PROCEEDINGS

Of SPIE-The International Society for Optical Engineering

Volume 291

Second International Symposium of

Biomechanics Cinematography and High Speed Photography

Juris Terauds
Chairman/Editor

Sponsored by
SPIE—The International Society for Optical Engineering
The Research Center for Sports
The American Society of Biomechanics
The International Society of Biomechanics
The Track and Field Association of the USA

August 24-26, 1981
San Diego, California

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INTRODUCTION

Biomechanics cinematography and high speed photography data acquisition and analysis procedures have gone through a technical explosion creating new horizons for imagination, adventure, creativity, and productivity. Often, in the race of progress, several researchers working diligently but independently may use the same procedures and arrive at the same results. At the same time the practitioner in the field may be left behind in a cloud of advancing technology. The purpose of the International Symposium of Biomechanics Cinematography and High Speed Photography was to bring together persons dealing with studies and the application of research in fields where an exchange of ideas would be most valuable. Researchers and practitioners working with the same technology but in different disciplines often face problems which turn out to be mutual. Disciplines and professions where this is frequent include biomechanics, physics, engineering, sports biomechanics, medical biomechanics, aviation, navigation, and others. The common interest is technology and procedures in movement data acquisition and analysis. Further, the purpose of the symposium was to bring in manufacturers and designers of the technology and display the state of the art. These proceedings further facilitate the needed communication. The papers in this volume have been refereed for their merit and content and represent a healthy cross-section of topics covered during ISBC/HSP. The first part of the symposium dealt with innovations in data acquisition instrumentation, procedures in biomechanics cinematography and high speed photography, and research papers emphasizing data acquisition aspects. The second part of the symposium dealt with innovations in image analysis instrumentation, procedures in data analysis, and research papers dealing predominantly with the analysis and "massaging" of data.

The editor, the Organizing Committee and the Scientific Committee, wish to thank the authors for their response in following the format outline for writing their papers and an extra thanks to all persons who contributed long hours of work and gave of themselves to make the Second International Symposium of Biomechanics Cinematography and High Speed Photography a success. At this time I can only hope that this volume will provide the reader with new knowledge in the "wonderful" world of biomechanics cinematography and high speed photography and that the new knowledge will further stimulate research that is meaningful to colleagues as well as to society. Let us continue to bridge the gap between the researcher and the practitioner and let us continue to be imaginative and adventurous.

Juris Terauds
Research Center for Sports

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BIOMECHANICS CINEMATOGRAPHY AND HIGH SPEED PHOTOGRAPHY

Session Chairman
Juris Terauds
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Light considerations for a biomechanics cinematography laboratory

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Abstract

Bio mechanics cinematography laboratories, by their nature require effective light levels, versatility in equipment selection and positioning, and intensity control by both mechanical and electrical means.

Comfort and safety is a prime consideration in the selection and placement of equipment. Because power services have to be rated for maximum utilization of lighting loads,electrical feeds must be sized for the maximum lighting load. The calculation of power factors based on the efficiency of continuous duty tungsten halogen lighting equipment require an understanding of the efficiencies of this equipment. By establishing the wattage per square foot demand based on maximum intensity values, the appropriate electrical services may be determined and distribution equipment properly selected.

Photographic lighting techniques designed to enhance the data quality are relatively simple and seldom used. Appropriate positioning and selection of lighting equipment to improve the image quality is discussed.

Introduction

Planning the lighting systems for a biomechanics cinematography laboratory is different than planning the lighting for a particular event. When you plan lighting for a given event, you solve the problems that are related only to that particular event. In planning lighting facilities for a biomechanics cinematography laboratory, you must plan for a series of varied events. For instance, a runner on a treadmill will basically be observed in one location as he moves on a treadmill. The same would be true of a subject riding a stationary bicycle. An athlete swinging a baseball bat would require a slightly larger area but he is still working in a very limited space. A runner moving over a prescribed course will occupy a greater spacial dimension and as a result, the planning for that type of an event will require more lighting and additional flexibility in the equipment planning.

A series of questions must be answered prior to planning the facility.

1. What type of data acquisition will be done in the facility. How complex will it be.

2. Over what area will the events take place in the facility. How much space must be allocated for the recording of the events.

3. What will the film and exposure requirements be. That is, what frame rates, exposure times, F-stops, and exposure indexes used be.

4. What camera angles will be used. If you are only going to film from one position, then you only need to light effectively for that position. Every camera angle will require its own set of lighting requirements. The lighting for each position must be planned in advance.

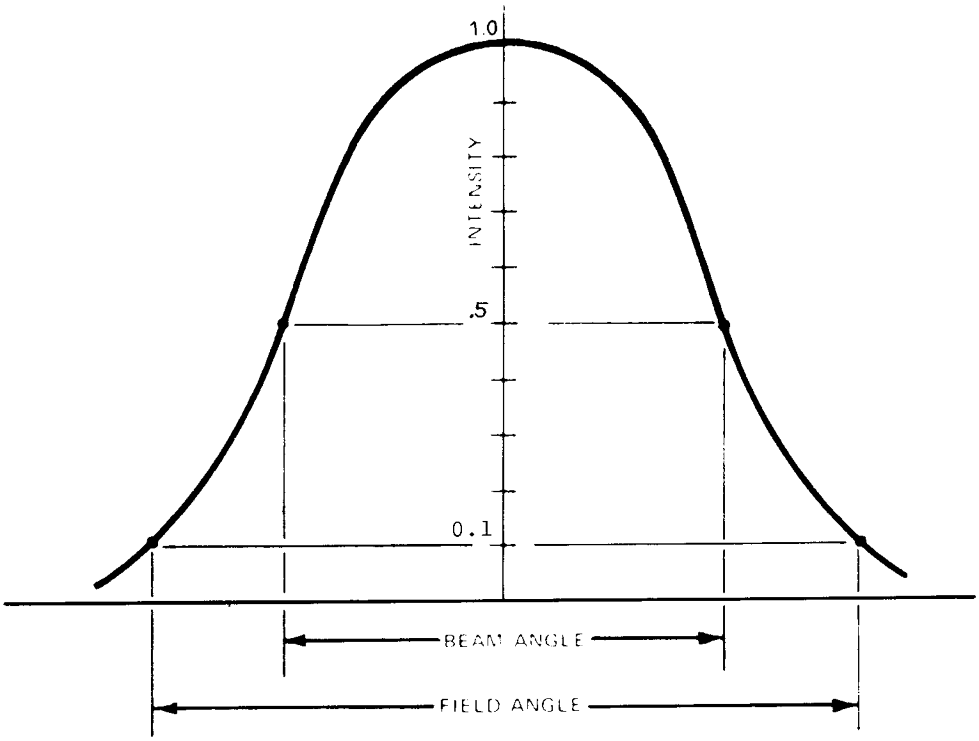
5. Once total lighting loads are calculated, that information should be provided to a mechanical engineer so that air conditioning loads can be calculated to keep the laboratory area at a comfortable level.

6. If very high lighting levels are to be used, consideration may have to be given to the use of filters to eliminate the infra red components from the light beams for improved comfort levels.

7. The power service requirements must be calculated on a full demand basis. For instance, if an installation requires a total demand of 200 amperes on a 3 phase 4 wire 120/208 volt feed, then that is the demand that must be planned for and a specifying electrical engineer should not be permitted to use a derating or diversity factor on that demand load. If you bring on a total of 600 amperes of tungsten lighting, and the service is undersized or derated for the demand, you are liable to trip your primary breaker on your power service and lose the lighting just when you need it.

The formula for calculating the size of the power service in amperage is 100% demand wattage divided by 120 volts. For a 120/208 volt 3 phase 4 wire feed, divide the total amperage by 3 to obtain the amps per phase. For 120/240 volt single phase 3 wire feed, divide total amperage by 2 to obtain the amperage per phase. And for a 120 volt single phase 2 wire service, the total amperage load equals the total amperage requirement.

Lighting equipment will not deliver all of its light output to your target area.



Generally, the performance of lighting equipment is specified in terms of beam angle and and field efficiencies. Beam angle efficiencies are lumen output of the equipment measured to 50% of center intensity values and as a result, represent 1 stop photographic performance. Field angle efficiencies represent performance measured to 10% of center beam intensities and while the field efficiencies of some equipment are attractive, they are misleading because of the losses incurred by the component of the light that does not reach the target area.

Typical beam efficiencies of continuous duty tungsten halogen lighting equipment based on lumens developed by the lamp versus beam lumens out of the lighting unit are as follows:

Fresnel Spotlights	4% to 18%
Average Efficiency	11% or 2.5 lumens per watt
Flood Lights	15% to 32%
Average Efficiency	23% or 5 lumens per watt
PAR-64 Lamps	20% to 36%
Average Efficiency	28% or 7 lumens per watt

Do not use field lumens for calculating your target area lighting levels unless the target area is extremely large. Then you can increase the efficiency factors by approximately additional 10% to 15%.

As an example of the impact of these efficiencies take a facility requiring a maximum of 2,000 footcandles over 50 square feet or 100,000 lumens and utilizing floodlighting with a beam lumen efficiency of 5 lumens per watt. Approximately 400 watts per square foot (2,000 footcandles divided by 5) would be required as a base power level. 400 watts per square foot times 50 square feet would provide a power base of 20,000 watts of demand power. Utilizing 2kW floodlights with 52,000 initial lumen input and 20% or 10,400 lumens out would require 9.6 or 10 units at 2kW each equaling 20kW of power.

By using production lighting techniques such as key, back, and fill lighting the 3 dimensional aspect can be enhanced to provide improved visual detail of the event. Careful consideration in the placement of power distribution equipment and lighting equipment will result in a clear definition of the facility requirements.

Using as a case history, a biomechanics laboratory for a major orthopedic hospital, we arrived at the following solution to the facility requirement.

A. Statement of Work

Illuminated area	6' x 24' or 144 FT^2
Frames Per Second	500
F Stop	3.5
Shutter Angle	72°
Exposure Index	400
Camera Angles	Lateral, Overhead, Frontal
Subjects	Athletes Running, Batting, Throwing

B. Power Calculations

Incident Light Level Required

$$\frac{25 \times 3.5^2}{400 \times 0.00040} = \frac{306.25}{0.1600} = 1914 \text{ F.C}$$

Total lumens = 2000 (1914 Rounded Up) x 144 FT^2

2000 x 144 FT^2 = 288,000 lumens for lateral lighting

C. Lighting Equipment

A luminaire called a 4kW Softlight with a large aperture that would provide uniform relatively shadow free lighting was selected. Its beam lumen efficiency ran approximately 30% delivering 32,000 beam lumens.

288,000 ÷ 32,000 = 9 fixtures at 4kW each

The 36,000 watts of load was controlled by 3 - 12kW dimmers for intensity control.

Overhead and frontal lighting was accomplished through the use of 3 additional 4kW softlights mounted over and slightly ahead of the runners' path of travel. The 3 - 4kW units were controlled by 1 - 12kW dimmer.

Back lighting power was calculated for an initial complement of:

3 - 2kW Fresnel Spotlights

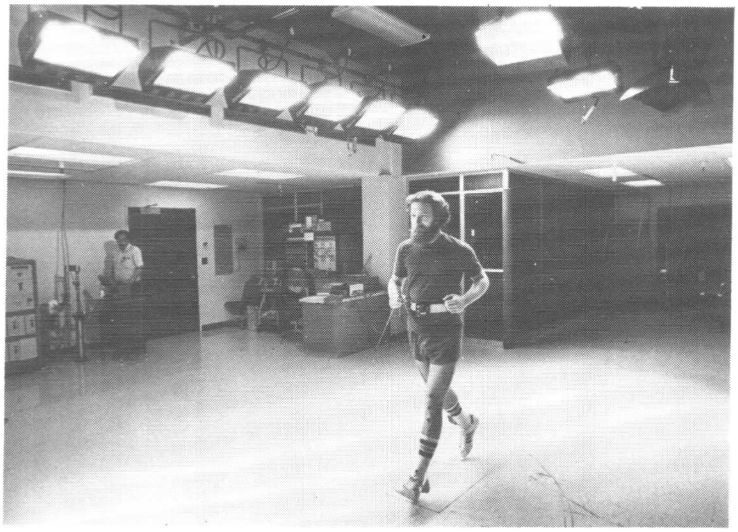
3 - 2kW spare circuits should the requirement for higher backlighting intensity levels arise. The Fresnels were selected because they provide a higher intensity variable spread beam of light that can be masked and controlled easily through the use of "barndoors" which permit the beam to be shaped and eliminate stray light that might cause flare problems in the camera lens. One 12kW dimmer was specified for control of the backlighting. The power totaled then 5 - 12kW dimmers with a service requirement of 166 amperes 120/208 3 phase 4 wire and was rounded up to a 175 ampere 3 phase 4 wire service.

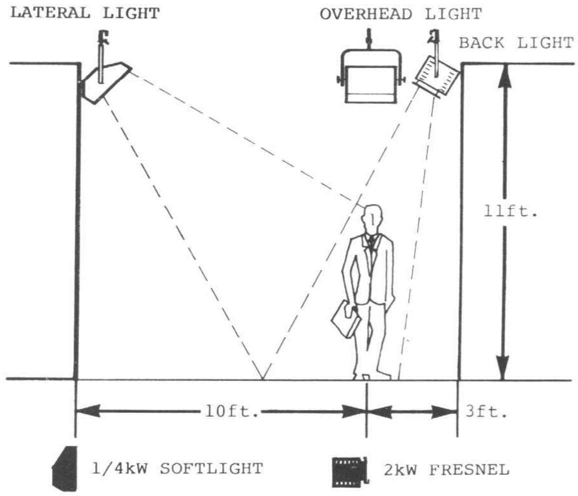
The dimming was provided to permit variable intensity levels for each of the 3 lighting elements to be established because considerations such as skin coloration, subject reflectivity, etc., have to be taken into account when photographing subjects. The variable intensity control permitted effective contrast ratios to be established between the 3 lighting elements.

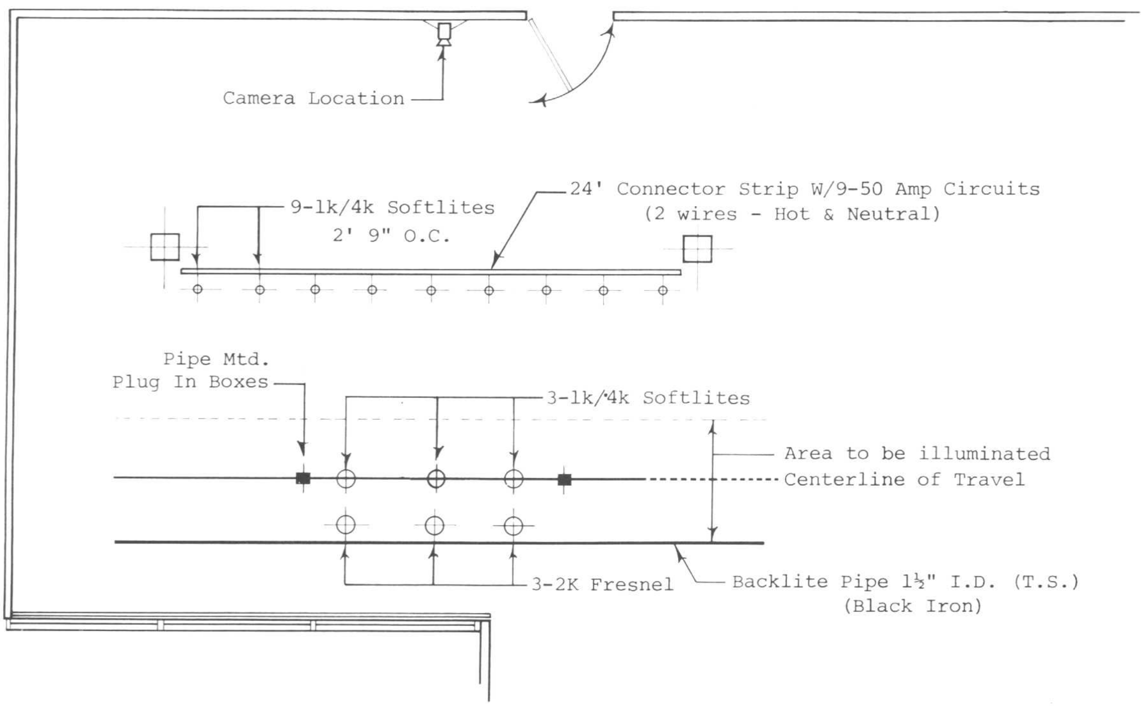
Three separate potentiometers were provided to permit the intensity levels to be set for each of the 3 main lighting elements. One master control potentiometer on an umbilical cord was provided to proportionally master the 3 individual potentiometers and to permit energizing of all of the lighting elements simultaneously as required.

The lighting equipment was powered through a distribution equipment network which consisted of a 24' x 4" x 4" prewired gutter with 9 - 50 amp circuits for the lateral lighting.

The overhead lighting was fed through 3 ceiling mounted plugging boxes, each with 1 - 50 amp circuit and the back lighting was fed through 1 - 20' connector strip with 6 - 20 amp circuits. All of these circuits in the distribution equipment were then routed back to the dimmer rack and wired to the appropriate dimmers. The entire system was phase balanced and rated for the full connected load.







The result was a very flexible facility in which a variety of biomechanic events could be photographed at varying frame rates and varying lighting conditions. The success of the installation was attributed to the considerations that were resolved early on in the project. By knowing the type of studies that were planned and the technical requirements, we were able to provide a cost effective highly flexible installation.

Interpretation of biomechanical data to a gymnastics coach

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Abstract

Several trials of many different gymnastics skills on various pieces of apparatus were filmed and the results were studied with the coach. The time to accomplish the entire skill as well as the time for each segment of the skill was important to the coach. He was also interested in angle of release or push-off and the path of the center of gravity. Lastly, graphs of velocities and accelerations of limb segments were revealing to the coach. Biomechanical analysis has helped him see why the performances were good; he is more interested in working with the investigator in all the events in gymnastics through the medium of cinematography.

The sport of gymnastics is undergoing rapid development; gymnasts all over the world are accomplishing increasingly difficult tricks in each event yearly. Although this is occurring at an alarming rate, actual biomechanical analysis of gymnastics skills is in its infancy. Because of the high risk involved in performing these tricks, teaching the underlying steps leading up to the trick is of paramount concern to the coach. Knowledge and understanding of biomechanical data based upon scientific principles is quickly becoming an asset to a good gymnastics coach.

At the University of Oklahoma, the men's gymnastics team is composed of national and world champions. Slow motion films at 48 or 64 frames per second were taken of many different skills on various pieces of apparatus and analyzed. The biomechanical data obtained from this analysis included temporal factors, the path of the center of gravity, linear and angular displacement and velocity.

Initially, the coach was shown the skill in slow motion. The marked joint centers were pointed out to him. He was told to observe the relationship among the body segments and then was asked if and how this helped him as a coach. He stated that the slow motion film verified some of his coaching techniques but contradicted other points, now that he could see what was actually occurring. Observing several gymnasts perform the same skill helped the coach see minor differences in performances. Important aspects of the skill were discussed including the angles of take-off, various styles of the tuck position and speed of movement. Most gymnastics coaches stand to the side of the performer or where the judges might be stationed to view routines so this coach was interested in the frontal aspect. This view gave him a different perspective of the skill. On the rings, for example, the gymnast performing the iron cross had had a shoulder injury. It was apparent from the frontal view that he was favoring the injured side because he was not totally symmetrical in his performance.

In addition to observing the actual skill, the coach was fascinated by the movements of the equipment of which he was not aware. The extraneous movements of the parallel bars when the gymnast released them for a trick was quite noticable. It was evident which gymnast used the flexibility and spring of the bars to his advantage as opposed to swinging in a rhythm which is counter to the movement of the bars. The coach surmised that this bar vibration could be the cause of the fear which gymnasts experience in the developmental stage when performing tricks where they must release the bars and then regrasp them.

The full-in back out is a double backward somersault with a full twist on the first flip. After observing the slow motion pictures, the coach compared the position of the shoulders at take-off of two subjects on a free body diagram and realized that the better gymnast had his shoulders over his hips whereas the lesser skilled gymnast had too much of a backward lean. This increased angle at take-off resulted in achieving less height. A composite drawing of the joint locations verified this point. Not only does the lesser skilled gymnast take off at a greater angle, he does not tuck much at all and has a lower trajectory as opposed to the better gymnast who takes off straighter, tucks not only sooner, but tighter, and attains greater height. A graph of the hip angle of each gymnast was shown to the coach. It revealed that the better gymnast took off at a lesser angle, or straighter, opened up briefly and then tucked tighter until the "kick-out" in preparation for landing. The lesser skilled gymnast took off at a greater angle, increased that angle and then attempted to tuck to gain angular momentum. He never did achieve as tight a tuck as the more skilled gymnast because the angular momentum of the upper body prevented him from tucking much at all with the lower body. Consequently, there was never a "kick-out" in preparation for landing. The coach then realized that the hint to "tuck more" was useless because the gymnast could not possibly tuck more in his position. The coach learned that he needs to tell the gymnast to take off straighter, to keep the shoulders more over the hips, which will allow for a better transfer of momentum and, therefore, greater angular rotation through a tighter tuck. Further discussion of the hip and knee angles of four gymnasts revealed that although the better gymnasts had good rotations, the best gymnast had the smallest hip and knee angles, allowing him to perform the full-in back out correctly and most efficiently.

Five gymnasts were filmed while performing the double backward somersault (DBS) which was shown to the coach. He knew that these men were excellent tumblers but he was not sure of all the characteristics until he saw the slow motion film and analysis. He observed the angle of takeoff for each gymnast and the height achieved by a marked backdrop. These performances all coincided with what the coach defined as quality, but the subsequent analysis, including the path of the center of gravity, angular displacement of body parts, and the temporal factors showed him why they were good performances. The path of the center of gravity showed the coach that all of the gymnasts performed the DBS approximately two feet above their standing height, but the best tumbler reached a higher elevation. This finding suggested to the coach the recommendation that a good tumbler should be able to complete one somersault two feet above his standing height before advancing to a DBS. He saw that the better tumblers did not throw their arms up and backward at takeoff, as many coaches suggest they do, but "blocked" them at forehead level, transferring this momentum to the body. Another point shown to the coach was the head position at takeoff and during each rotation. Many coaches believe that the head is thrown backward to assist in rotation. The analysis, however, showed that the head is never far from the vertical alignment of the trunk, being slightly forward at take-off and slightly backward at the beginning of each rotation. The second rotation was always faster than the first. The coach studied composite tracings which showed that the first somersault does not need to be completed during the ascending phase of the flight in order for the DBS to be a good performance but it would benefit both the quality and safety of the performance if it were.

According to the coach, the performance of the peach hand is not performed exceptionally well by many United States gymnasts. The peach hand is a trick on the parallel bars where the gymnast executes a pike or "basket" below the bars from a standing position, then kips to a handstand above the bars. Having access to a 1976 Japanese Olympian team member, a film analysis was done comparing his peach hand with one performed by a University of Oklahoma team member. First, the slow motion films revealed to the coach that although they appeared to have the same velocity below the bar, the better performer somehow carried that velocity with him to complete the trick above the bar. Further graphic analysis of hip angles and velocity showed the coach that the better performer had a tighter tuck, allowing him to create that velocity to get above the bar more efficiently. An increased velocity allows the gymnast to hold onto the bars longer, which is better, before releasing them and regrasping the bars to push up into the handstand. The coach stated that what was important to know was how to create that velocity below the bar to perform the trick correctly. The path of the center of gravity showed the coach that the better performer had less horizontal movement and a smoother path whereas the lesser skilled performer traveled horizontally on the bar and his center of gravity path was erratic. Paths of the hip and shoulder joints were plotted for both gymnasts, and again, the better gymnast was considerably smoother in all parts of the body. The circling of the shoulders and the speed generated to move them above the bars has to be the most important aspect of the peach hand. Tied closely to that is the open-close-open action of the basket and the extension from the basket. The open-close-open action of the basket and the extension from the basket forms the circling motion of the shoulders and generates the speed necessary to move the shoulders above the bars to complete the circle properly. The better performer completed the peach hand in 2.94 seconds, spending 64% of that time below the bar, whereas the lesser skilled gymnast completed the trick in 3.36 seconds and spent 41% of that time below the bar. The coach was able to see that his gymnasts needed to be told to use the swing and pike to obtain the velocity to get into the handstand position efficiently and without traveling.

An analysis of three Japanese gymnasts performing the single backward somersault, the double backward somersault and the triple backward somersault off the high bar was discussed with the coach. He was amazed at two important findings. First, the time to perform each kind of somersault was approximately the same. Also, the angle of release of the bar to perform each kind of somersault decreased as the number of rotations performed increased. The conclusions from this analysis showed the coach that regardless of the number of rotations performed, only so much time is available to execute the trick, and that since the bar must be released sooner, resulting in a lower trajectory, the gymnast must generate considerable speed from the giant swing and tuck tighter as the number of rotations increase.

The coach was impressed with the analyses and is willing to have many other skills filmed and analyzed. He stated that on the high bar, for example, there are four or five high risk moves that a gymnast must perform to be in the elite class. These tricks can be dangerous if a coach does not understand the mechanics of them. He was pleased with one of his gymnasts who analyzed himself compared to others on a particular trick and greatly improved his own performance. Athletes as well as coaches can benefit from biomechanical analyses.

In conclusion, establishing contact with the coach is the first step toward a mutual working relationship. Explain to the coach the various aspects of biomechanical analysis and how they might assist him in his coaching. Take some film footage of a skill in a sport, preferably in a scientific setting for credibility, analyze it, and discuss the results with the coach. The findings should be meaningful to the coach so that he/she can make sense out of the graphs, charts, and diagrams if they are kept simple. The University of Oklahoma coach as a good "sense" of what constitutes a good performance but biomechanical analysis has helped him see why the performance is good; it has helped him look at each skill in a different perspective. He stated that very few coaches read highly technical analyses. Since he is an outstanding gymnastics coach, perhaps we should listen closely. Keep the analysis simple, easy to understand and meaningful. Explain carefully each aspect of the analysis and work with him/her to find reasons for the results. This appears to be the best way to "bridge the gap" between researcher and coach.

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