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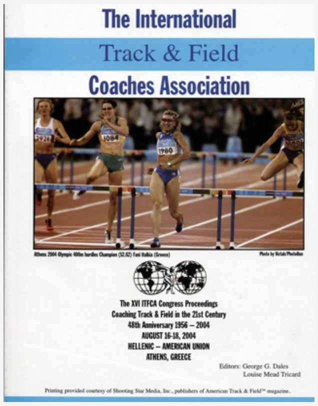
The Biomechanical Wizard

Athens Olympic Congress



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Below find a reprint of the 7 relevant pages of the article "The Biomechanical Wizard" in "International Coaches Association":

The International Track & Field Coaches Association

Athens 2004 Olympic 400m hurdles Champion (52.82) Fani Halkia (Greece) Photo by Victah/PhotoRun

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The Biomechanical Wizard

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Introduction

Biomechanics is the field of study which makes use of the laws of physics and engineering concepts to describe motion of body segments, and the forces which act upon them during activity. In sports, optimal performance can be achieved by applying biomechanical principles to the activity. For example, in the shot put event, regardless of how athletes put the shot, and regardless how they use their body segments, the distance thrown depends on physical principles such as:

1. Height of Release
2. Velocity of Release, and
3. Angle of Release

No matter what the athletes do and how they do it, the distance depends on these parameters. The same applies to any athletic event. In the long jump, the factors that determine the length of the jump are:

1. Velocity at take off,
2. Height of the Center of Gravity, and
3. Angles of takeoff and landing

Throughout the years, various methods were devised to measure these parameters in order to assist the coach and the athlete to biomechanically optimize the activity. Unfortunately, in the past, technology did not allow an easy way to measure biomechanical variables. Currently, it is possible to analyze athletic events on the field in almost real time with the advent of new technology, such as:

- Sensors,
- Wi Fi,
- Modeling,
- Internet, and
- Miniaturized equipment

History

The history of Biomechanics can be traced back to the Greeks followed by the Romans (Galen, Leonardo de Vinci, Galileo, and Borelli). Modern biomechanics started with Braune and Fischer (Germany 1896) who for the first time applied Engineering Mechanics to the Human Body. However, those scientists did not have the advent of computers but they utilized the old technique of pencil and paper to analyze Human Movement.

Kinematics 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:

1. Slow motion cinematography,
2. Special tracing equipment to convert the data, and
3. The high speed computer.

Appropriate programming results in a segmental breakdown of information of the whole motion including the total body:

1. Center of gravity,
2. Segment velocities and accelerations, and
3. The timing between the body segments.

This analysis provides a quantitative measure of the motion and allows for optimization and perfection of human performance applications of biomechanical analyses which permit:

1. An objective, quantitative assessment of performance replacing the uncertainty of trial and error,
2. Eliminating the element of doubt, and
3. Provides a realistic opportunity for improved performance.

Data was collected on the field, at the Mexico 1968 Olympic Games, for the purpose of biomechanical analysis. One of the events analyzed was the long jump.

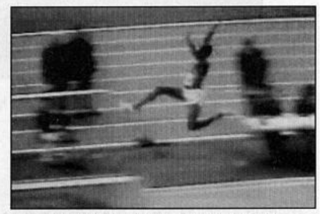

Figure 1. One frame of the famous World Record jump (8.90m-29'21/2") by Bob Beamon captured by the author.

The data was filmed with a spring loaded camera called the Kodak Cine Special as can be seen in Figure 3. Multiple steps were involved in analyzing the data:

1. The 16mm film was developed which took 3 days
2. Then the film was manually trimmed in order to maintain only the frames of interest which took a few hours.
3. Then the trimmed film, utilizing a rear projector, was projected on a screen made of mat glass, so the image was visible. (Fig. 4)

Digitization required the ability to determine the body joints such as:

- the ankle,
- the knee,
- the hip,
- the elbow, etc.

Every time the joint is marked the coordinate values of this point were determined manually with the Mexico City data. These coordinates were then drawn into 2 dimensional space as shown in Figure 5.

Next step was to combine 2 orthogonal placed cameras into 3D analysis. This was all done utilizing the first computer program ever written to do this function at the University of Massachusetts. The Control Data Cyber 74 Main Frame computer at the University of Massachusetts computer center was utilized in reading the thousands of punch cards to yield positional and its derivative kinematics results. For example, Figure 6 illustrates velocity curves. In fact, Figure 6 illustrates the first ever kinematics results, in 1969, output by a computer to show Olympic performance results. These procedures took days to accomplish.

Graphical output was transmitted utilizing the ARPANET system to send graphics in ASCII form as can be seen in Figure 7. This particular photograph illustrates Bill Toomey, the Mexico 1968 Gold medalist throwing the discus in the decathlon. There was no other way to transmit computer graphics and the time of transmission through FTP took hours. We utilized this technology as early as 1972. ARPANET was the foundation for the Internet today.

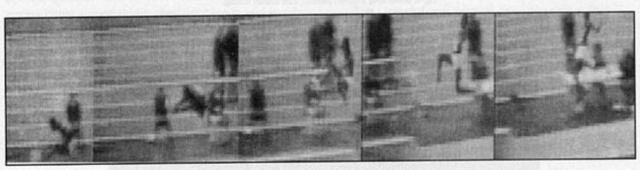

Figure 2. Strobe presentation of the World Record Jump

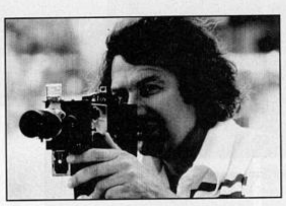

Figure 3. Utilizing the Kodak Cine Special, spring loaded camera, at the 1968 Mexico Olympic Games.

Figure 4. Digitizing from rear projection

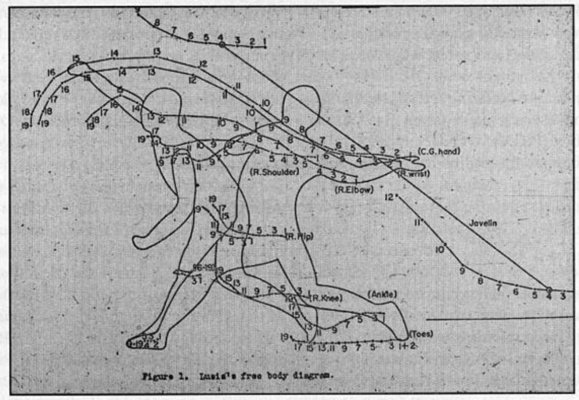

Figure 1. Lusis's free body diagram.

Fig. 5. Drawn body segment position from manual tracing.

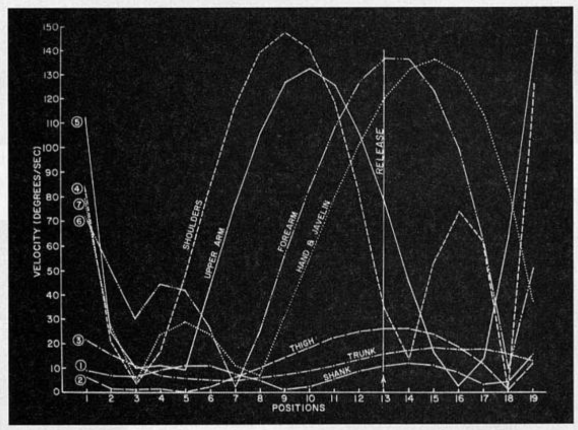

Figure 6. Velocity curves generated by the Main Frame computer.

Fig.7 ASCII composed photograph

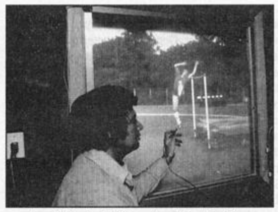

Figure 8. Utilization of Mini computers and electronic digitizers.

Another great advance in the field was the introduction of electronic digitizers. With the electronic digitizers it was possible for the first time to determine the coordinates of any body joint by a touch of a pen on the screen. However, still there was no video. We had to use the rear projection method to trace the activity.

The ability to use film in combination with electronic digitizer and computers open a whole new World in looking at athletic performance. The computer has become indispensable in Sports Analysis. Our sport scientists know a good thing when they see it, and it didn't take them long to "discover" the electronic wizard. In competitive athletics, everyone is always looking for perfection, or at least an edge, and the computer lends itself perfectly to the analysis of technique. It is the one device that surpasses the limits of what the human eye can see and the intuition deduce.

Human judgment is still critically important, however. As in the world of commerce, where decisions are based upon an executive's experience and interpretive ability, the coach must be the ultimate decision-maker.

The computer must be regarded as a tool in the achievement of the desired end. The success of East Germany in international competition in the 70s, can be considered a triumph for national organization for what can be accomplished by the pooling of national resources. The East Germans made victory in international competition a top priority. They sought out their best young talent for intensive training in the finest of facilities, and recruited science in the development of national training institutes. For that they utilized some of the original systems the author devised.

The United States learned something from East Germany. The U.S. Olympic Training Center at Colorado Springs which the author initiated in 1976, attests to the principle that winning requires more than the dedication of individual athletes, that it also requires a national effort. The United States has always had the resources in talented young athletes, dedicated coaches, brainpower and wealth. All that was needed was to blend them.

In the 70s this author started to work with elite athletes as can be seen in the photographs. (Fig. 9)

Figure 9. Working with Al Oerter, Mac Wilkins, Al Fuerbach, Evelyn Ashford, Brian Oldfield, and the USA Women's Volleyball team.

In the past, athletic achievement depended mainly upon individual talent. Genetically superior athletes who successfully interacted with the available facilities, equipment and personnel dominated the list of world record holders. The constant improvement in equipment and techniques has complemented this raw talent. However, the advent of new measuring tools and scientific knowledge has added a new dimension, and the coach must learn to use such technology in optimizing the function of the body in each event.

Since the body abides by the same physical laws as all other earthly objects, its performance must be governed by the laws of motion. It's impossible to throw the shot 20 meters without attaining specific values in shot velocity and angle of release. These values cannot be altered for different athletes. Each particular shot velocity has just one optimal angle.

For a long jumper to leap 8 meters, he must produce certain forces on the ground to propel his body with a specific reaction force at a particular angle. This force is unique; it is impossible to cover the same distance with only a fraction of this force, as gravitational pull acts uniformly, regardless of the jumper.

The concept emphasized here is that all bodies, athletes, implements or machines, are affected by and must adhere to the laws of motion. Scientists have long recognized these facts of force and motion and their relationship to humans. But they lacked the kind of equipment that could measure and analyze the motions and forces involving the kinematics and kinetics, and this impeded further research. The computer provided the initial resource.

Another important contributor was the National Aeronautical and Space Agency, which made detailed measurements of the human body. These measurements included the relative mass for body segments such as arms, legs or hands when given the overall height and weight of the individual.

Another critical element was the high-speed movie camera that provided sequences of the body in real time motion. Knowing the speed with which film travels through the camera, the scientist and the coach can determine the velocity and acceleration of the body segments, using the joints as points of reference. If, for example, the shutter speed is 200 frames per second, one can determine the location of the right knee at the start of a sprint and then compare it with the position of the right knee in the 20th frame, thereby learning how far the right knee has moved in one tenth of a second. The data can be further utilized to ascertain the involved:

1. Velocities
2. Accelerations, and
3. Forces.

A computer can store information rapidly, retrieve it, and perform numerous computations. Without such calculating abilities, an architect, for example, would be in the impossible position of trying to build a cathedral one stone at a time with the blueprints only in his head.

Before a computer can perform its job, whether it is to build a house, guide a robot, print a check, or retrieve a space vehicle, it needs a program. That is, it needs a sequence of instructions which tell it how and what to do. The beauty of a computer (and its program) is that it can play the great coaching game of "what if". You can ask, "What if I hold the shot down here and then whirl in this fashion?" The computer will tell you how far the shot would go, applying the amount of force developed in previous analyses. The computer, then, helps the coach write equations and construct models which will produce optimal performance.

The dramatic effect of computer application to sports analysis first struck the author when beginning to analyze human motion. There was no direct way of inputting the motion-picture observations into the computer. Each frame of the film sequence was manually outlined on a sheet of paper fixed to a wall. Then, for each frame, the angles made by the segments as well as their lengths were measured. All of this was done with rulers and protractors, and the information was then recorded on computer keypunch cards. If the cards were accidentally dropped, it was impossible to rearrange them into the proper sequence and the process would have to be redone.

This method was too laborious for any large scale analysis. In 1971, the medical school at Dartmouth College employed a device called the sonic digitizer to measure angles required for scanning laser beams in the brain. Since its principles fit the author's needs, it was adapted.

With the digitizer, the frames from a film could be projected onto a glass screen. With the sonic pen, one needed only to touch the points of reference (such as the body joints or the outline of a hockey puck) on the screen and the information would instantly be recorded in the computer memory. Angles and lengths could all be swiftly measured.

Since that time, high technology has allowed us to adapt a newer method that uses electronic scanners. These capture the motion in digital forms which represent gray scales for subsequent analyses, eliminating the necessity of film and manual digitizing.

Along with the analyses based upon films taken during actual events, sensitive force platform applications have been adopted. These allow controlled laboratory testing of forces, such as when an object such as the human foot strikes the plate during a sprint. The plate is capable of recording four different kinds of forces:

1. Vertical
2. Horizontal
3. Sideways or Lateral, and
4. Moment or Torque

We never stop advancing technology. In the late 70s videos and better sensors were used. In the 80s more methods were adopted. In the 90s a big advance in technology and programming came with the utilization of the Internet in its present form. In the Atlanta 1996 Olympic Games Notebooks were used to transmit wireless information to centers for immediate analysis. Software became automatic to determine joint center locations automatically.

Chinese Delegation with Dr. Gideon Ariel (Center)