INTRODUCTION TO BIOMECHANICS CINEMATOGRAPHY AND VIDEO AS TOOLS FOR THE RESEARCHER AND COACH

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The compact personal computer, with a large memory and a small price, is about to make biomechanics cinematography and biomechanics videography a part of the modern coach repertoire for advising the individual performer and for directing team strategy. However, before this happens the person trained in biomechanics will have to develop a "cook book" approach which can be turned over to the coach for practical implementation. There is a qualitative and quantitative side to biomechanics cinematography and biomechanics videography which will be discussed further.

We can agree that to understand human movement we must first see it, and to analyze that movement we must freeze it in the mind's eye. This, of course, is being done by the coach working with his performers in the same way as Leonardo da Vinci (1452-1519) did years ago. Although the eyes as instruments for data acquisition are quite remarkable, they simply are not designed for this type of application. The eye can not freeze and hold an image for analysis. The eye is also limited to relatively slow movement recognition; perhaps equal to 1/30 of one second exposure time with a camera. As you know, that long an exposure time will leave a blur of fast moving body parts.

The biomechanics researcher, with the latest technology in hand, uses biomechanics cinematography (BC) and soon will be using biomechanics videography (BV) to investigate and improve sports performances. This is done qualitatively, with the qualitative nature of the movement being studied, and quantitatively, with the motion described in precise numbers for such parameters as velocity, acceleration, force, momentum, moments, kinetic energy, etc.. From the point of view of the coach the researcher lives in the tower of academia, protected from real life. There the researcher develops projects which will result in papers for refereed journals to be stashed away on the dusty shelves of the library. Periodically the biomechanics research person comes out of safety, attempts to dazzle and confuse the practitioner with esoteric jargon and vanishes somewhere in the laboratory. From the biomechanics researcher's point of view the coach simply does not have the background to understand.

Both, the coach and the biomechanist must reach common ground if there is to be a benefit and value to biomechanics research. The biomechanics researcher must "come out" and condust work in real life while the coach must come to grips with the new technology at hand. Perhaps the basics of BC and BV is a good starting point for both.

SEQUENCE OF EVENTS

Before any data acquisition takes place the purpose of the project must be clear and outlined from beginning to end. You would hardly start a trip without knowing where you are going or what road you plan to take. Once the plan is made work out the details of all parts and only then begin the actual filming (data acquisition). Above all, consider the practical value of the project. Without a visible and understood present or future value the research project is nothing more than an academic game. There are times when the researcher is sincere and still produces results without value because the event studied was not clearly understood. For this reason alone the advice of an experienced coach has great value. The coach knows where the real problems are. Also, it will be the coach who will transmit the useful findings to the sports person.

The sequence of events during biomechanics cinematography is decided in the same fashion as in most photography work. The problem is identified and then solutions and results are found. The manner in which data is acquired is dictated by the nature and extent of the analysis intended. The usual sequence of events during biomechanics cinematography has nine or ten steps and goes as follows: the nature of the required results is determined; the subject is filmed; the film is processed; the film is edited; a contact print is made of the edited film; the image from the contact print is projected on an analyzing surface or a digitizing board; digitized data is fed to a computer; computerized analysis is conducted; results are arranged in desirable form, and, if required, a computer model of the performance is made.

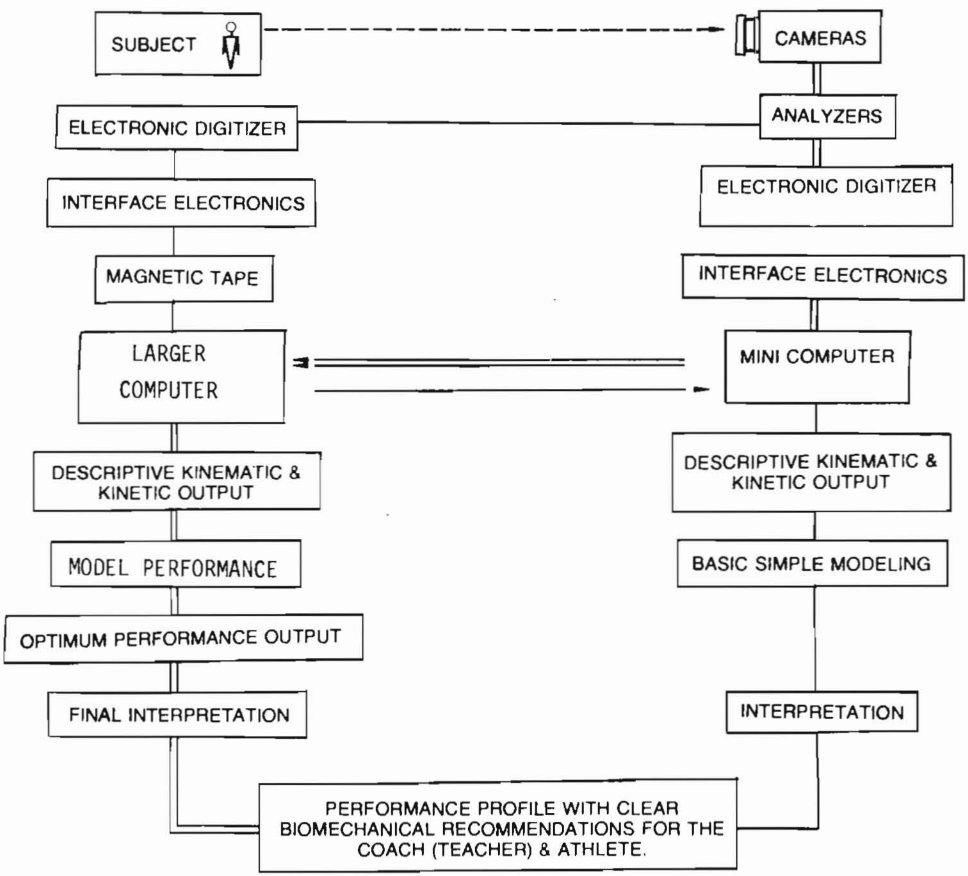
The flow of events in the process of BC is roughly the same for all situations, however, there is an extensive range in the sophistication and price of instrumentation. The usual flow goes as follows:

CAMERA → ANALYZER-DIGITIZER → MINICOMPUTER → CRT OR OTHER OUTPUT

With sophistication the procedure takes on new twists with more elaborate, and more expensive instrumentation and software. Unfortunately, however, there is no evidence that greater sophistication has lead to greater practical productivity in the improvement of sports performances. As an example the laboratory procedure at the Research Center for Sports is illustrated in Figure 1.

Figure 1

Biomechanics Cinematography Laboratory and Procedure



DATA ACQUISITION

Experience has produced evidence which seems to indicate that often findings from within a laboratory setting are not the same as those from competitive situations. In a laboratory the subject tends to put on an act for the camera, which in turn produces movement not found in real life. This raises, or should raise, questions for the biomechanics cinematography researcher. Is it more desirable to control the event in a laboratory to increase measurement precision of an event that does not happen in real life ? Or, should the researcher capture the real thing with less accuracy ? The obvious answer to these questions has been a factor in increased field bases, or real life BC activity. The turn to data acquisition during competition may have been the BC conducted during the 1976 Olympic Games in Montreat. For the first time BC became an official part of the total event. This turn to data acquisition during competition has continued, with most biomechanics researchers increasing their real life research efforts.

With a turn away from the comfortable laboratory, to a relatively hostile playing field environment, increased emphasis must be placed on data acquisition instrumentation. Instrumentation must be the most precise, and it must be "researcher friendly". During field based data acquisition the filmed event can not be repeated whenever instrumentation fails or the researcher is not ready. There is only one time to get data and that time is limited and filled with disturbances from other competitors, officials and spectators.

In biomechanics cinematography, the camera with a good lens is the most important research instrument, and its importance increases as the researcher moves out of the laboratory setting. While in the laboratory, awkward and heavy cameras with limited flexibility can be tolerated, such cameras are a liability in a competitive sports setting. In a competitive setting, the subject (athlete) cannot wait patiently while all the instruments are adjusted. The events do not wait for the researcher; the researcher cannot make any adjustments to the filming site, and he cannot instruct the subject.

In order to make an intelligent and correct choice in cameras for a specific purpose, the needed characteristics of the instrument should be clearly and carefully listed. The specifications have to be reasonable and should not include luxury items. An example of minimum requirements that are necessary for biomechanics cinematography cameras goes as follows:

* 16mm film format capability.

Through experimentation we found that a super-8 format was not adequate for research purposes. We also decided that a 35mm format was not practical from a financial point of view.

* Frame rates of 10 to 500 frames per second.
For most human movements frame rates of 100 to 200 F/S are most desirable, but there are situations where lower and higher frame rates are necessary.

* Frame rate error not to exceed one percent.

* Intermittent pin film transport.
With a minimum of two registration and two pull-down pins, with one pin on each side of the film frame. An intermittent pin system is essential for higher frame rates so that the film can be held precisely in place for each exposure.

* Film capacity of 130m (400') or greater.

* Magazine daylight-load capability.
In competitive situations time used to reload the camera while the event is in progress may result in a loss of essential data. Also, reloading film in the camera disturbs its position. These errors cannot be corrected while sports events are in progress. Therefore, a magazine-load concept with the ability of quick magazine changes is a requirement in real-life filming.

* Variable shutter with quick adjustment capability from roughly 7° to 160°.
In competetive situations, unexpected light changes are frequent (as on a sunny day with clouds), and so the flexibility for quick exposure time adjustments must be available.

* DC electric motor drive.
DC rather than AC is required since AC is often not available at the competition site, and AC generators are clumsy and noisy. DC batteries, on the other hand, can be charged well ahead of the filming event.

* Weight of cameras should not exceed 7.0 kg.

* The camera should have two built-in timing lights, one on each side of the film (neon or LED are satisfactory).

* A built-in heater with a thermostat is desirable.
A heater with a thermostat becomes an essential item when filming in low temperature, for example when filming winter sports.

* Phase-lock capability at frame rates from 10 to 500.
A phase-lock capability is essential for three-dimensional movement analysis so that a minimum of two cameras can operate frame-by-frame at exactly the same rate.

* Reflex optics for continuous viewing of subject.

A reflex optics capability for biomechanics cinematography is essential in a sports-competition setting where adjustments may have to be made during the event. Panning would be very difficult, if not impossible, without a reflex optics system.

* Reliable low-maintenance operation.

In a competition setting, reliability of the camera is more important than one may realize. A breakdown or malfunction may result in a loss of all the needed data from subjects who perform only once at their competition time.

Of all cameras considered for biomechanics cinematography, we managed to come up with a list of seven which would be excellent or satisfactory in most respects. The seven are: Photo-Sonics 16mm Biomechanics 500; Photo-Sonics 16mm 1W--overqualified-(has 24-1000 fps capability and eight pulldown with four registration pins); Photo-Sonics 16mm 1-PL; Photo-Sonics 16mm Actionmaster 500; Photo-Sonics 16mm Actionmaster 200, with 200' capability; Redlake 16mm Locam and Milliken 16mm.

OPTICS

Lenses with fixed focal lengths are not economical to use in sports cinematography situations where the camera-to-subject distance cannot be chosen by the photographer. In competition areas, specific locations are assigned for camera use, which can create problems when using fixed lenses. Invariably the fixed lens is too long or too short, resulting in a smaller than desirable or otherwise inadequate image of the subject. Mainly for this reason we use the Angenieux reflex zoom with an equivalent focal length of 12-120mm. With this kind of flexibility, we can, in most cases, get an image that is of higher quality than if we had to use a fixed focal length lens.

TIMING SYSTEMS

An electronic timing system capable of leaving marks on the film is essential for all quantitative biomechanics cinematography analysis. In the past we have used several systems. At the Olympic games and the Commonwealth games, we used the Photo-Sonics TLG series which are neon-light generators capable of settings at frequencies of 10, 100, and 1000 Hz. At the U.S. National Championships we used the Photo-Sonics Series 77 photo-digital recording system, but found that for our needs, the less-sophisticated TLG series was adequate. Of course, we have not been concerned with timing systems when using the Photo-Sonics Biomechanics 500 camera since it has a built-in system similar to the Series TLG.

FILM STOCK

Black-and-white film for biomechanics cinematography during competetive events is no longer used. Since 1973, all Research Center for Sports projects have used color film predominantly for real-life competitive situations. For biomechanics cinematography the film must have the following characteristics to be fully-acceptable: it must have high-contrast characteristics; the film's exposure index must be relatively high to meet the need for short exposure times; the film should have high force-process capabilities so that the exposure index can be increased without serious quality loss; the film should be easy to process at most sports competition locations in commercial laboratories, and the film should have the broadest possible capability for recording data, which essentially means that the film will record the greatest possible detail under the widest range of conditions.

Film base has been an important consideration in film selection in biomechanics cinematography since the film base carries the photographic emulsion through the camera mechanism and preserves the image for the future. Today, most films are manufactured on triacetate film base. However, technology is perfecting the Estar base film. To gain an understanding of the triacetate and Estar polyester base films, comparisons need to be made. While there is no such thing as absolute dimensional stability in film, there are differences in dimensional stability between different film bases which include thermal expansion, humidity expansion, processing dimensional changes and shrinking.

When the temperature change is isolated from other environmental variables, the triacetate base film shrinks or increases in size roughly 0.006 percent per degree C. On the other hand, the thermal coefficient for Estar-base film is 0.002 percent per degree C. It must be kept in mind that in all dimensional stability questions, the change is proportional for the full frame and consequently not as damaging as it first seems. The humidity coefficient of linear expansion per one percent of relative humidity is roughtly .006 percent for triacetate base and .002 percent for Estar base. Processing dimensional changes combined with aging shrinkage are approximately 0.25 and 0.04 percent for triacetate and Estar base respectively, over a storage time of a month. So, in terms of dimensional change characteristics, the Estar base is superior.

In terms of tear strength, the Estar base film is very difficult to rip by hand, while the triacetate base film can be torn with ease. In fact, on numerous occasions, processing laboratories refused to develop Estar base film that we had shot at competitions for fear of damage to their machines if there were some malfunction. Since Estar base film is thinner than triacetate base film, it is less brittle, and more film can be held by the same camera spool. All of the above characteristics are positive factors in favor of Estar polyester film for biomechanics cinematography.

Film stock that we have found most satisfactory for biomechanics cinematography includes the following (in most situations we push the film two stops): Ektachrome 7239, 160 ASA daylight; Ektachrome 7250, 400 ASA tungsten; and Ektachrome 7251 400 ASA daylight (new film, 1981).

DATA REDUCTION

The usual data reduction system includes a projector or a projection head with or without pin registration, a digitizing surface, interface electronics to a computer or recording device, a minicomputer or, in the more sophisticated laboratories, a minicomputer interfaced with a large computer. These systems are expensive but are essential in the whole process of biomechanics cinematography. Unfortunately, even under the most favorable conditions, the film data can be overwhelming and drastic improvements are highly desirable to increase film-reading speed with accuracy.

Data reduction systems are being developed for automatic data reduction of human movement from film. The hardware involved in this process includes the Photo Digitizing System Model 200 with digitization performed through the use of a motorized and encoded crosshair cursor, an integrated digitizing camera subsystem, and controlling mini-computer with peripheral devices.

The digitizing camera is connected directly to its own power supply and system control unit containing logic circuitry, deflection and digitizing circuitry, as well as switches and indicators for manual control. A scan converter and local monitor provide a display for viewing digitized data stored in the computer. The digitizing camera is under the control of the computer system, with 12-bit digital to analog deflection resolution at 0.5 percent linearity, with a video gray scale of eight bits analog to digital. A maximum digitization rate of 2.0 MHz has been accomplished.

Circular black or white marks roughly 2cm in diameter are placed on the subject's joint centers and the estimated cm of the head, hands and feet. The circular targets are found by scanning from the center in radial directions looking for edges normal to the scan direction. Once the edges have been found, the center and radius of the target are determined.

There are two steps used to find the true center of the circular targets on the subject. The first step locates an initial center by scanning from the expected trial location, while the second step locates a final center by scanning from the initial center location as determined above.

In situations where the markers may not be visible for some part of the movement, a prediction is made as to their expected paths so that the digitizing camera can pick them up as they become visible. The steps then in using this system require the identification of all the markers on the first frame, followed by a switch to automatic mode. From here on, the digitizing system is fully-automatic in digitizing and advancing to every designated frame to follow. Each frame for any number of frames for the measurement described above takes roughly five seconds with far greater accuracy than a manual procedure. This means that the digitization of all information for biomechanics cinematography of 50 frames takes only four minutes, where only a few years ago, it was a day's work. Unfortunately, the system is not at a stage yet where precise readings can be made without body markings, but progress is being made.

VIDEO SYSTEMS

Video systems have been kicked about by biomechanics cinematography researchers for over a decade without being used for any serious research. Even the Videonetic Model 1300 Stop-Action System, which was developed in 1968, received little serious thought, although it had managed to eliminate much of the blur via a shutter system. New video systems are being developed with exposure-times comparable to exposure times achieved by pin-registered cameras. These innovations have roused interest, but present indications suggest that video systems are not in competition with film cameras for quantitative biomechanics cinematography work. Rather than competing with film cameras, the video systems will become a complement centered around qualitative biomechanics cinematography. Some commercial clinics have taken advantage of the new video machines and promise to eliminate potential little league elbows and tennis elbows for all who are willing to spend the money to be analyzed. But there are also biomechanics laboratories which are using video increasingly when quick feedback is needed and quantitative data is not the important consideration.

Some very sophisticated video systems have made it to the marketplace and are now developing their markets. Several of these systems show promise in biomechanics laboratories. A partial list includes: the NAC HVS-200 with a maximum of 200 F/S (fields per second) in color, the AVX system with a maximum of 180 F/S in b/w (black-and-white only), the Video Logic Instar with a maximum of 120 F/S in b/w, the PCSC-2000 with a maximum capacity of 60 F/S in color, the PCSC-2300 and 6500 with a maximum of 60 F/S in b/w, the Unilux 900-2C with a maximum of 60 F/S in b/w and SP-2000 with a maximum of 2000 F/S in b/w.

THE HIGH SPEED VIDEO SYSTEM FOR YOU

When considering a high speed video system for your BV needs consider its capacity before making a choice and purchase. In relationship with film the best video systems have roughly the same practical resolution as 8mm film. This is hardly enough for most quantitative research. On the other hand, the resolution is adequate for qualitative analysis. In considering frames per second (fields per second) FPS, remember that in most biomechanics applications 100 to 200 FPS is adequate. What is of utmost importance is the exposure time. In most biomechanics videography or cinematography work exposure time should not be much longer than 1/1000 s ,- at the same time a shorter time than 1/3000 is seldom needed. Other items to be considered include: (1) price of whole system, (2) availability and cost of video tape to be used, (3) color or black and white capability, (4) maintenance costs and maintenance availability, and (5) compatibility of the high speed video system with existing instrumentation.