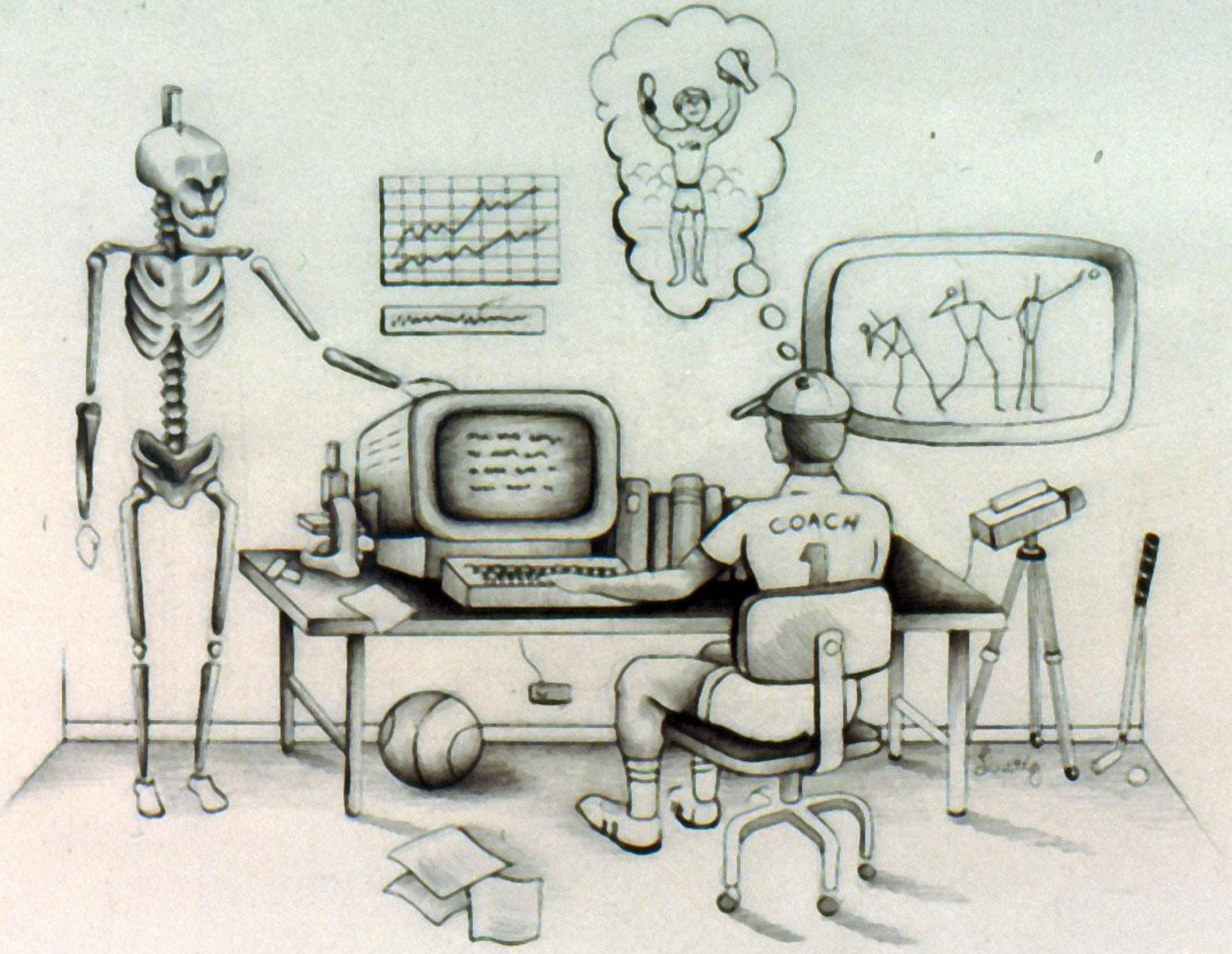
# ACES

Computerized
**Exercise**
System




Biomechanical Wizard
www.sportsci.com/wizard
Our database
Expertise
Data
www.sportscience.org
Internet
APAS/Wizard
Activity
- In the field
- In the lab
Video 1
Video 2 - 6
Analysis Templates
Our Data Expertise
Report Templates
Data collection and pre-processing
Data Entry
Analysis
Report Generator
Capture
Digitize
Transform
Trim
Filter
Analog
APAS Modules
Your Data Expertise
Your Style Templates
Reports
Other devices
Your database


Modern Way of Sports
at
13th ASIAN GAMES SCIENTIFIC CONGRESS
November 30, 1998 to December 3, 1998
at Siam City Hotel
Bangkok, Thailand
SCIENTIFIC
CONGRESS


COACH
1

# Isaac Newton

*(1643-1727)*

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

# In Biomechanics we owe the same sentence to the following:

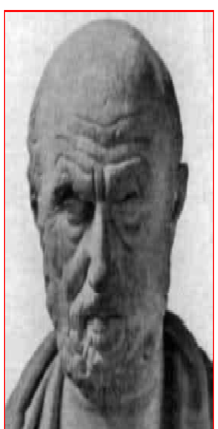
**Pythagoras of Samos**

- 596 – 475 B.C.E.
- World's first pure mathematician
- Founded a philosophical and religious school in southern Italy

**Plato**

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

**Hippocrates**

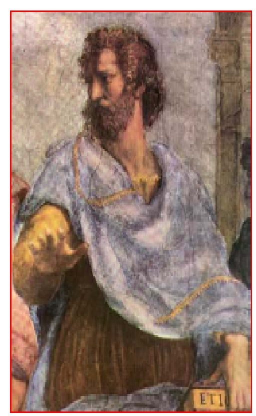


- 460 – 370 B.C.E.
- Applied a scientific approach to medical conditions

**Principle of causality**

"…that chance does not exist, for everything that occurs will be found to do so for a reason" (Sarton, 1953).

**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

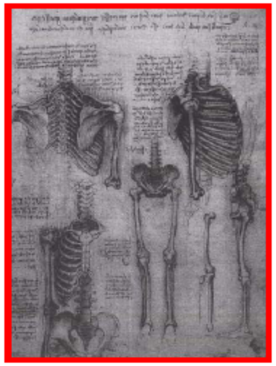
*On Floating Bodies*

- 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

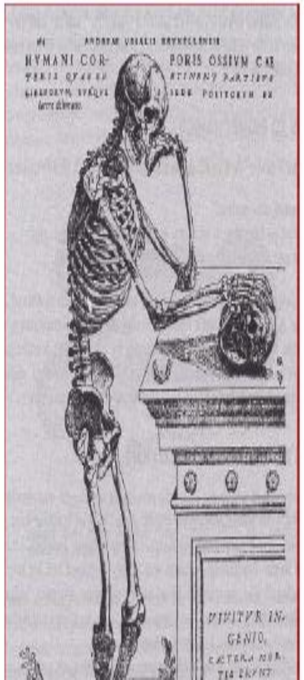
Applied mechanical concepts to studying human movement



- 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

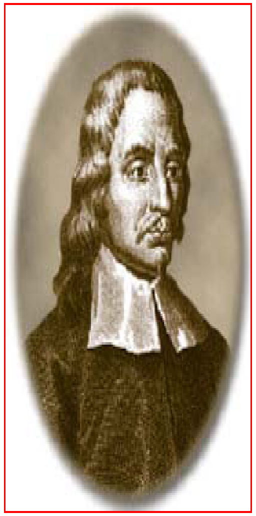
- Established a mechanical approach to the study of nature

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

Considered to be the "Father of Biomechanics"

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

**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)

**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

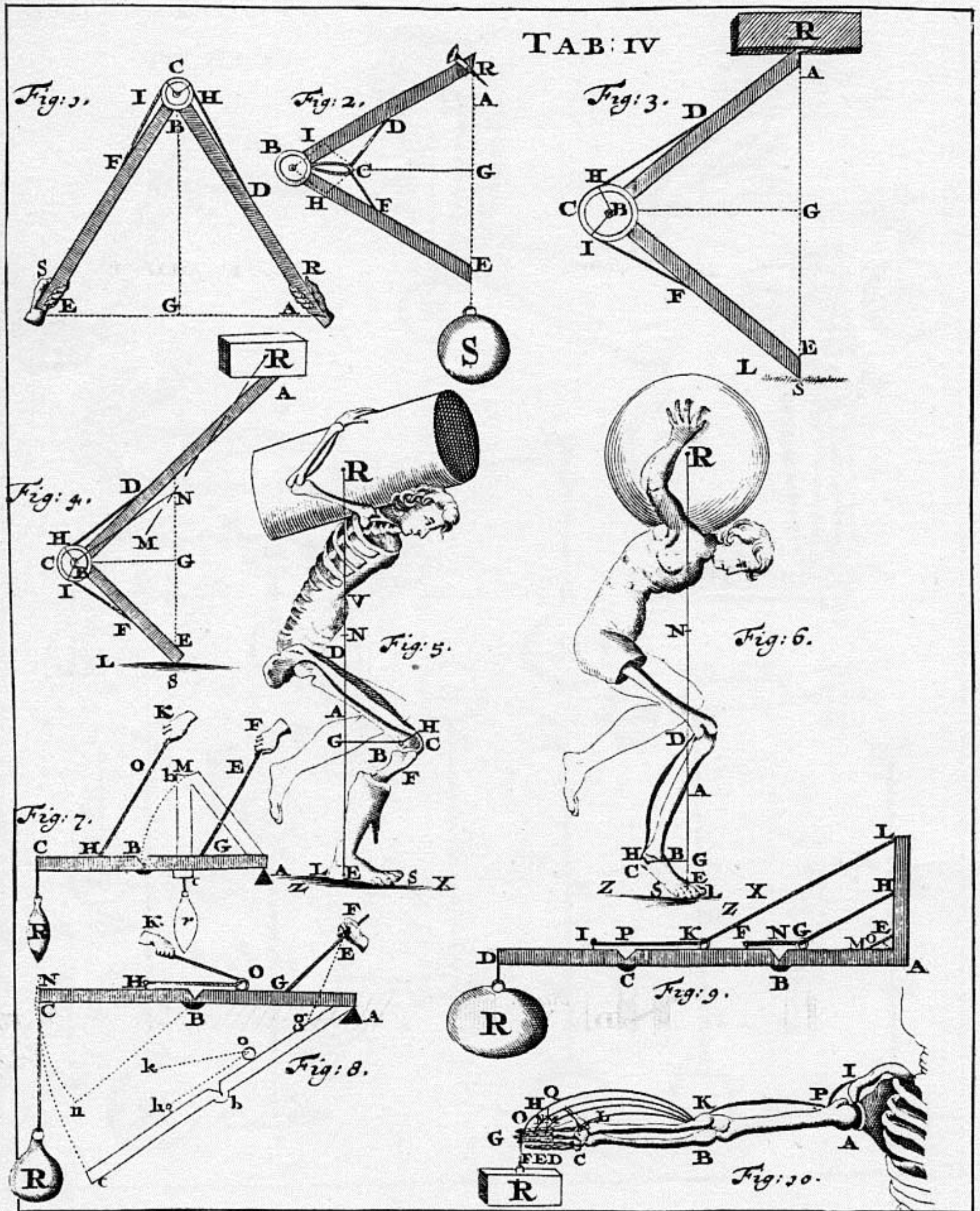
Springer-Verlag

## *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. Therefore[1], 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.

# Table IV



## *Proposition CXL*

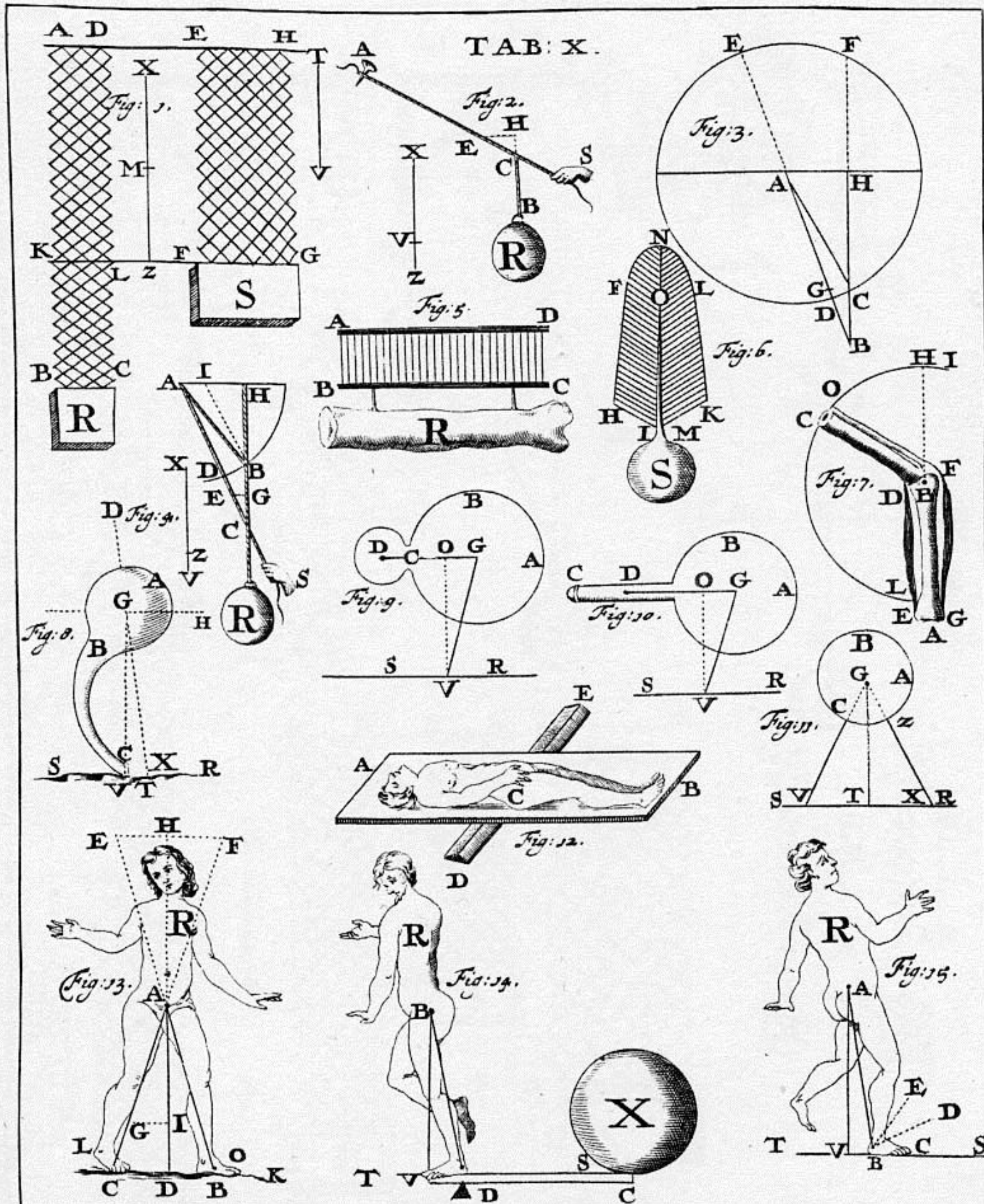
**When the line of gravity of the human body is outside the plantar sole of the one supporting foot or outside the quadrangle delineated by the two supporting feet, no muscle can prevent the body from falling.**

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.

# Table X


TAB: X.
Fig: 1.
Fig: 2.
Fig: 3.
Fig: 4.
Fig: 5.
Fig: 6.
Fig: 7.
Fig: 8.
Fig: 9.
Fig: 10.
Fig: 11.
Fig: 12.
Fig: 13.
Fig: 14.
Fig: 15.

W. Braune O. Fischer

# On the Centre of Gravity of the Human Body

Springer-Verlag Berlin Heidelberg New York Tokyo

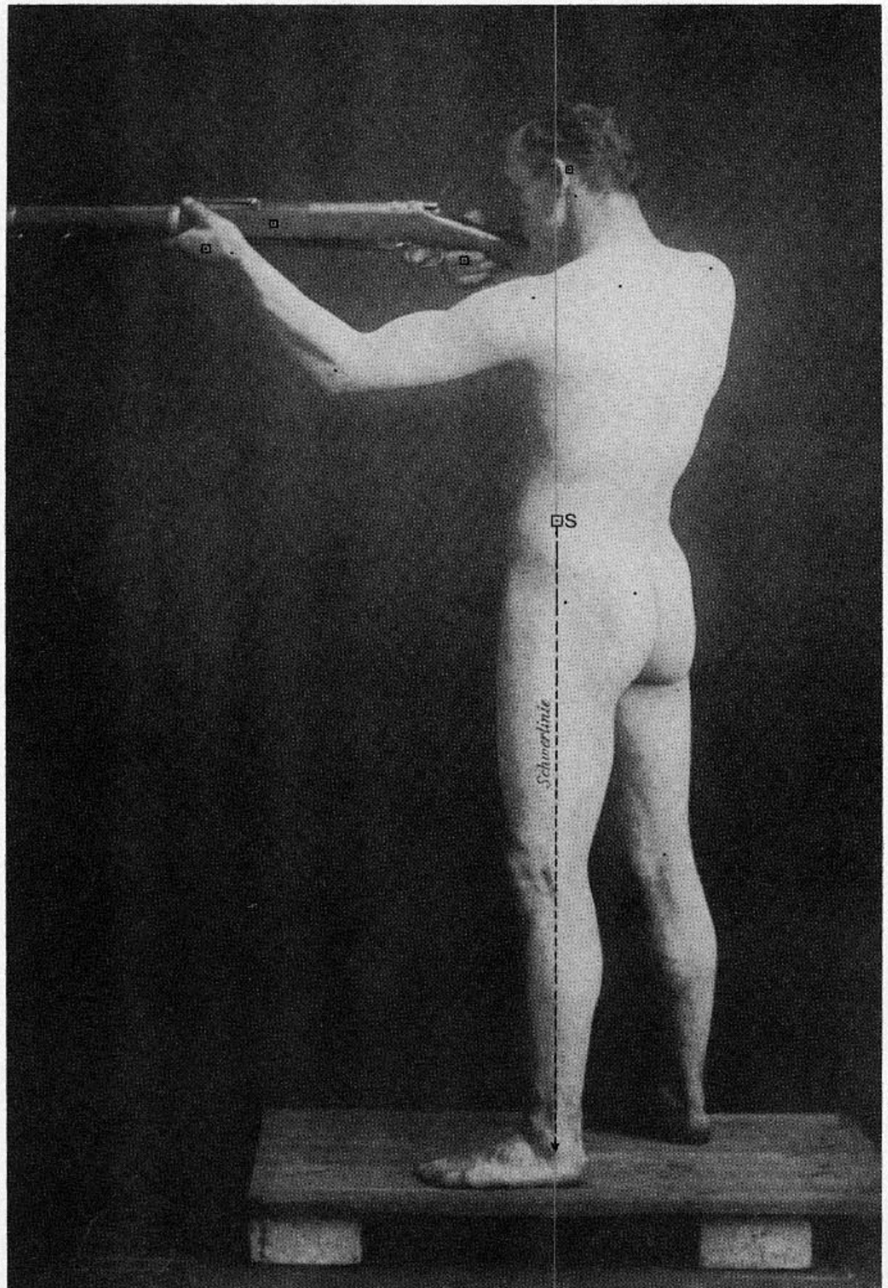
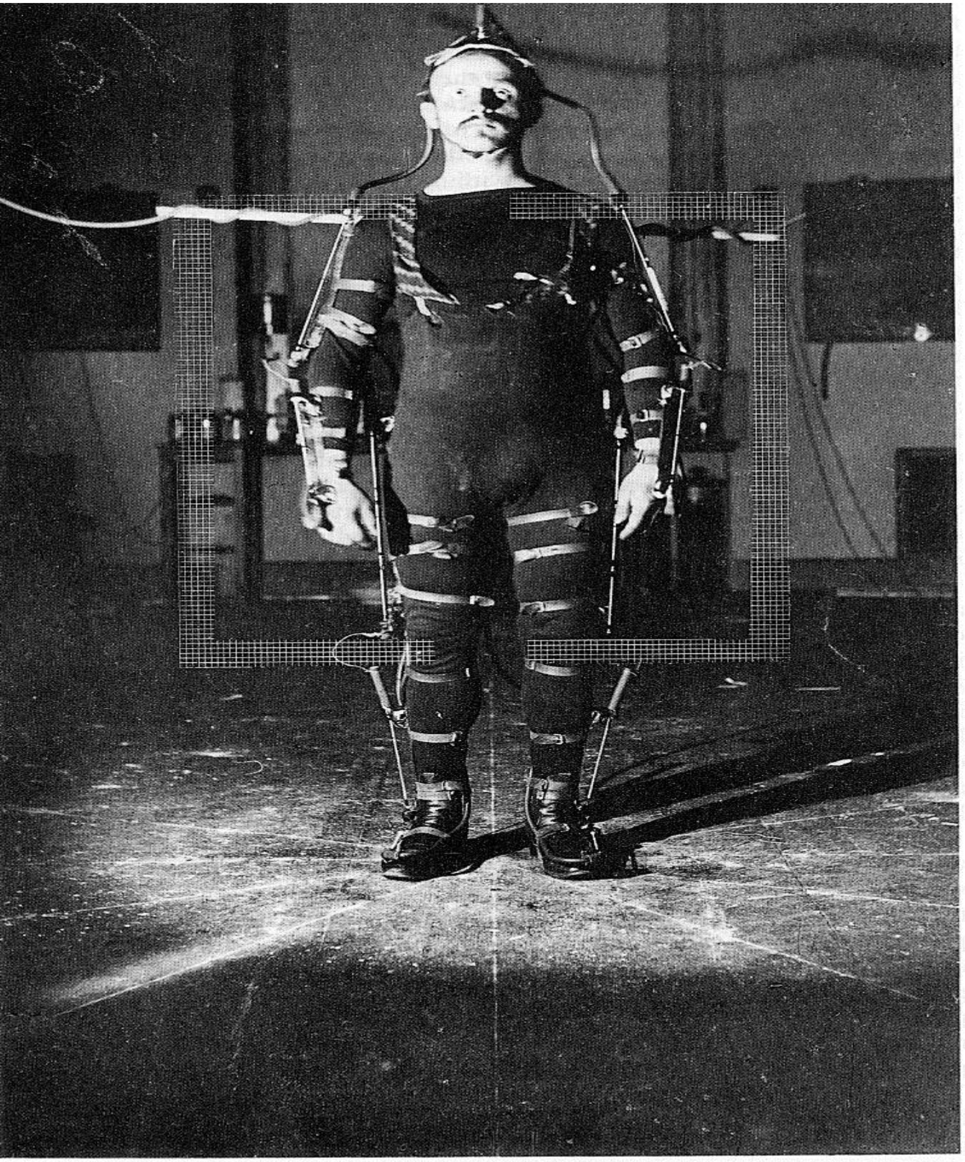
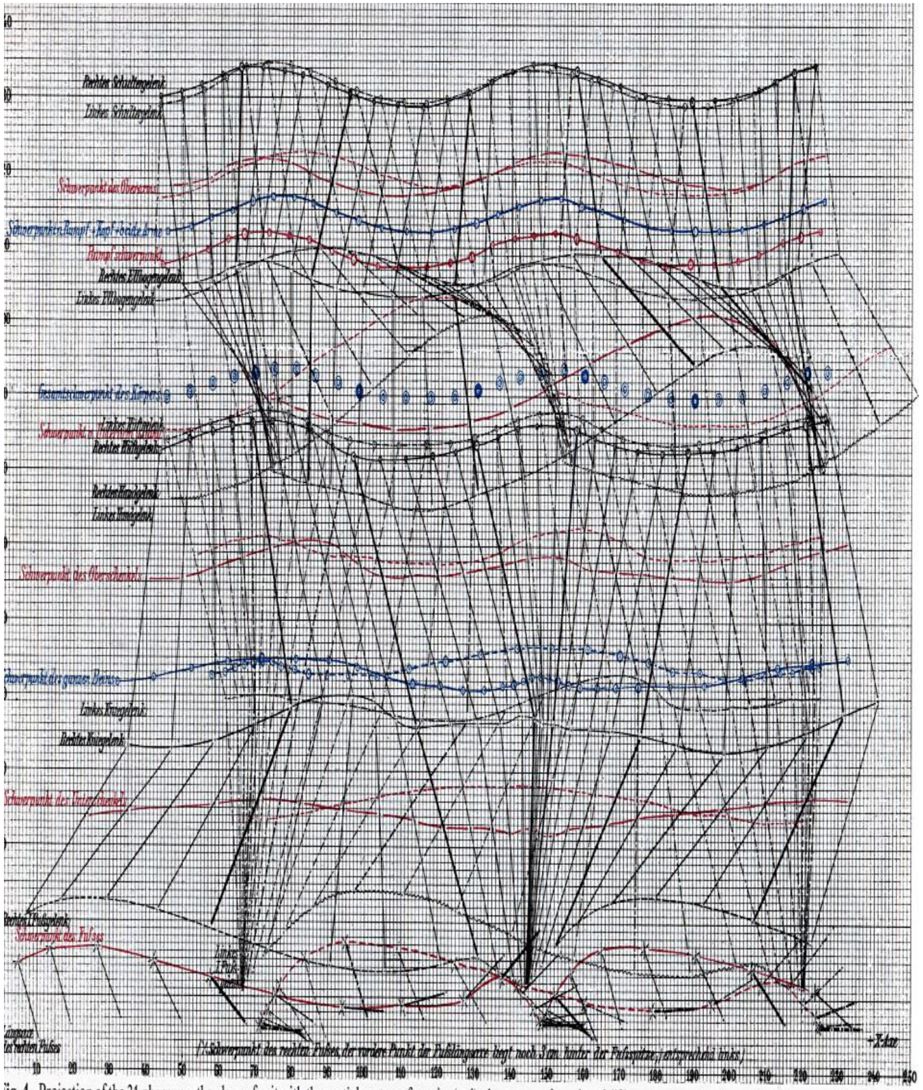



*Fig. 12.* Shooting attitude without regulation equipment, side view. · Projection of the centres of the joints; ⊡ projection of the centres of gravity of the head, hands and rifle; ⊡ *S* projection of the centre of gravity of the whole body with rifle

# Early Mechanical Analysis of Human Movement

## Brune and Fischer





ig. 4. Projection of the 31 phases on the plane of gait with the partial centres of gravity (red), the centres of gravity of different systems (blue) and the total centre of gravity of the ody (⊙)

**Edweard Muybridge**

- 1830 – 1904
- Photographic analysis of animal and human locomotion
- Stanford University

# One of the first book related sports to mechanical principles

Gideon Ariel
Nov. 1963

## The Mechanics of Athletics


GEOFFREY H. G. DYSON

*Chief National Coach,*
*Amateur Athletic Association (1947-1961)*



UNIVERSITY OF LONDON PRESS LTD
WARWICK SQUARE, LONDON E.C.4

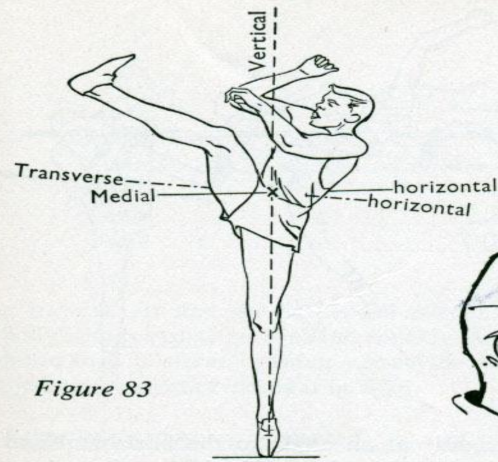




*Figure 83*

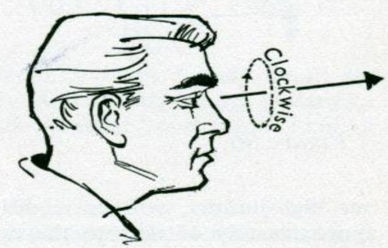



*Figure 84*

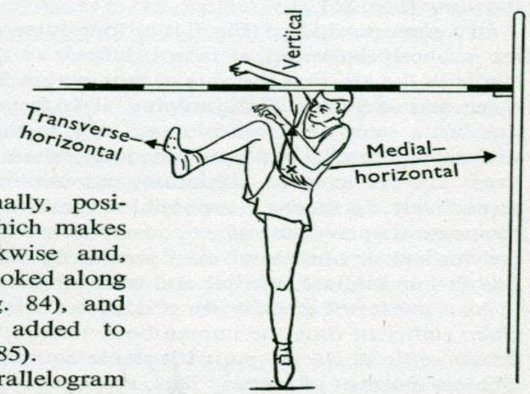



*Figure 85*

another by the same athlete.

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

By using the parallelogram method (already described in connection with velocity and forces, pages 17 and 35) the magnitude and direction of the total angular momentum and the position of the axis of momentum can then be established. The latter, in the case of

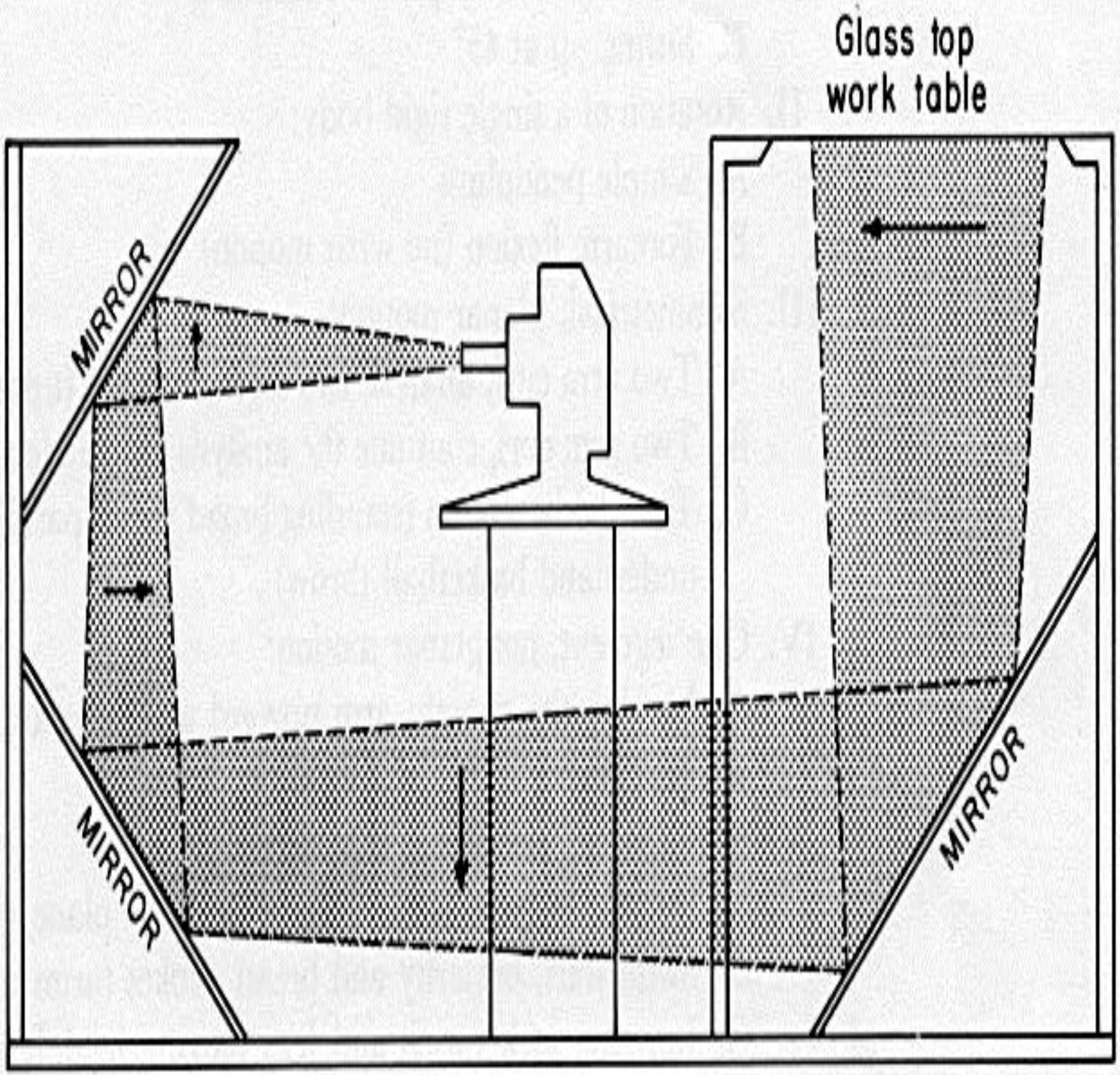



**Fig. 2-17**
Glass top tracing table. This equipment is used when the paper must be moved for each frame because of camera movement or in recording a body motion relative to a moving object (i.e., rowing, bicycling).

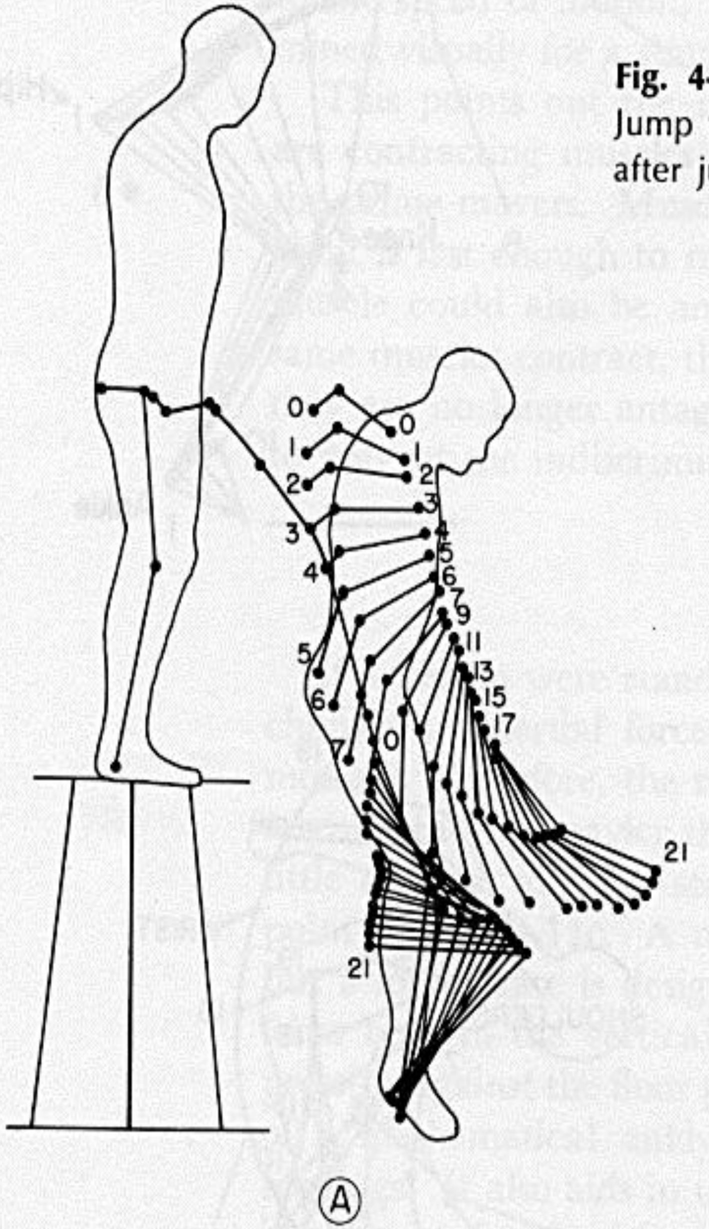
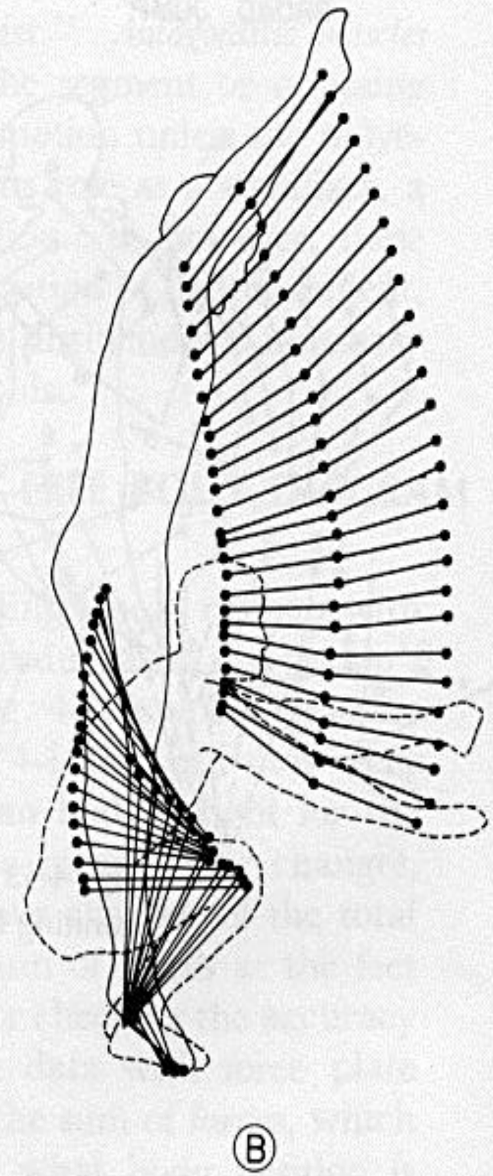



**Fig. 4-15**
Jump from stool (a) and jump up after jump from stool (b).



segment is a combination of trunk flexion extension and shoulder rotation.

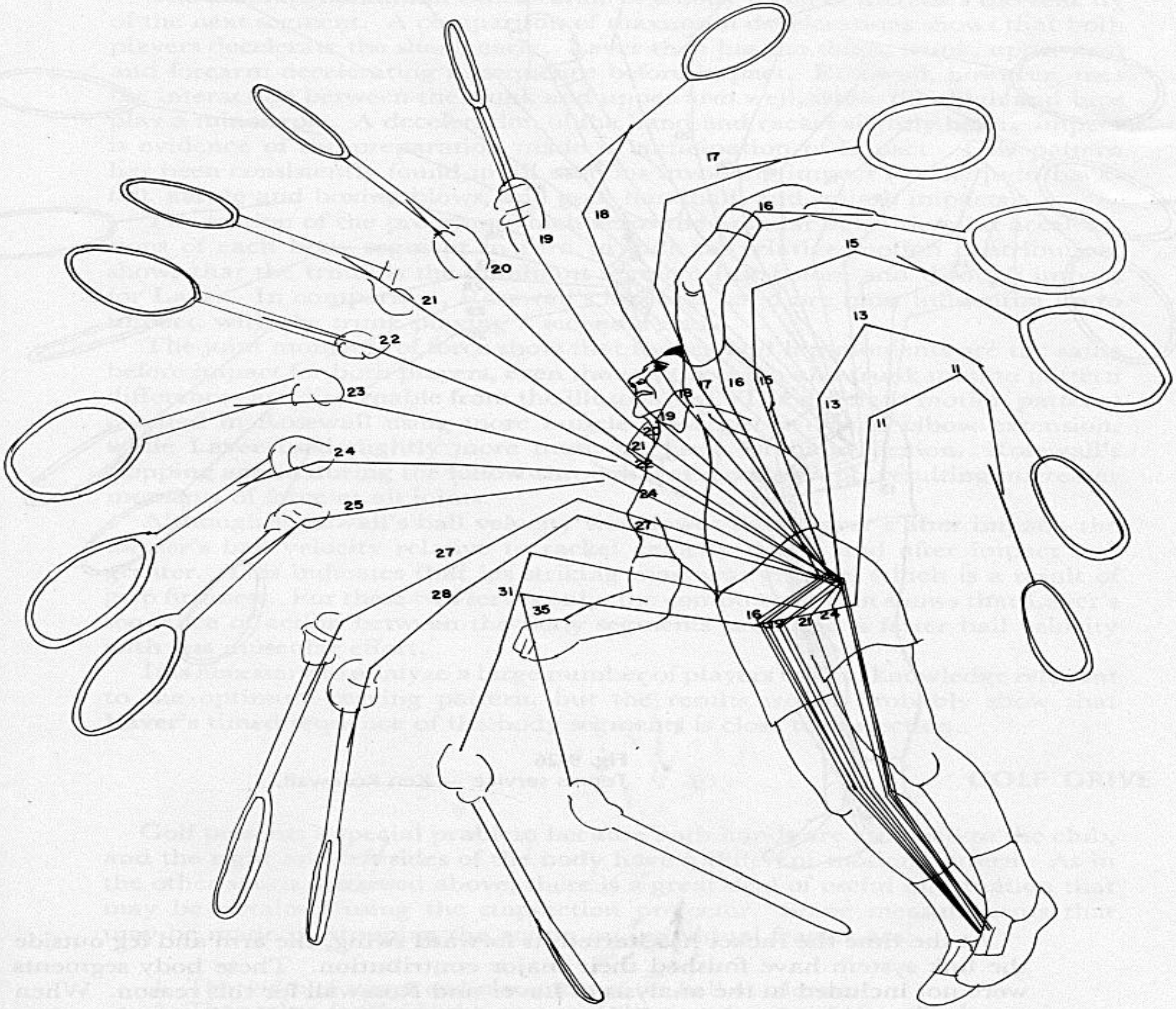



**Fig. 9-25**
Tennis service — Rod Laver.

efficiency. The contribution of each body segment to the whole motion may also be found. This is obtained in the computer program, Appendix B, when the relative velocity and acceleration for a given segment is zeroed, and the whole motion recalculated to find out how much change occurs without the movement of that particular segment. The velocities and accelerations are reinserted and the entire analysis is repeated with the next segment velocities and accelerations zeroed. In this manner the relative contribution of each segment's movement can be determined. This could not be done using the absolute motion method. (The absolute motion method is presented in Appendix C.)

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

## 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:

Segment 3

$$F_{y_3} = -WT_3 + m_3r_3\alpha_3\cos\theta_3 + m_3r_3\omega_3^2\sin\theta_3 - m_3R_1\alpha_1\cos\phi_1 + m_3R_1\omega_1^2\sin\phi_1 + m_3R_2\alpha_2\cos(180° - \phi_2) + m_3R_2\omega_2^2\sin(180° - \phi_2) + m_3(2\omega_1V_2 + 2\omega_1V_3 + 2\omega_1\omega_2r_3)\sin\theta_3 - m2\omega_2V_3\sin\theta_3$$

$$F_{x_3} = -m_3r_3\alpha_3\sin\theta_3 + m_3r_3\omega_3^2\cos\theta_3 + m_3R_1\alpha_1\sin\phi_1 + m_3R_1\omega_1^2\cos\phi_1 + m_3R_2\alpha_2\sin(180° - \phi_2) - m_3R_2\omega_2^2\cos(180° - \phi_2) + m_3(2\omega_1V_2 + 2\omega_1V_3 + 2\omega_1\omega_2r_3)\cos\theta_3 - m2\omega_2V_3\cos\theta_3$$

$$M_{o_3} - WT_3\cos\theta_3r_3 + m_3k_3^2\alpha_3 + m_3R_1\omega_1^2\sin(\phi_1 - \theta_3)r_3 - m_3R_1\alpha_1\cos(\phi_1 - \theta_3)r_3 + m_3R_2\omega_2^2\sin(\phi_2 - \theta_3)r_3 - m_3R_2\alpha_2\cos(\phi_2 - \theta_3)r_3 = 0$$

Segment 2

$$F_{y_2} = -WT_2 + m_2r_2\alpha_2\cos(180° - \theta_2) + m_2r_2\omega_2^2\sin(180° - \theta_2) - m_2R_1^1\alpha_1\cos\phi_1^1 + m_2R_1\omega_1^2\sin\phi_1^1 - m2V_2\omega_1\sin(180° - \theta_2) + F_{y_3}$$

$$F_{x_2} = +m_2r_2\alpha_2\sin(180° - \theta_2) - m_2r_2\omega_2^2\cos(180° - \theta_2) + m_2R_1^1\alpha_1\sin\phi_1^1 + m_2R_1\omega_1^2\cos\phi_1^1 + m2V_2\omega_1\cos(180° - \theta_2) + F_{x_3}$$

$$M_{o_2} + WT_2\cos(180° - \theta_2)r_2 - m_2k_2^2\alpha_2 - m_2R_1^1\omega_1^2\sin(\theta_2 - \phi_1^1)r_2 - m_2R_1^1\alpha_1\cos(\theta_2 - \phi_1^1)r_2 + F_{y_3}l_2(\cos 180° - \theta_2) + F_{x_3}l_2(\sin 180° - \theta_2) - M_{o_3} = 0$$



$$F_{y_1} = -WT_1 - m_1r_1\alpha_1\cos\theta_1 + m_1r_1\omega_1^2\sin\theta_1 + F_{y_2}$$

$$F_{x_1} = +m_1r_1\alpha_1\sin\theta_1 + m_1r_1\omega_1^2\cos\theta_1 + F_{x_2}$$

$$M_{o_1} - WT_1\cos\theta_1r_1 - m_1k_1^2\alpha_1 + F_{y_2}l_1(\cos\theta_1) + F_{x_2}l_1(\sin\theta_1) - M_{o_2} = 0$$

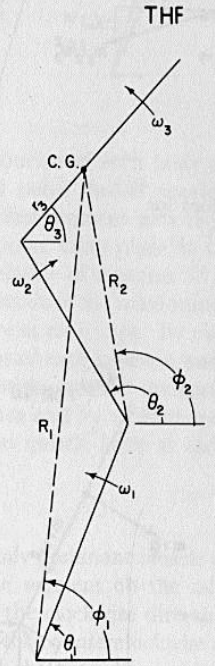
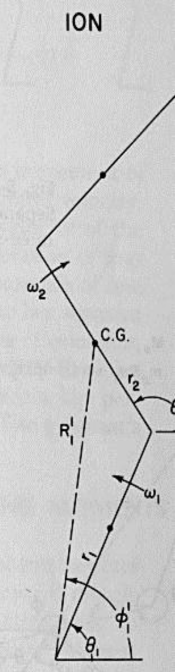



Fig. 5-5
Three-segment motion.



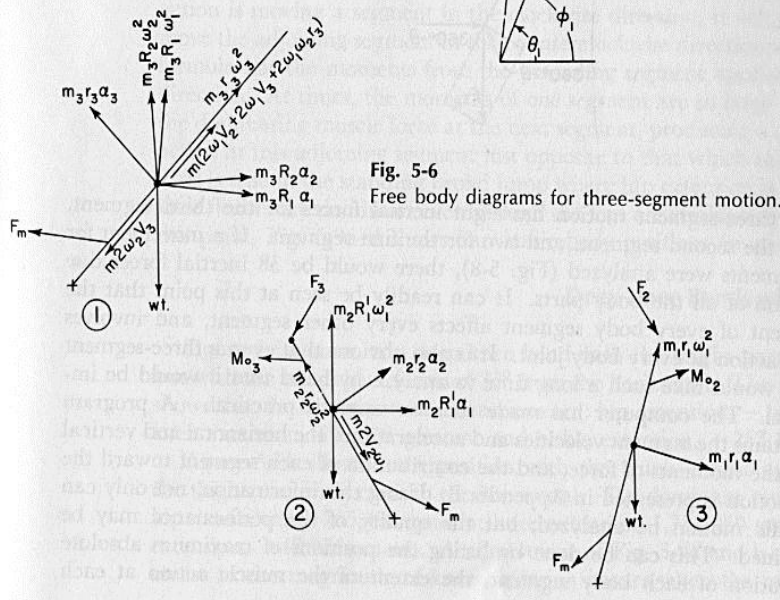
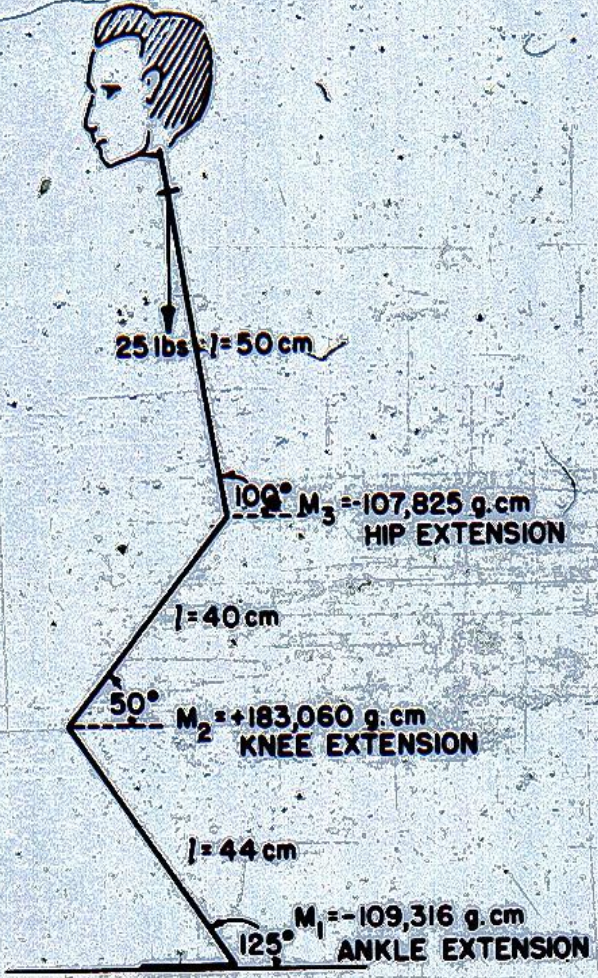
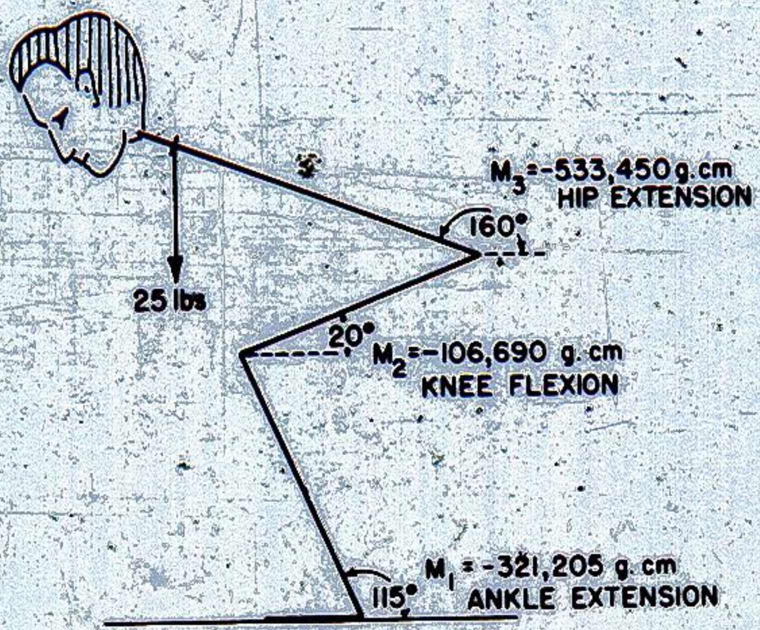




Fig. 5-6
Free body diagrams for three-segment motion.

# MUSCLE FUNCTION CHANGE DUE TO 25 LBS. ON SHOULDERS




$$M_3 - 11{,}350 \cdot 50 \cdot -.19 = 0$$
$$M_3 = -107{,}825$$
$$M_2 - M_3 - 11{,}350 \cdot 40 \cdot .64 = 0$$
$$M_2 - (-107{,}825) - 290{,}560 = 0$$
$$M_2 = +183{,}060$$
$$M_1 - M_2 - 11{,}350 \cdot 44 \cdot (-.588) = 0$$
$$M_1 - 183{,}060 + 292{,}376 = 0$$
$$M_1 = -109{,}316$$




$$M_3 - 11{,}350 \cdot 50 \cdot -.94 = 0$$
$$M_3 = -533{,}450$$
$$M_2 - M_3 - 11{,}350 \cdot 40 \cdot (.94) = 0$$
$$M_2 - (-533{,}450) - 426{,}760 = 0$$
$$M_2 = -106{,}690$$
$$M_1 - M_2 - 11{,}350 \cdot 44 (-.43) = 0$$
$$M_1 - (-106{,}690) + 214{,}515 = 0$$
$$M_1 = -321{,}205$$

**Table B-3 Computer Program**

```
C       (1) COMPUTE THE M + 1 VALUES OF XBAR (I), WHERE M IS THE DEGREE
C       OF THE POLYNOMIAL Y(M).
C       (2) NORMALIZE THE INITIAL VALUES OF X(I) 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(I) - X(I) - 1).
C       Y(J) = VALUE OF THE ORIGINAL Y CORRESPONDING 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       F(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
        DIMENSION Y1(90),DATTH(8,50),DATV(8,50),DATA(8,50),NFBD(8,50)
        DIMENSION S(20),V(90),Y(90),C(20),F(20),DATY(8,50),DATL(8,50)
        DIMENSION YGRAPH(4),IC(4),DATW(8,50),DATR(8,50),DATK(8,50)
        DIMENSION W(8),XL(8),R(8),A(8),B(8),XMASS(8),CG(8,2),Z(8,2)
        DIMENSION PCTR(8),PCTK(8), EN(8),NFB(8),CIS(8),CXL(8),DATM(8,50)
        DIMENSION DUMW(8),DUMR(8),DUMK(8),WHOA(10),WHOB(10),MP(8),YMAXX(8)
       1,OMEGA(8),ALPHA(8),OMEG(8),ALPH(8),FX(8),FY(8),XMOMT(8)
       2,FXA(8),FYA(8),AMOMT(8),XK(8),IZ(8),DFX(8,50)
       3,FXE(8,50),FYE(8,50),  XFI(8),XFA(8),YFI(8),YFA(8),MI(8),MA(8)
       4,DFY(8,50),RE(8,50),RR(8,8),AA(8,8),THETA(8),STORE(5,50,8)
        COMMON PI,CONST,W,XL,XK,R,A,B,XMASS,CG,Z,OMEGA,ALPHA,OMEG,ALPH
       1,NSEG,IT,FXE,FYE,NPOS,RE,RR,AA,THETA
        EQUIVALENCE(YGRAPH(1),X1),(YGRAPH(2),X2),(YGRAPH(3),X3)
      1 READ 300,WHOA
        IF(EOF,60)9999,9998
   9998 READ 300,WHOB
    300 FORMAT(10A8)
        PRINT 301,WHOA,WHOB
    301 FORMAT (///1X,10A8/1X,10A8)
        PRINT 302
    302 FORMAT(* ANG.= DEG., VEL.= DEG. PER SEC., ACC.= DEG. PER SEC. SQ.*
       1)
        READ 5,NSEG,  NPOS,XMIN,DELTX
  5     FORMAT(I1/I4/2F10.5)
        READ 104,NTRK,TRNKNL,KIP,NSPEC,NSPEC1
    104 FORMAT (I1,F10.3,3I1)
        READ 101,(PCTR(I),PCTK(I),I=1,NSEG)
        READ 101,( EN(I),I=1,NSEG)
    101 FORMAT(7F10.3)
        READ 136,COR
    136 FORMAT(I3)
        READ 101,(W(I),I=1,NSEG)
        READ 303,(MP(ID),ID=1,NSEG)
    303 FORMAT(7I1)
        READ 101,(YMAXX(ID),ID=1,NSEG)
        DO 3000 I=1,NSEG
   3000 READ 3010,XFI(I),XFA(I),YFI(I),YFA(I),MI(I),MA(I),IZ(I)
   3010 FORMAT(6E8.1,A2)
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Mexico City Olympics 1968

# Mexico City 1968 Olympics

# 20/20

ITY-858-3022

# Analysis of Long Jump

## BOB BEAMON (8.90m) VS CARL LEWIS (8.71m)

Gideon Ariel

Coto Research Center

The purpose of this analysis is to compare the kinematic characteristics of Bob Beamon's jump (1968 Olympics in Mexico City) of 8.90 meters (29'2.5") to Carl Lewis' jumps (1982 T.A.C. meet). Lewis' first jump was officially approved and the distance was 8.71 meters (28'7"). Lewis fouled on the second jump (by as much as 1.5") the distance measured was 8.82 meters (28'11.3"). It is important to note that Beamon's jump took place at an altitude of approximately 6000 feet. Carl Lewis jumped at an altitude closer to sea level.

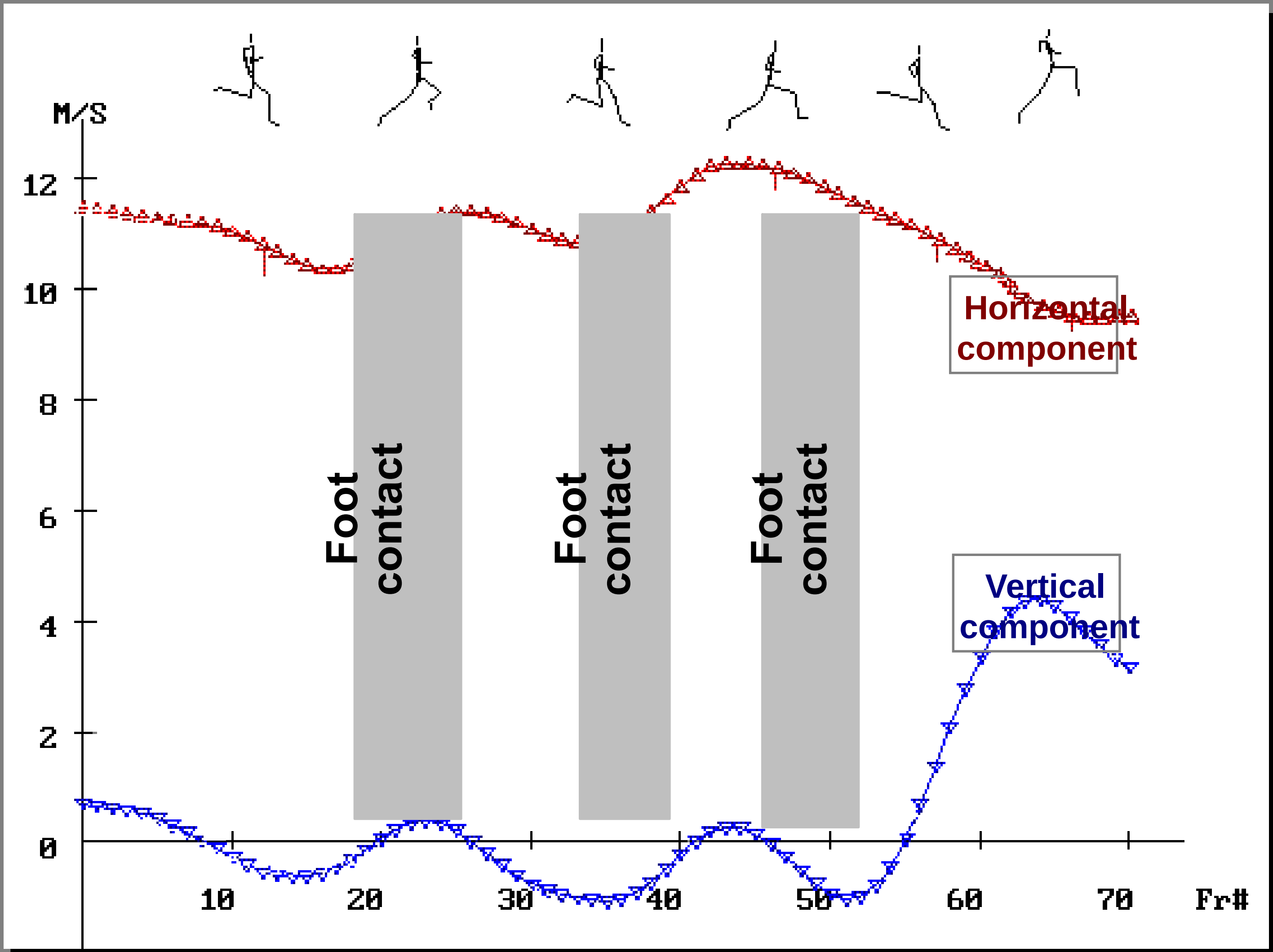
The film on the jumps was actually taken from a video recording taken during the competition. The camera speed was 30 frames per second; the camera was penned, but not zoomed. A special technique was used to digitize the performance. A fixed point on the field, in the same plane of the athlete's movement, was digitized. Later on all the displacement and velocity data were plotted relative to the "moving" fixed point. In this manner the penning speed was partialed 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 athletes 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

| | *Bob Beamon* | *Carl Lewis* | *Carl Lewis* |
|---|---|---|---|
| Distance (Meters) :<br>Distance (Feet) :<br>Legal jump :<br>Year : | 8.90<br>29'2.5"<br>*Good*<br>1968 | 8.71<br>28'7"<br>*Good*<br>1982 | 8.82<br>28'11.3"<br>*Foul*<br>1982 |
| Distance measured from the landing mark to the end of the pit | 3.10m<br>10'2" | 3.29m<br>10'9.5" | 3.18m<br>10'7" |
| Distance digitized from the landing mark to the end of the pit | 60.3cm<br>23.75" | 28.6cm<br>11.25" | 51.4cm<br>20.25" |
| Scale measure digitized on the screen | shank = 4.02" | shank = 2.17"<br>1 meter = 4.25" | shank = 4.08"<br>1 meter = 8" |
| True length of the scale measures | shank = 52.5cm | shank = 51.0cm<br>1 meter | shank = 51.0cm<br>1 meter |
| The digitized distance between the feet landing mark and the buttock landing mark | ....<br>.... | ....<br>.... | 7.6cm<br>3" |
| The true distance between the feet landing marks | .... | .... | 35.0cm<br>13.75" |
| Velocities of the Center of Gravity at breaking point. . . .<br>X–Horizontal<br>Y–Vertical<br>R–Resultant<br>Angle to the horizontal | <br>11.76m – 38.55'<br>2.68m – 8.8'<br>11.45m – 37.54'<br>13.5 degrees | <br>12.97m – 42.52'<br>2.33m – 7.30'<br>11.66m – 38.23'<br>11.5 degrees | <br>12.58m – 41.25'<br>2.49m – 8.17'<br>11.09m – 36.36'<br>13 degrees |
| Velocities of the Center of Gravity at Take-off. . . .<br>X–Horizontal<br>Y–Vertical<br>R–Resultant<br>Angle to the horizontal | <br>11.79m – 38.66'<br>3.92m – 12.85'<br>11.12m – 36.50'<br>20.5 degrees | <br>13.00m – 42.62'<br>4.00m – 13.11'<br>10.20m – 33.44'<br>23 degrees | <br>11.73m – 38.50'<br>2.96m – 9.71'<br>9.04m – 29.64'<br>19 degrees |
| The vertical height of the C.G. at take-off | 1.085 meters<br>3.56' | 0.982 meters<br>3.22' | 1.004 meters<br>3.29' |
| The calculated (*) horizontal distance of the C.G. | 12.00m<br>39.45' | 13.18m<br>43.40' | 9.93m<br>30.40' |

* $X=(V_x (V_Y+(SQRT(V_Y**2+2gY))))/g$

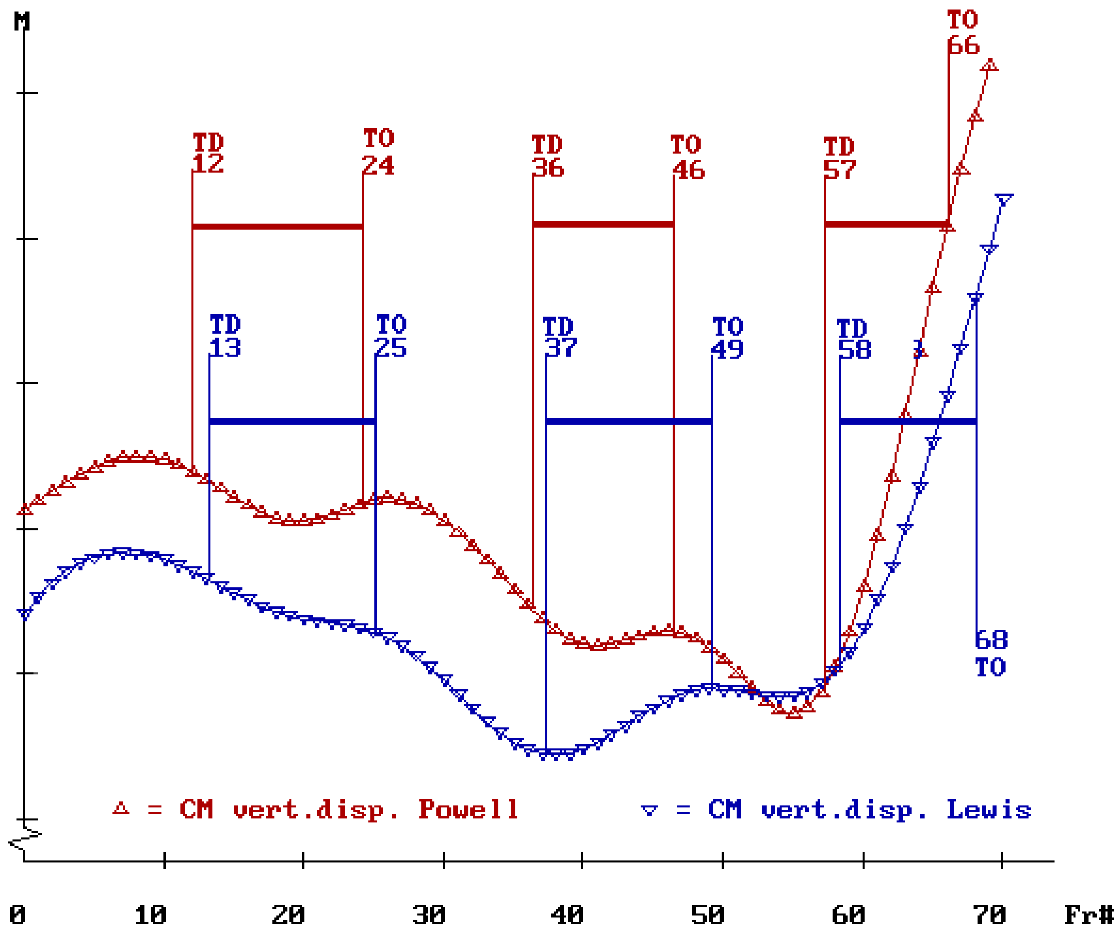
# Velocity of the Center of Mass





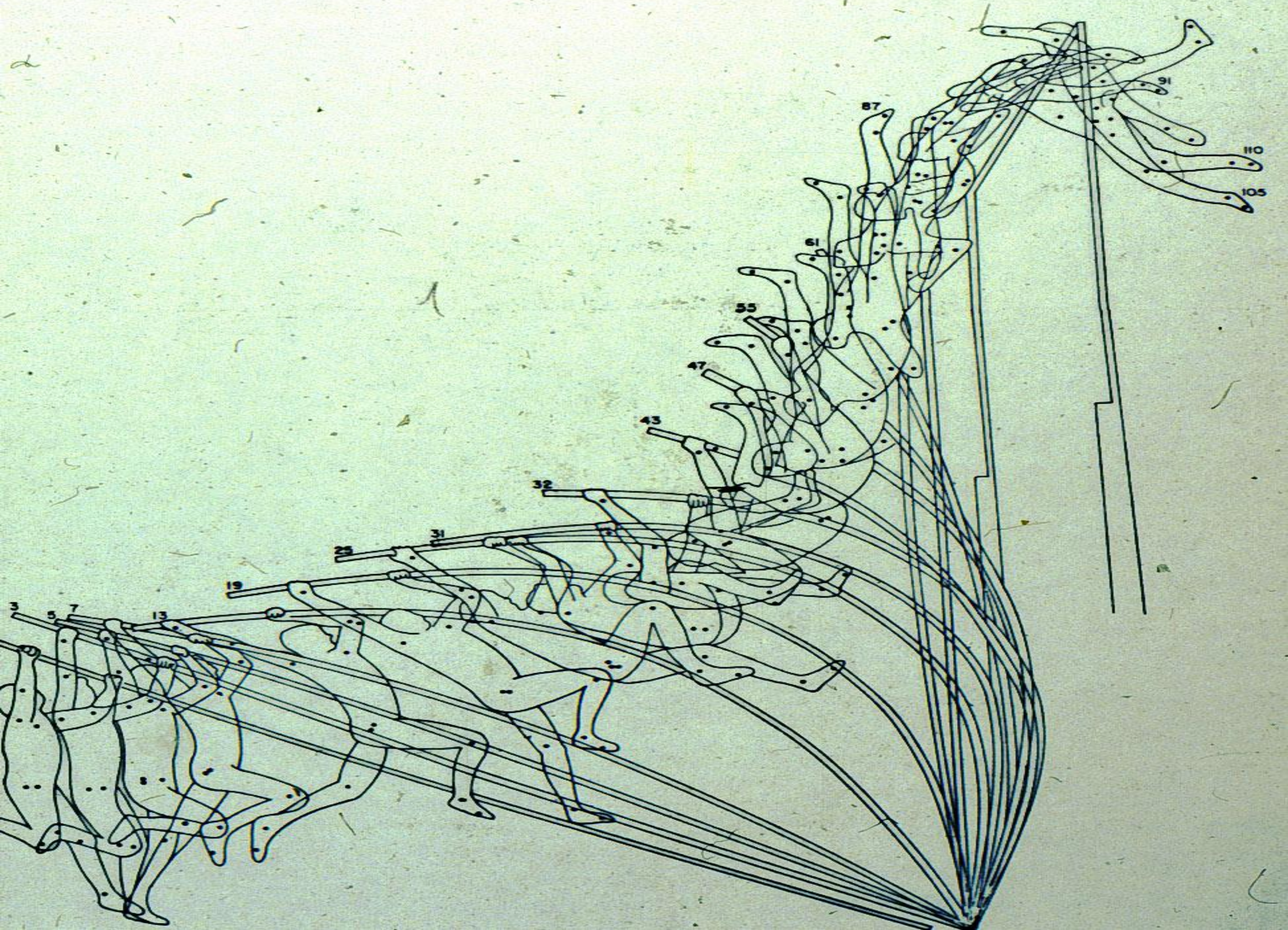
Mike Powell 8.95m - World Record

# Change of the Height of CM



# Comparative Kinematic Characteristics

| Parameters of the Long Jump | M.Powell | C.Lewis |
|---|---|---|
| General Information | | |
| Official Distance [m] | 8.95 | 8.91 |
| Effective Distance [m] | 8.98 | 8.91 |
| Favorable Wind Velocity [m/s] | 0.3 | 2.9 |
| The Approach | | |
| Average Speed: 11-6m to the Board [m/s] | 10.79 | 11.23 |
| Average Speed: 6-1m to the Board [m/s] | 10.94 | 11.26 |
| The Length of the Third-Last Stride [m] | 2.4 | 2.23 |
| The Length of the Second-Last Stride [m] | 2.47 | 2.7 |
| The Length of the Last Stride [m] | 2.28 | 1.88 |
| The Take-Off | | |
| CM Horizontal Velocity [m/s] | 9.27 | 9.11 |
| CM Vertical Velocity [m/s] | 4.21 | 3.37 |
| Angle of Projection [deg] | 24.1 | 20.3 |
| Angle of body Lean at Touch-Down [deg] | 71.8 | 77 |
| Angle of body Lean at Take-Off [deg] | 73.9 | 67.5 |



3
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105

75

# THE CONTRIBUTION OF THE POLE TO THE VAULT★

**_Gideon Ariel_**
**_Department of Exercise Science_**
**_University of Massachusetts_**

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

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

**The Contribution of the Fiberglass Pole to the Vault:** Figure 1 presents 105 frames 1/64 seconds intervals of Seagren's 18 - feet, 5¾ inches world record performance.

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

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

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

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

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

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

*★ Paper presented at the International Sport Scientific Congress, sponsored by the Organization Committee for the Games of the XXTH OLYMPIAD, Munich, 1972, and at the International Track & Field Coaches Meeting.*

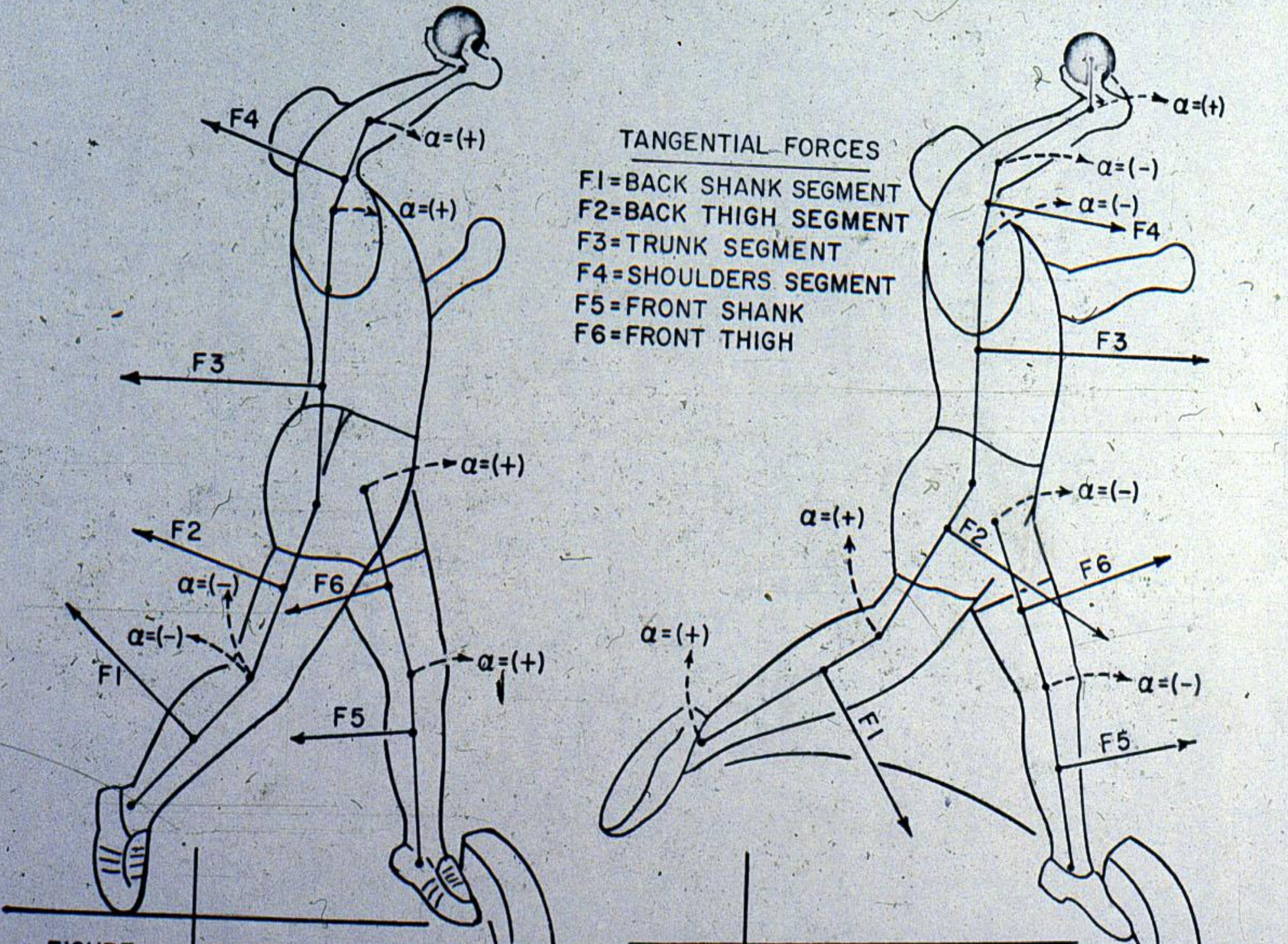



FIGURE: TANGENTIAL FORCE DIRECTIONS WITH DOUBLE CONTACT AND SEGMENT ACCELERATIONS AT RELEASE.

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

79#4

# Biomechanical Analysis of Shotputting *

Gideon B. Ariel, Ph.D.

Computerized Biomechanical Analysis

*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, Kruegger, Laut, Marks, Pyka, Schmock, Stones, Summers, Vincent, Walker, and Weeks. Comparison of the throws of these athletes was made with those of the top six finishers in the 1976 Montreal Olympics. The Olympic athletes who were analyzed were: Beyer, Mironov, Barisnikov, Alan Feuerbach, Gies, and Capes.

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. These films were interpreted through several analytic techniques: visual observation, frame counting, and computerized biomechanical analysis. Following the computations, tables and graphs were generated to determine 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 were stored in 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 parameters such as segment velocities, accelerations, and body center of gravity displacements.

In November, 1978, Alan Feuerbach, who finished fourth in the 1976 Games, were invited to the laboratory of Computerized Biomechanical Analysis, Inc. to examine his style cinematographically and to obtain direct kinetic measurement of the forces produced during foot impact. 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 these 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.

*RESULTS*

*Cinematography*

The present biomechanical analysis revealed that the most important factor in shotputting is the velocity of the shot at release. This factor is more important than either the height or 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 5 phases which are illustrated in Figure 2 (from Marhold). The first is the starting phase when the athlete accelerates his body and the shot. The rear foot leaves the ground at the end 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 rear foot again contacts the ground. It is important during this airborne phase for the rear leg to actively and rapidly bring the foot under the body. The third phase is a transitional phase when the rear foot touches the ground at the beginning and the front foot contacts the ground at the end of the phase. In this phase the athlete should minimize the deceleration of the center of gravity and allow transfer of energy to the push-off phase. The fourth phase, the pushoff, is 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 phase which differentiates between the 50- and 70-foot shotputters. In order to optimize this interrelationship, the athlete should acquire certian 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. Too rapid a start can be as detrimental to producing an optimum final velocity as a low initial beginning can.

Figure 3 illustrates the resultant shot velocities of the Olympic competitors and revealed remarkable similarities among the athletes. Beyer, the gold medalist, demonstrated the highest shot velocity; however, Feuerbach, the fourth place finisher, produced a significantly lower shot velocity. In order to throw more than 69 feet, the athlete must release the shot at a speed exceeding 45 feet/second.

Figures 4 to 6 illustrate the resultant ball velocities of the athletes who attended the 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.

# LUSIS

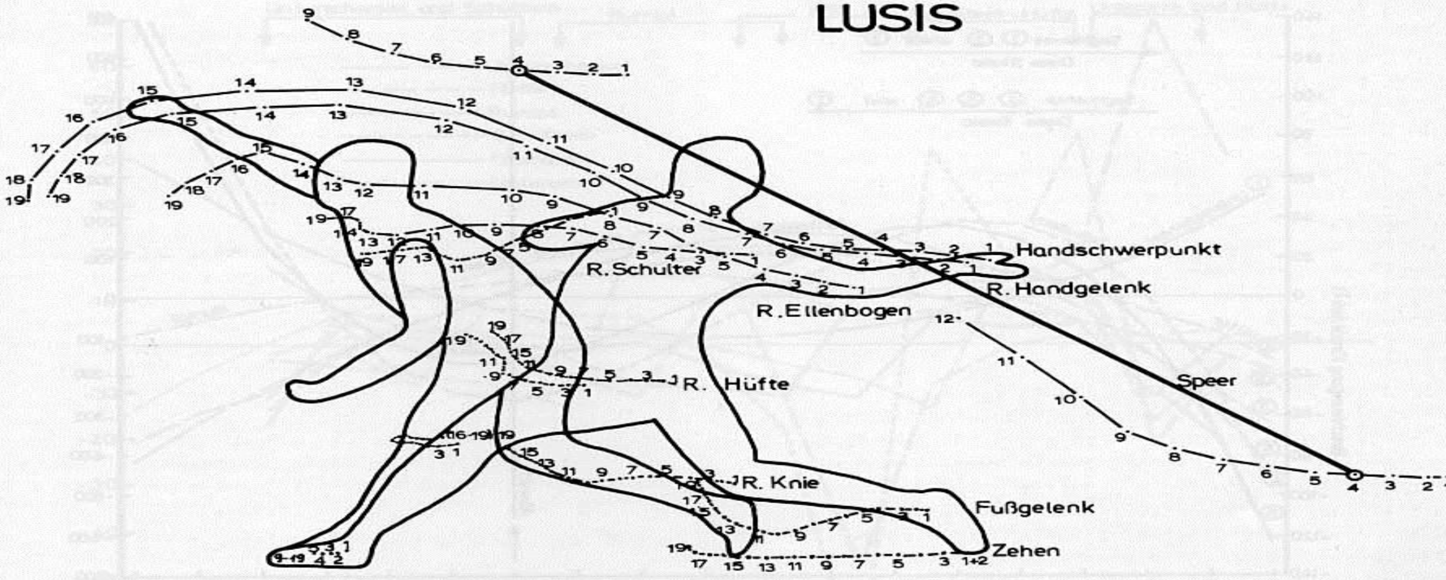



Abb. 2 Lusis freies Körperdiagramm

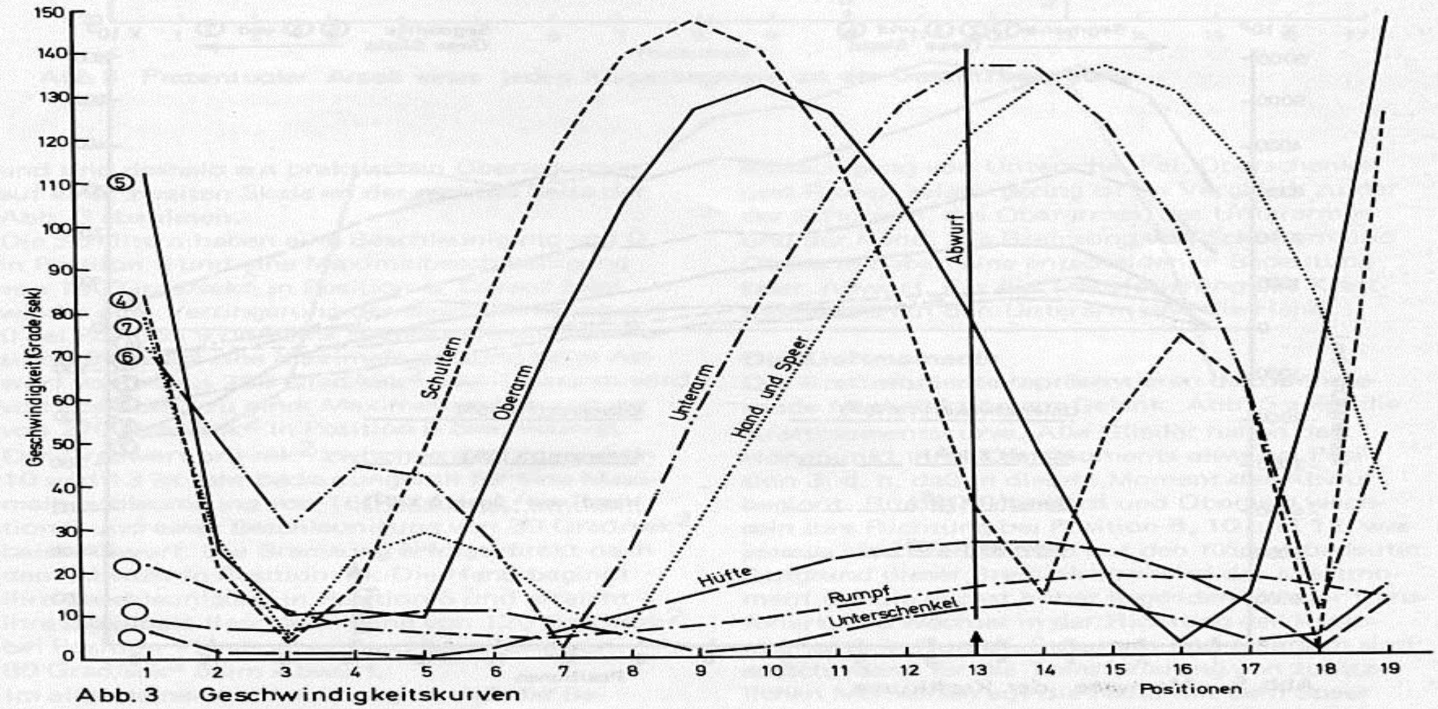
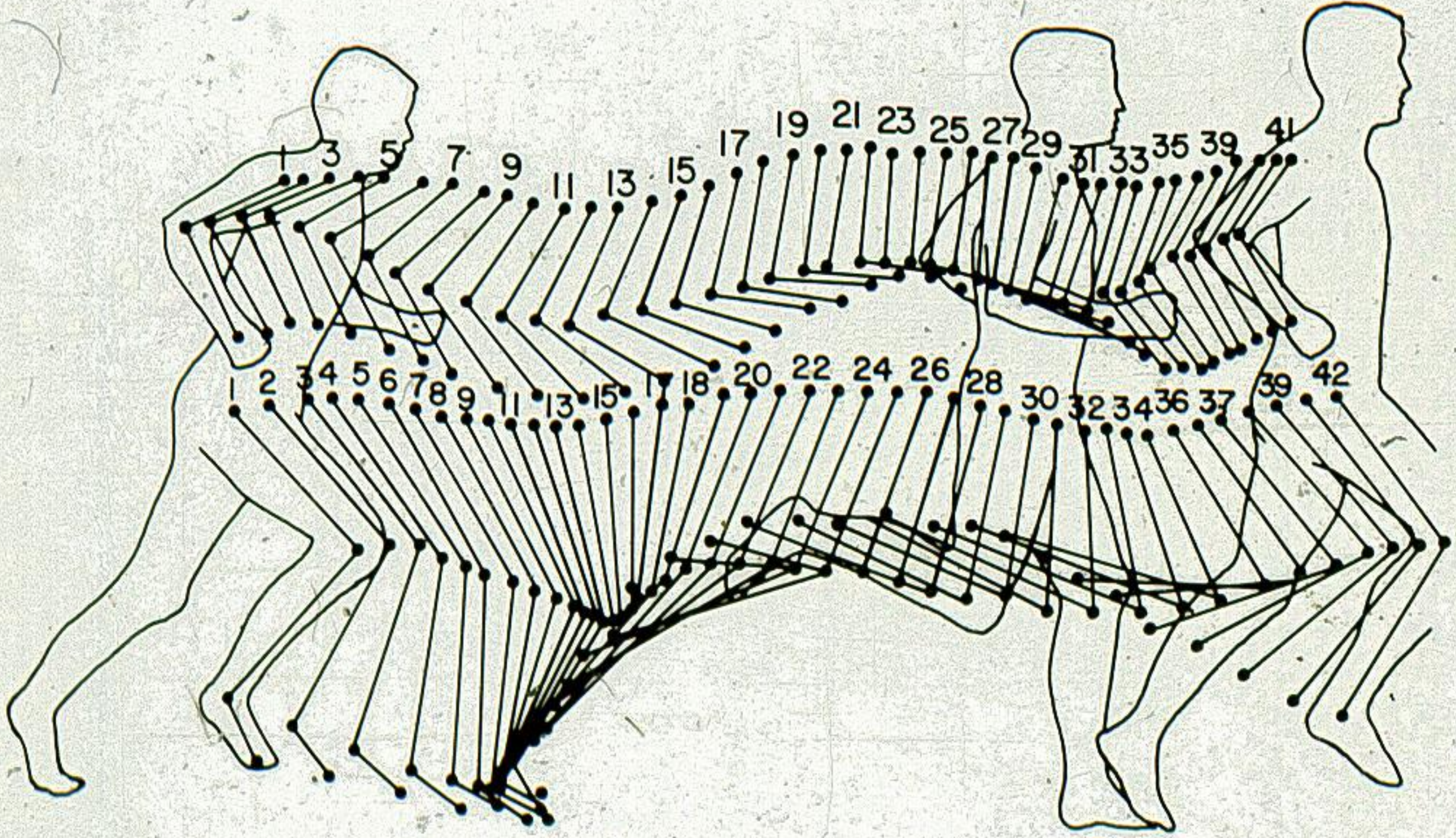



Abb. 3 Geschwindigkeitskurven

RUNNING



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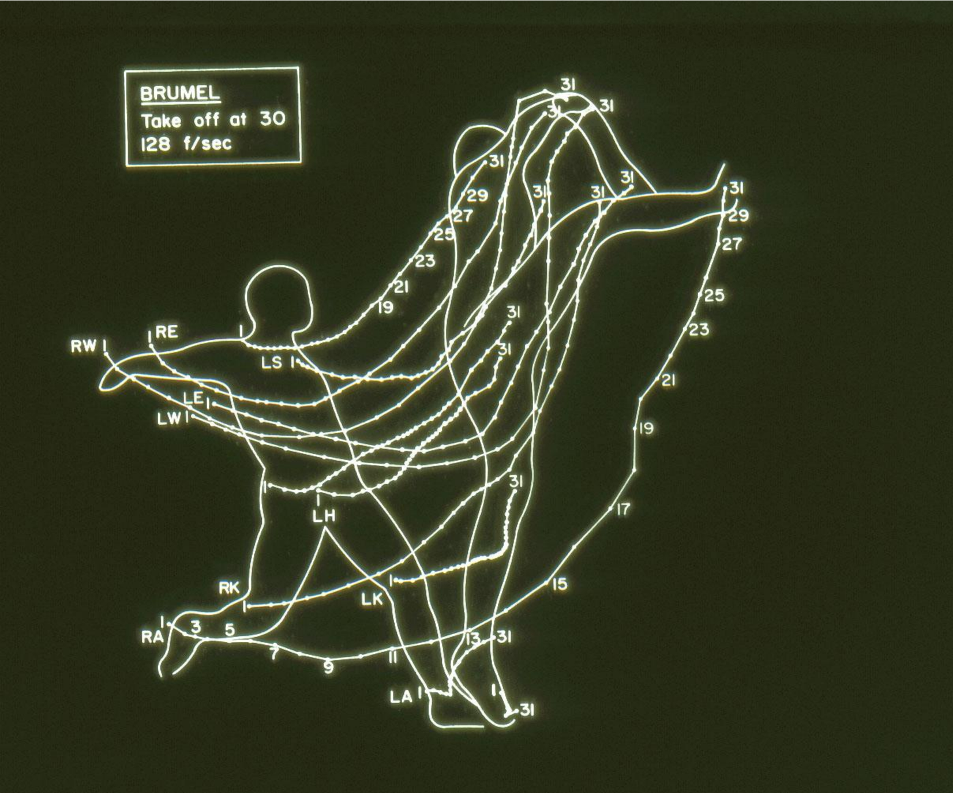
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RW
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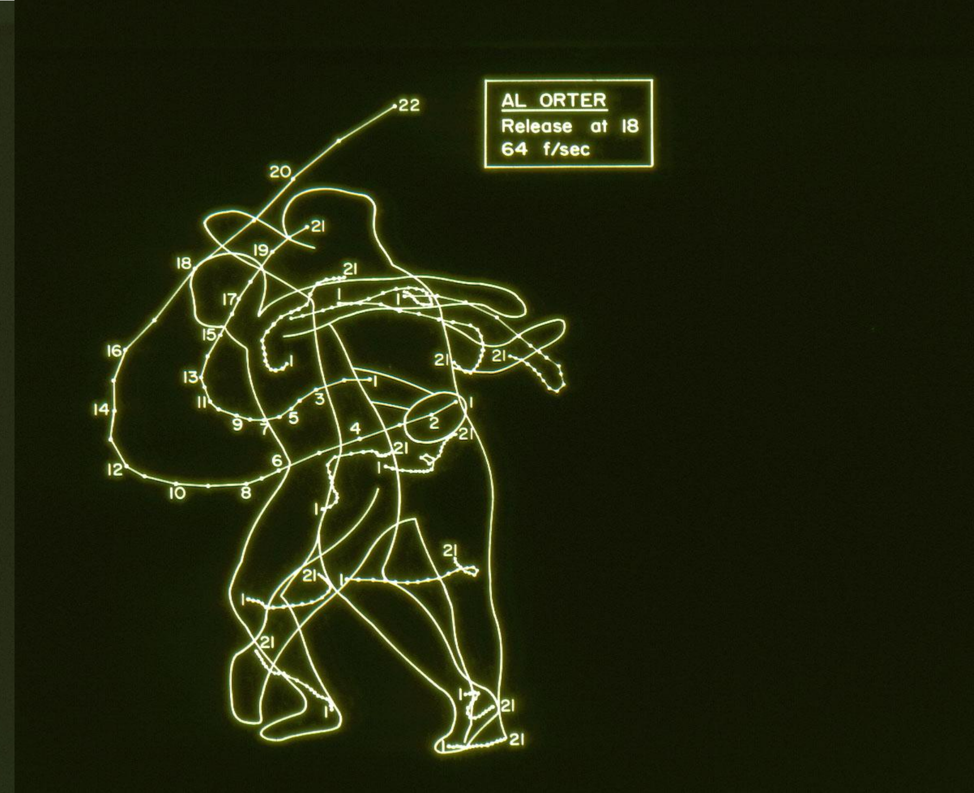
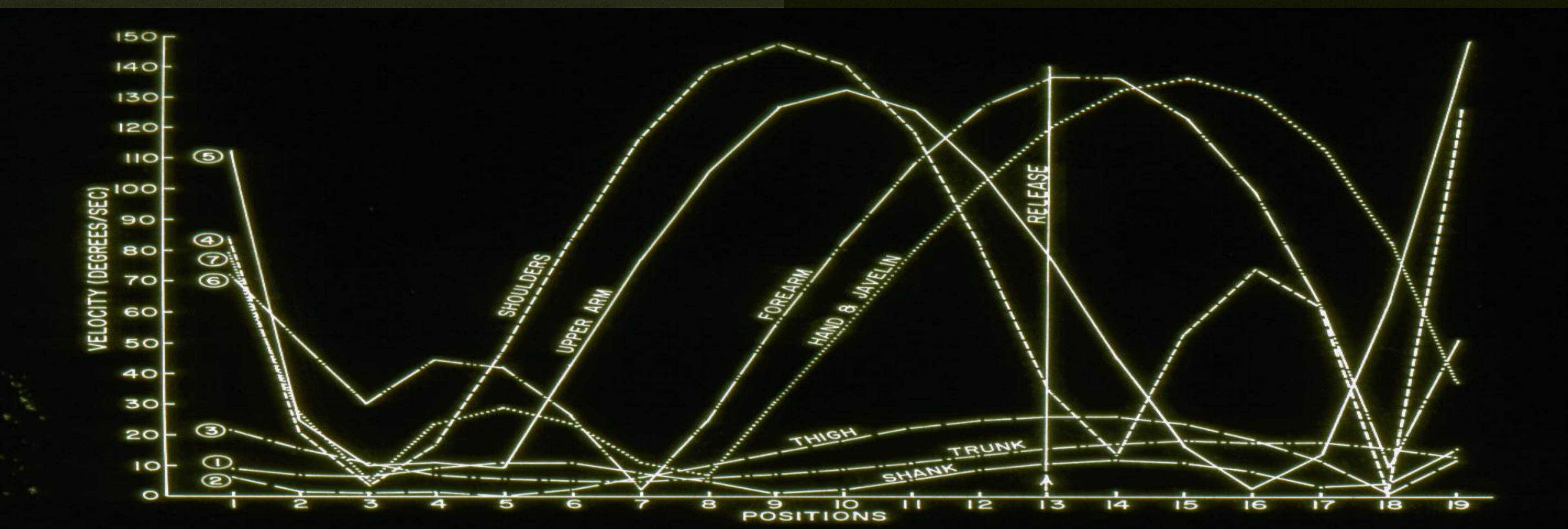

AL ORTER
Release at 18
64 f/sec


VELOCITY (DEGREES/SEC)
POSITIONS
SHOULDERS
UPPER ARM
FOREARM
HAND & JAVELIN
RELEASE
THIGH
TRUNK
SHANK

# 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 am 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 builds. 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 Lusis 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 are important in performance technique and gait analysis.

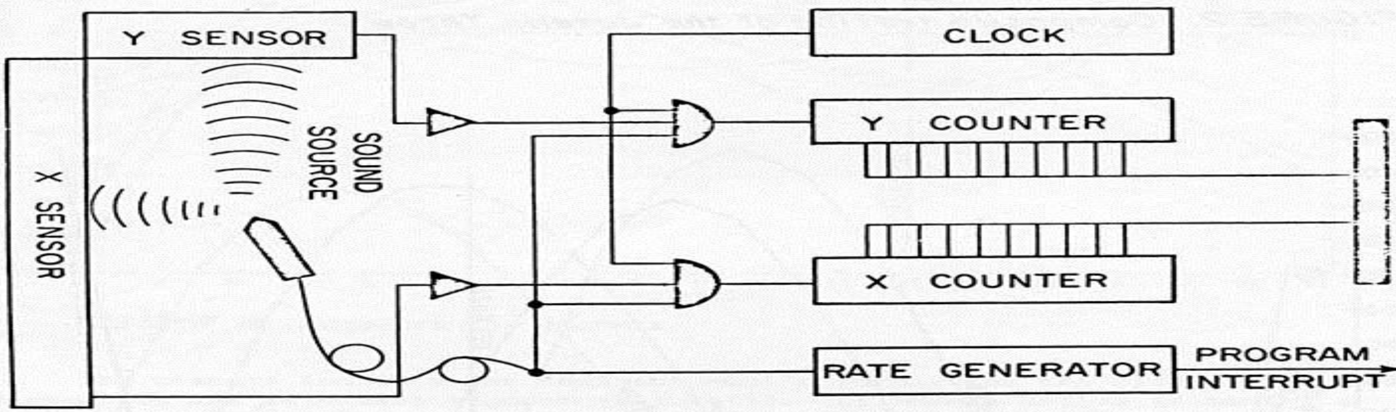



*FIGURE I. Schematic representation of Graf-Pen operation.*

First Digitizer in the World - 1969

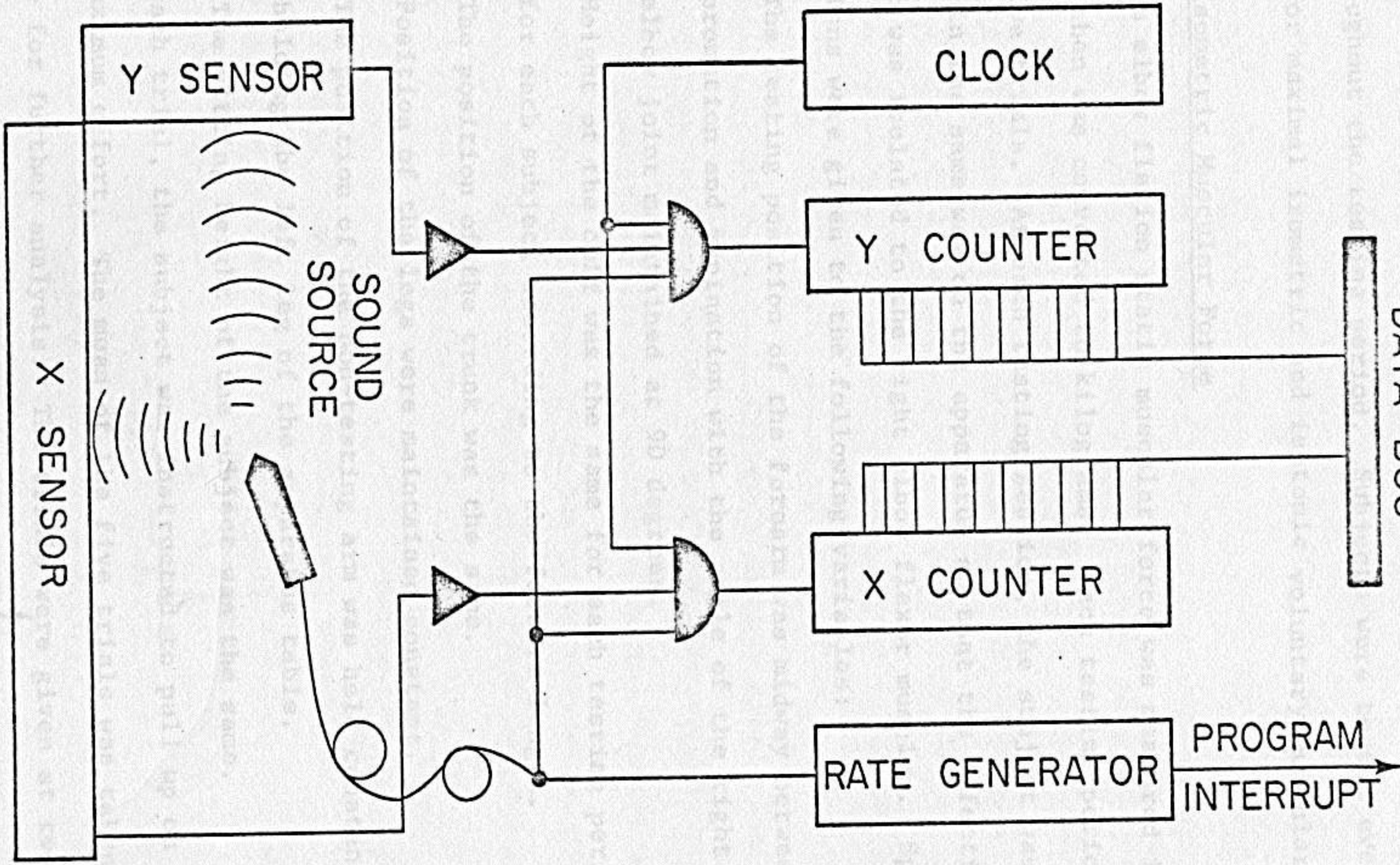
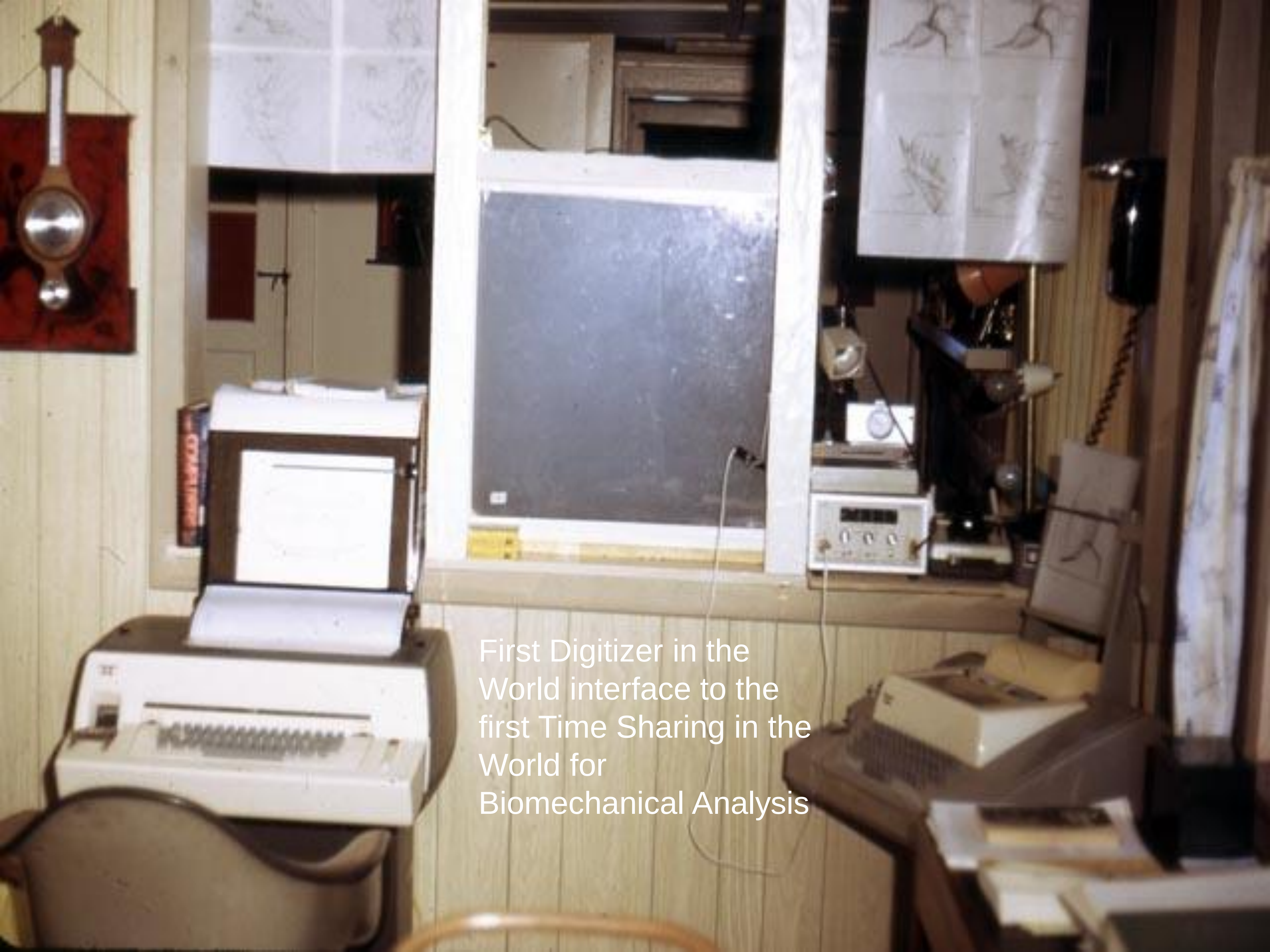



*FIGURE 4. Schematic representation of Graf-Pen operation.*

CBA Inc. Amherst Massachusetts, 1971

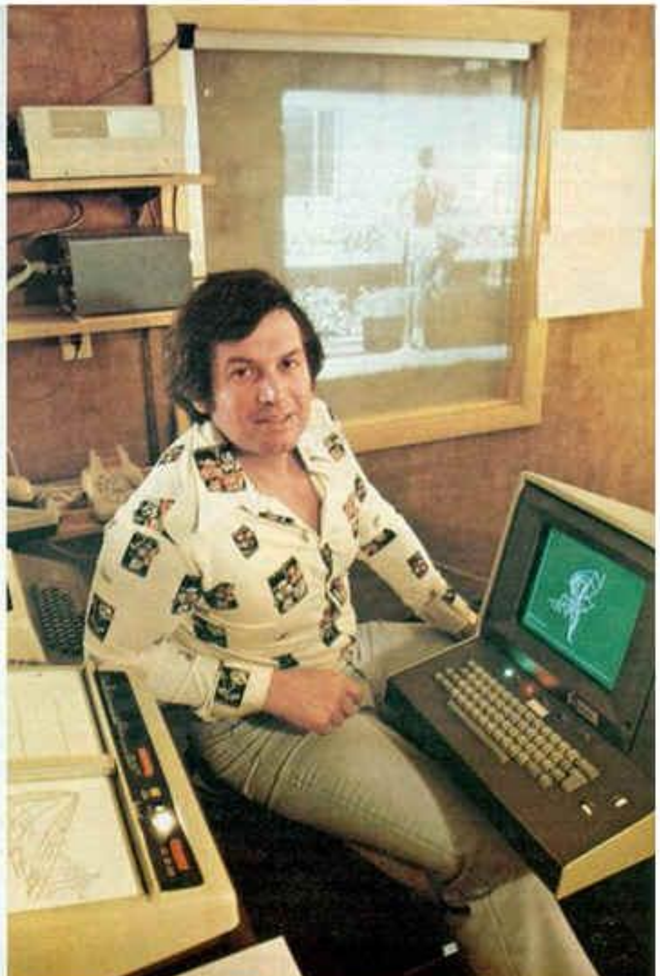

First Digitizer in the
World interface to the
first Time Sharing in the
World for
Biomechanical Analysis

# Rear Projection Digitizing

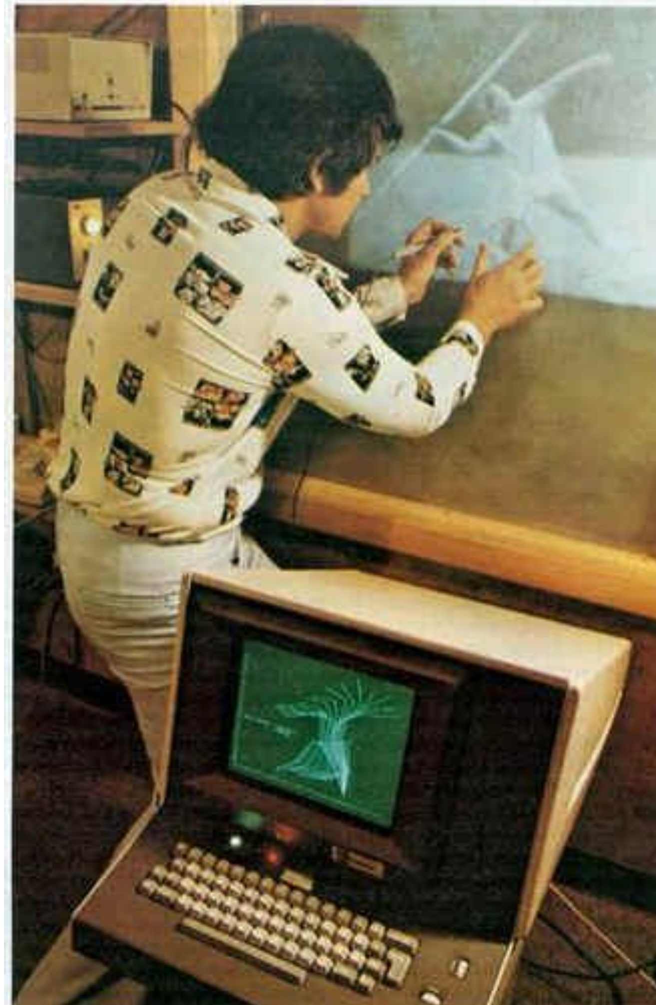
*Sports Illustrated, August 1977*

COMPUTER
*continued*

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

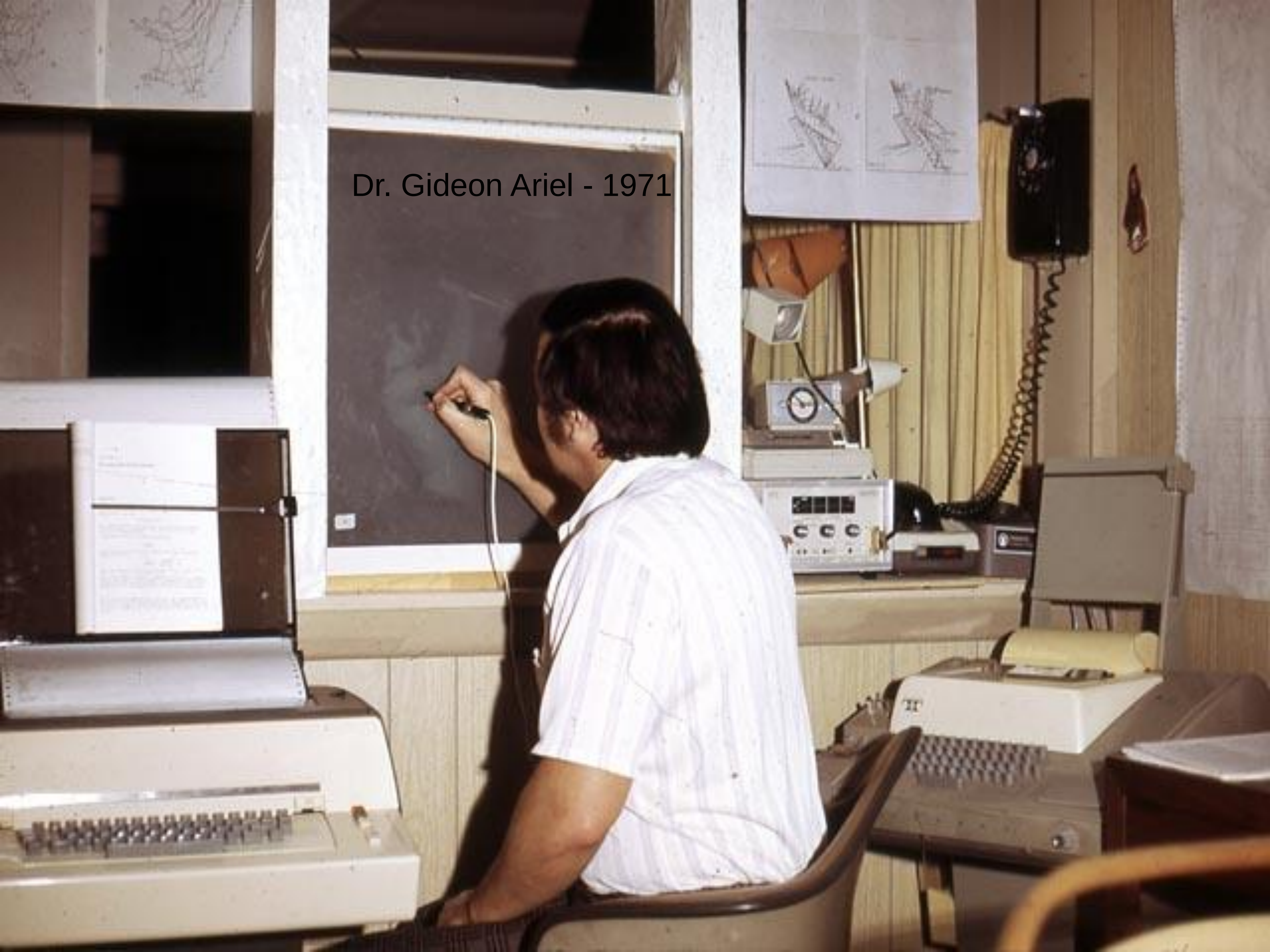


It took Ariel more than 10,000 hours to program his computer to analyze an athlete's motions.



Digitizing, Ariel uses his sonic pen to determine the coordinates of javelin thrower Bill Schmidt.

Dr. Ann Penny 1971



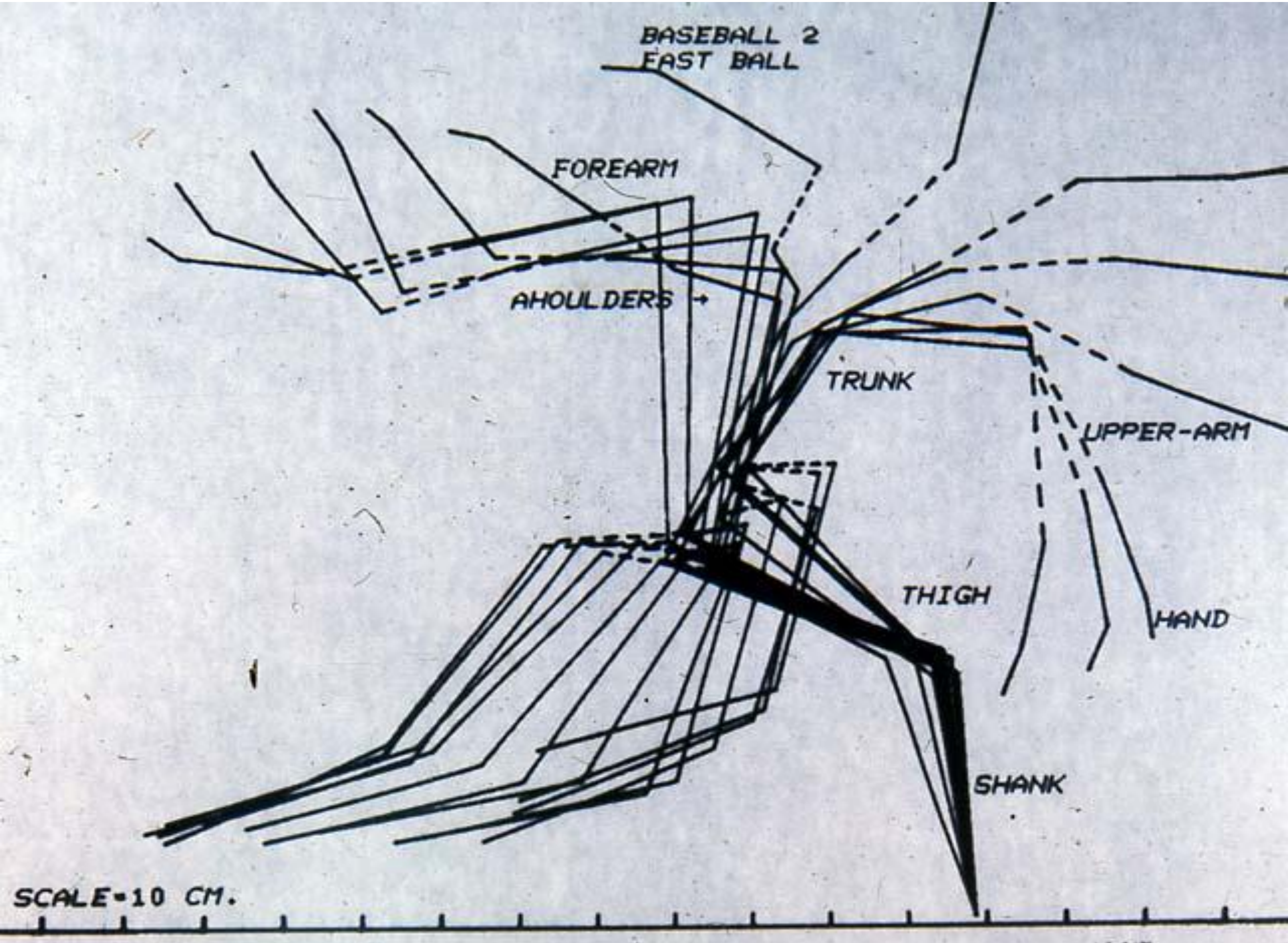
Dr. Gideon Ariel - 1971


CBS
MORNING
NEWS


DATA GENERAL
NOVA SYSTEM
Data General


DATA GENERAL NOVA SYSTEM
Data General


XIII Olympic
Winter Games
Lake Placid
1980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FAST BALL
FOREARM
AHOULDERS →
TRUNK
UPPER-ARM
THIGH
HAND
SHANK
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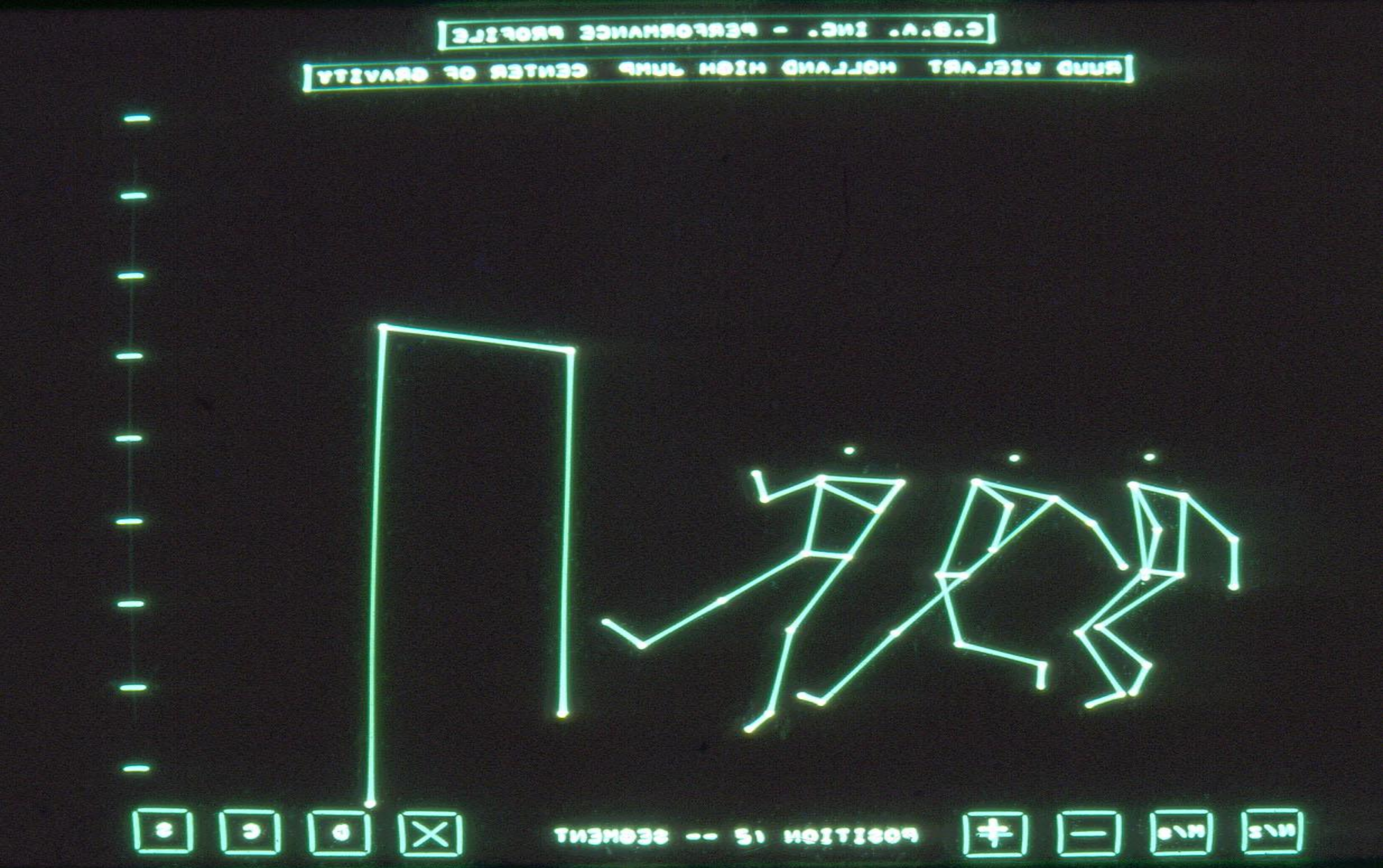
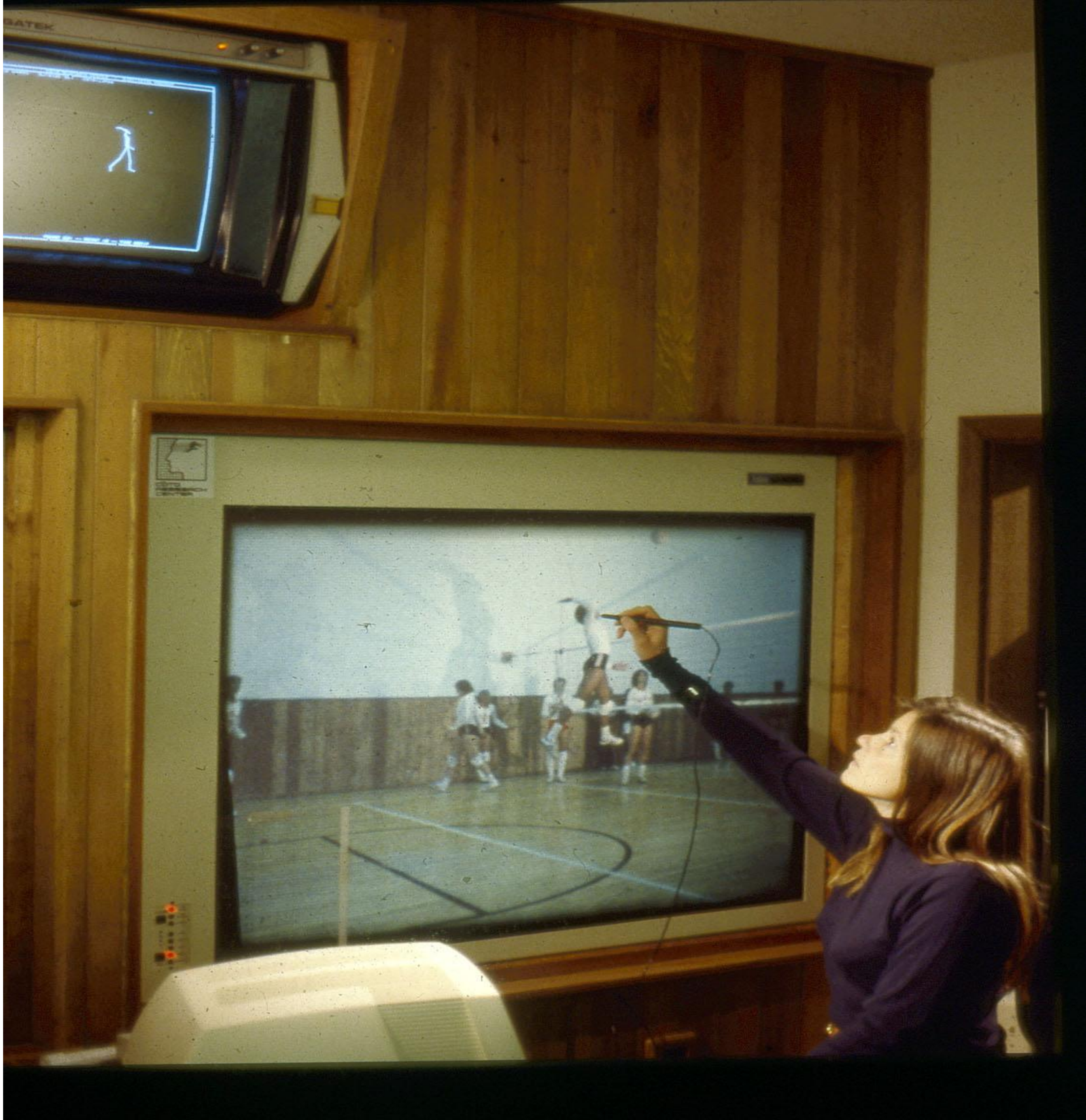

C.B.A. INC. - PERFORMANCE PROFILE
RUUD WIELART HOLLAND HIGH JUMP CENTER OF GRAVITY
POSITION 12 -- SEGMENT
N/2
N/8


AST



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# THANK YOU