METHODOLOGIC CONSIDERATIONS FOR QUANTITATIVE EVALUATION OF PADDLING

Robert SHAPIRO and Jay T. KEARNEY

University of Kentucky
Health, Physical Education and Recreation Department
215 Seaton Building
Lexington, Kentucky 40506

No one can dispute the increased role that sports science and particularly biomechanics is currently playing in the development and training of elite athletes. Recently, organizations such as The United States Olympic Committee and Sport Canada have sponsored research and performance enhancement projects that have been published or presented on many Olympic sports including but not limited to track and field (Gregor et al, 1985), swimming and diving (Miller and Munro,1985), skiing (Martin, 1980), weightlifting (Garhammer, 1985) and gymnastics (Dillman et al, 1985). At the same time that interest and support for these types of studies has increased, sports science has also undergone a technological explosion. This is readily apparent in the area of image processing. As the era of automated digitizing becomes reality, all the projects that have been put off or neglected because of a lack of manpower or time can now be undertaken.

However, before one undertakes the ultimate analysis of flatwater canoeing or kayaking, lets review two previously completed biomechanical studies and examine their methodologies and the variables investigated. We can then examine these methods and discuss advantages, disadvantages, recent improvements, etc. Plagenhoef (1979) published a biomechanical analysis of both flatwater canoeing and kayaking based on nine years of data collection. His analysis was based upon films taken both during practice and competition. The subjects ranged from good to world class paddlers. Plagenhoef used both spring driven and motor driven 16 mm cameras. Frame rates ranged from 64 to 100 frames per second. This investigator's methods included utilizing stationary cameras, cameras moving at a velocity similar to the boats being filmed, and panning the cameras. The multiplier for the analysis was a length measured on the boat being analyzed.

The variables Plagenhoef ultimately selected for analysis were:

1. "Stroke times and a four-part division of the total stroke.
2. Paddle angles and body positions.
3. Tracings of the paths of joint centers.
4. Tracing the absolute motion of the paddle under water." (page 446-447)

Plagenhoef ruled out other kinematic and kinetic variables as too complex, costly to analyze and not meaningful to the coach and performer.

Mann and Kearney (1980) examined the biomechanics of the kayak stroke. These investigators utilized a motor driven camera operating at 70 frames per second. Paddlers were filmed after being given 40 m to accelerate to racing speed. The field of view was 12 m wide and the scale factor was obtained by filming a meter stick in the field of view. Timing was obtained by filming a digital clock subsequent to other filming.

Computer analysis of the digitized data for this study examined the following variables:

1. Boat displacement, velocity and acceleration.
2. Whole body and body segments center of gravity displacement, velocity and acceleration.
3. Joint center displacement, velocity and acceleration.
4. Paddle motion.
5. Timing of three paddling phases
   a. entry
   b. vertical
   c. exit

In light of these two studies, lets briefly review the requirements to obtain an objective two dimensional record of a performance.

1. Assume that activity to be analyzed occurs in two dimensions.
2. Camera is set up so the film plane is parallel to action plane and the camera is level.
3. Distance scale factor is available
4. Timing system, either internal or external is required.
5. Appropriate field width and image size obtained.
6. Appropriate camera speed and exposure time selected.
7. If possible subject is marked and wearing minimal amount of clothing.

For analysis of the data:

1. Appropriate points selected for digitization based upon variables selected for analysis.
2. Correct information, such as body segment data selected for analysis.
3. Appropriate smoothing techniques applied.
4. Appropriate mechanical solution utilized.

Looking at these in detail now, let us see how they apply to the specific case of paddling. Our first assumption is that the movement occurs in a single plane. It would appear that a significant portion of the stroke, while the paddle is in the water, occurs in the saggital plane. This is more so the case with the canoe stroke. The kayak includes more upper body rotation. We can minimize errors due to movement in and out of the plane by using a telephoto lens and moving a large distance away from the subject. A frontal view may also be possible. This view however, presents more difficulty as camera-subject distance and focus change continually.

Camera set up should not be a problem providing the area along side the race course is low enough to set the camera up and view the paddlers without having to tilt the camera down to the water. Using the boat or portion of the boat as a distance scale is an advantage. This can enable a linear measurement from the frontal view, such as distance of the hands from the middle of the boat during various phases of the stroke. It also enables you to film boats in different lanes of the race if a competition is being filmed. If a number of different lanes are to be utilized a zoom lens is recommended. This will enable you to adjust image size for the different lanes. If this type of data collection is desired it would be best to predetermine the focal lengths and focusing distances to avoid unnecessary time delays while actually filming.

Assuring accurate time with most high speed cameras is not difficult as they come with internal timing systems. If one is not available an external clock will work. In this case a clock in the field would not be possible so a clock would need to be filmed prior to or after the filming session. If a spring driven camera is utilized always wind the camera between trials to keep spring tension and hopefully frame rates constant during data collection. Timing techniques such as dropping an object through a known distance are not recommended as they are subject to digitizing error.

The most difficult problem facing the investigator in this situation is obtaining field width and subject size that meet analysis requirements. The field width is governed by the distance the canoe or kayak travels during one stroke. Subject size, in order to minimize digitizing error should be approximately half the image size. The height of a 16 mm frame is 7.6 mm, therefore, if your subject is 6 m in height, that length should project an image at least 3.8 mm high on the frame of film. For example, in Mann's and Kearney's study a 25 mm focal length lens was utilized and the camera set up 20 m from the subject. From the basic lens equation we can obtain field width (Fw)

$$Fw = (OD * W)/Fl \tag{1}$$

where OD is the lens to subject distance, 20 m, W is the width of a 16 mm frame, 10.5 mm, and Fl is the focal length of the lens, in this case 25 mm. Making the appropriate substitutions in equation 1, Fw is 12 m. To obtain image height (IH) we rearrange the lens equation

$$IH = (Fl * SH)/OD \tag{2}$$

where Fl and OD are used previously defined and SH is average subject height, reported by Mann and Kearney to be 1.79 m. Substituting for the appropriate values IH is then 2.2 mm. This represents only 29% of frame height. One then has to determine if this is the best case that can be obtained or where compromises can be made to obtain acceptable subject size. One compromise is to pan or move the camera. This greatly increases the problems of analyzing the data. If in the case presented, the camera was positioned to obtain minimal acceptable subject height, the field width would be reduced to 5 m. This is certainly not a reasonable value. The problem with the small image size is the error introduced in the digitizing procedure by the inability to locate specific markers. While the ability to digitize markers is always a problem, the smaller the image, the greater the effect a small error has on a resulting calculation. A possible solution is to set up two cameras with overlapping views. If these cameras are properly calibrated and synchronized then the information obtained from each view can be combined for an anlysis of the complete stroke.

Another problem is selection of appropriate frame rate and exposure time. Winter (1979) indicates that sampling at too low a rate can cause alaising errors. Generally, according to Winter, one should sample, at a rate "at least twice as high as the highest frequency present in the signal itself". (page 28) In most cases, however, investigators over estimate required rates. While this does not represent a sampling error, it does substantially increase time and cost of analysis. The problem with exposure time represents a manipulation of the frame rate and the shutter of the camera. The frame rate is basically determined by sampling considerations. The exposure time is selected such that no blurring occurs while the frame is exposed. Kodak (1975) suggests that if the image of the moving object projected on to the film plane moves less then .051 mm then the image will appear without blur. To calculate this an estimate of the maximal linear velocity to be observed is needed. This is usually the velocity of an extremity or implement. The distance (d) traveled by this body during one frame is then determined by

$$d = v*t \qquad (3)$$

where v is the velocity of the part and t is the exposure time. The time required can be obtained from the following equations:

$$d = (OD*IS)Fl \qquad (4)$$

where OD and Fl are as before, IS is the image size, in this case

$$t = (OD*IS)/(Fl*v) \qquad (5)$$

Mann and Kearney report maximal horizontal velocities for the wrist as high as 8.2 m/sec, estimating vertical velocity at that time to be 5 m/sec would yield and wrist velocity of 9.6 m/sec. The exposure time required for this situation to prevent blur is then .004 seconds. At 70 fps, a 90 degree or 4 factor shutter would be appropriate. The only element that would prevent this exposure time from being utilized is the amount of light required to expose the film. This depends on the film speed and available light. Generally, sunlight will easily support exposures up to .0004 sec for film with an ASA of 250.

If possible, the subjects and boat should be marked. Anatomical landmarks, usually representing body joint centers are selected. However, this is not always possible. Again it is important to have a large image which will enable the person digitizing to select appropriate points for analysis. If the subject is to be marked, choose appropriate points. If a frontal view is selected, marking the paddler on the saggital plane will not be helpful. Be well aware that digitizing is an art as well as a science and a digitizer who is familiar with the movement and with human anatomy will have a great advantage. Often points are hidden or not clear and their location is determined by the digitizer. The new automated systems predict missing points by calculating trajectories. An especially difficult object to view is the blade of the paddle after immersion. The location of the blade can be estimated by the position of the shaft, but due to bending is not going to be accurately placed. This critical phase of paddling must be evaluated with other measurement techniques.

In addition to dealing with these problems make sure you have a steady tripod, light meter, level, power source, extra take up reels and some forms to record information. Also be sure to have the appropriate film, indoor rated film will give you an embarrassingly orange tinted picture if used outdoors without a filter. Screw drivers, allen wrenches and tape are also a requirement.

Once the film is shot and processed the hardest part of the project begins. Coordinates for appropriate points are digitized and stored on the available computer system. Then the previously selected variables are calculated for analysis. In both the Plagenhoef and Mann and Kearney studies linear displacements were determined. The horizontal and vertical coordinates can be plotted against time or each other depending on the type of information desired. Most smoothing techniques will provide a reasonable displacement plot. Often just drawing sequential stick figures can be helpful to the coach and athlete. The angular displacement of different body segments and the paddle can also provide important information to the coach and athlete.

The calculation of angles is in a sense simpler than linear values. Because the angle is independent of the scale, front or rear views are appropriate for calculating angular position even if a scale factor is not present. We most often deal with two types of angles. The angle formed by the shank and thigh is considered a relative angle (Figure 1). It is independent of the orientation of the legs in space and enables us to see the motion of the shank about the knee joint. To

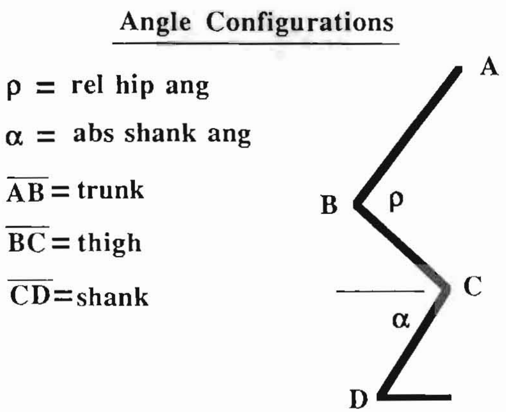

FIGURE 1. ANGLE CONFIGURATIONS

calculate this angle we use the law of cosines:

$$\Theta_i = \text{ARCOS } (\bar{a}^2 + \bar{b}^2 - \bar{c}^2)(2\bar{a}\bar{b})) \quad (6)$$

where Θ_i is the relative angle at the i^{th} joint, $\bar{a}$ is the length of the proximal segment, $\bar{b}$ is the length of the distal segment and $\bar{c}$ is the distance from the proximal end of a to the distal end of b. Before ascribing motion at the joint based on the calculation be sure to ascertain which segment is fixed and which is moving.

The second angle that can be calculated is an absolute angle. (Figure 1) In this case, the angle formed by the segment and a fixed reference, either a horizontal of vertical line through the segment is investigated. Utilizing the cartesian coordinate system established during digitizing, the absolute angle, in this case with reference to the horizontal axis, can be determined as follows:

$$\Theta_i = \arctan ((X_p - X_d)/(Y_p - Y_d)) \quad (7)$$

where Θ_i is the absolute angle of the segment, X_p and Y_p are the coordinates of a proximal part for the segment, X_d and Y_d are coordinates or the distal portion of the segment. This angle gives the angular position of the segment relative to a fixed external reference. The change in this angle may be due to a movement of the segment, movement of other parts of the system, or in a combination motion. An interesting way to examine the relationship between segments is to utilize angle-angle plots in addition to typical angle-time plots. The angle-angle plot allows the evaluation of action at one joint with respect to the action of another.

In a situation where an athlete moves in a moving object, as in canoeing or kayaking, the choice of a reference frame becomes important. The performance can be looked at with respect to the motion of the boat. While this can provide useful information about the action of body segments, it may also be misleading. The action of the paddle will be seen as continually moving. If a reference is selected outside the boat, it can be more clearly seen that the paddle remains almost stationary in the water and the boat is pulled past. In actuality the bottom hand does not move backward during the power phase. Therefore, just as one chooses the bar for a reference when looking at arm action in a pull-up, the references for examining the canoe or kayak stroke must be based on the information desired.

While it is not the purpose of this paper to present details of complex biomechanical variables it is important to note several items. If velocities, accelerations or kinetic variables are desired, the care in setting up the data collection increases. Selection of a data smoothing technique becomes critical. Many articles have been written (Wood, 1982; Zernicke et al, 1977; Winter et al, 1974) that discuss the techniques and problems of smoothing data from cinematographic analysis. The bottom line is in most cases one particular smoothing technique is not always best. The one chosen depends on the type of motion, the degree of smoothing required and constraints associated with the technique. If one is familiar with the expected acceleration curves, the choice of an appropriate smoothing technique can be enhanced.

Another factor to consider when calculating more complex variables is the use of appropriate anthropometric data. Mass, moment of inertia and segmental weights are key factors in kinetic analyses. Input of inappropriate values make the analysis invalid. Dempster (1965) and Clauser et al. (1969) are typical sources for this type of data.

As indicated earlier, technological advances are making the anlysis of complex biomechanical variables more readily accessible. Three-dimensional analysis is becoming more and more feasible. In most cases, the Direct Linear Transformation (DLT) (Abdel-Aziz and Karara, 1971) is the basis of techniques now being utilized for film analysis. A major advantage of this technique is it allows tremendous freedom in camera positioning. A difficulty will be the establishment of a set of control points needed to calibrate the experimental space. Another technique that is impacting greatly on analysis procedures has been the use of electronic media. Video analysis provides an immediate image of the performer as well as an electronic signal that can be grabbed by a computer for immediate analysis or stored on tape or disc for subsequent analysis. Utilizing this technology with the DLT provides on line three dimensional analysis. The problem with the video system is the current need to provide the computer with high contrast points to follow. In a practice setting reflective markers and filming lights can be utilized. However, the range the markers and lights are effective is limited and this would be a difficult system to implement in a competitive situation. Other systems utilize light emitting diodes which when placed on a subject can also provide immediate feedback as to location of the various landmarks. In this type of system you do not however, get a true visual image, but you can generate figures on the computer. An important fact to realize about these types of methods is that it is the manual digitization process that is being eliminated. You must still have appropriate software to do the biomechanical analysis required, be it 2-D or 3-D.

Currently, the availability of three dimensional data collection techniques for either cine or video systems is fairly wide spread. With every lab having access to computers the ability to calculate three-dimensional kinematic and kinetic values is easily achieveable. Based upon this author's experience with professional athletes, it is important to present research findings to the athlete and coach in a meaningful manner. While discussion of Euler angles and three-dimensional transformations may provide critical details to the biomechanician, angle of the paddle as it enters the water, time of stroke or some other simply determined variable may be more critical to the coach or athlete.

A useful correlate to cinematographic analysis is often the use of EMG. Logan and Holt (1985) report on the results of an EMG analysis of the kayak stroke. The improvements in telemetry capabilities make the use of EMG a useful tool. Care must be taken to synchronize EMG with the film or video record.

Now, how can we apply this to the canoe/kayak situation? An important consideration to bear in mind is the conclusion Plagenhoef draws about competitive and non-competitive setting for data collections and the need to interpret those data from a less than top competitive situation carefully. It would be extremely unusual for an elite athlete to provide championship form and effort in a non-competitive situation. Given the desire to film in competition, limits on types of variables and amounts of information collected must be considered. This point cannot be overemphasized.

Once the methodology has been established one can then begin to investigate appropriate variables for example:

a. body position relative to blade/shaft position at
   1. contact
   2. emersion
   3. vertical
   4. exit
b. blade/body and boat interactions
c. effective muscles during the stroke
d. timing of movement patterns
e. optimatization of stroke mechanics

In this presentation we have overlooked another complete area of interest. That being design of boats and paddles. The design area presents another exciting and interesting area for research. At some time in the future we will place the optimal paddler in the ultimate boat.

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