BASIC BIOMECHANICS APPLICATIONS FOR THE COACH

Anne E. Atwater
Department of Physical Education, University of Arizona
Tucson, Arizona 85721, U.S.A.

During the past ten years, the term "biomechanics" has become quite well known to the American public, and particularly to coaches and athletes. To many, it represents a miraculous science that can, with the aid of computer generated stick figures on a video screen, decipher the faults of a performer and identify the key technique modifications that will produce improved performance. Indeed, because of publicity regarding exciting developments on the forefront of biomechanics research, consumers may have been led to expect -- as a rule -- that most biomechanists can easily provide not only rapid data collection, but also instant diagnosis, analysis, and correction of faults. I would like to propose that we strongly consider the need to educate the public, especially coaches and athletes, to look beyond these publicized "WOW" factors of sport biomechanics and more realistically appraise contributions and limitations of this fast-growing science.

One topic that I believe deserves more attention than it has heretofore received by sport biomechanists is that of fault identification, more frequently termed "error detection". As I address my remaining comments to this topic, I will probably do more to raise questions than I will do to provide answers.

What is a fault? Are you confident that, in a given sport skill performance, you would recognize a fault when you saw one? By what criterion is a particular aspect of technique judged to be a fault? Furthermore, can we easily see faults? These questions are all deserving of a considerable thought, discussion, and investigation.

People who claim that they can observe a motor skill and detect faults are most likely referring to rather gross technique errors that can be seen with the naked eye, in beginning level performers, as opposed to more subtle movement errors of highly skilled athletes that may even be difficult to observe from high speed film. Also, these experts most likely have in their "mind's eye" a mental image of an ideal form to which the observed performance will be compared. In some of the examples which I will present, I think you will see that the criterion of ideal form, as pictured in the mind, can sometimes itself be faulty. Even in coaches and top-level athletes, the perception of ideal technique does not always conform with reality.

One of the main hazards of identifying faults as deviations from ideal form is that there is rarely one form that is ideal for every performer. Even the best athletes may differ, one from another, and some may have forms that are clearly less than ideal. Until we have considerably more biomechanical data obtained from research on a fair number of outstanding athletes, we will not be able to confidently describe the amount of technique similarity and variability that exists among these athletes.

21

Perhaps the best way to prepare for an analysis that would encompass the detection of technique errors is to first identify clearly the result or desired outcome of the performance. For example, time, height, or distance are the performance results in most track and field events. Failure to achieve a good result would indicate either that technique faults existed in the performance or that physical or mental attributes of the athlete needed improvement. Next, the mechanical factors which produce the result can be determined. Jim Hay, in his biomechanics texts (Hay, 1978, 1982) has formalized the theoretical model on which this mechanical analysis method is based. With this approach, the science of biomechanics can help the coach to identify errors as deviations from the mechanical model and can improve the coach's ability to locate the causes of various faults.

Evaluation of an athlete's performance, in comparison with a mechanical model, still involves making observations of the technique used and making judgments about the extent to which the technique can or should be changed to improve the performance result. Pertinent to this process are data from research, where available, concerning the kinematic and kinetic aspects of the technique employed by athletes who achieve outstanding performance results.

In the attempt to quantify and better understand the biomechanical factors associated with successful performance of throwing and running skills, I have focused my research on the kinematic analysis of basic components of these skills. Some of the analysis procedures and illustrations as well as some of the findings of this research have proved to be of interest to coaches and will receive focus in the remainder of this paper.
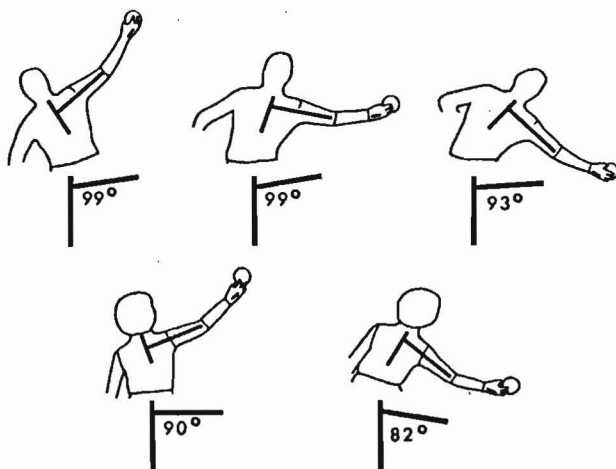
RELEASE POSITION IN THROWING

In the analysis of throwing skills, focus on the release position has clearly revealed the technique factor that is primarily responsible for determining release height. This factor is the amount and direction of lateral trunk inclination just prior to release. The influence of lateral trunk lean on height of release relative to head level is better illustrated when the same subjects are asked to throw using different release heights. Notice in Figure 1 that the angle between the upper arm and the vertebral column remained approximately 90 degrees, $\pm$ 10 degrees, for overarm and sidearm throws. However, the ball release height ranged from well above the head to below waist level.

It is possible for a highly respected professional athlete to incorrectly perceive the technique he uses to vary ball release height. Bob Shaw, in his book on baseball pitching (Shaw, 1972), demonstrated in photographs what he believed to be the adjustments necessary to produce an overarm throw and a sidearm throw. His adjustments consisted primarily of shoulder joint motion in the frontal plane which positioned the upper arm either above the shoulder line for an overarm throw or below the shoulder line for a sidearm throw. However, he apparently failed to study the photos of his own pitching delivery included later in the book. These photos showed that his trunk lateral inclination and shoulder tilt were directed away from the throwing arm to produce an overhead release, and that his upper arm remained approximately in line with his shoulders.

Some pitchers change their trunk lean and ball release height when they throw different types of pitches. In Figure 2, the fastball and the curve pitches were delivered from the stretch position, that is, without a windup. This simple illustration, prepared from film tracings, shows that a batter might be able to detect the greater trunk lean

and higher release for the curveball and might thus predict the type of pitch to be thrown. Other pitchers, such as Nolan Ryan whom I filmed in 1977 during spring training (Figure 3), have almost identical release positions, except for the grip on the ball, when throwing different types of pitches.

RELEASE POSITION – THROWING

Figure 1. Rear view of overarm and sidearm throwing release positions for two subjects.

Data presented in graphic form (Figure 4) show the relationships between trunk lean (bottom) and release height above head level (top) for five different pitchers throwing several types of pitches from both the windup and the stretch positions. Notice, in general, the consistency within some pitchers (particularly Subjects TJ, JK, and CH), regardless of the type of pitch thrown. However, for the two pitchers at the right (Subjects SW and JR), the curve balls were released higher and with greater trunk lean than were their other pitches. Such deviations from a pitcher's "normal" release position may clearly reveal to a batter the type of pitch to be thrown.

The careful selection of a combination of photos, film tracings, and data can thus be used as a set of evidence to clarify components of technique for coaches and athletes. In this case, examination of the relationships between trunk lean and release height allows a better understanding of the means by which a pitcher like Sandy Koufax achieved such an "extreme" overarm delivery. Understanding of this basic relationship is important for coaches at all levels, particularly Little League. I have frequently heard coaches yell at pitchers saying, "Don't throw sidearm, throw overhand." Yet, they rarely tell the youngster how to achieve the overarm delivery.
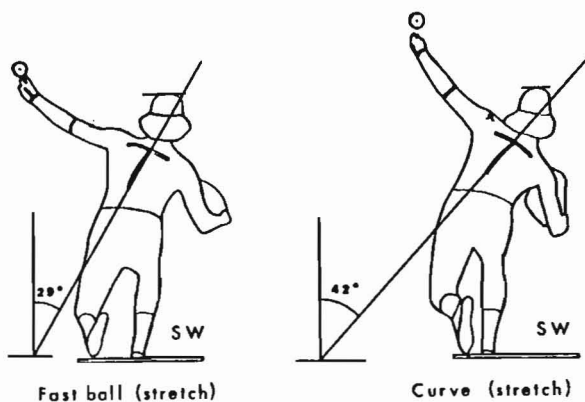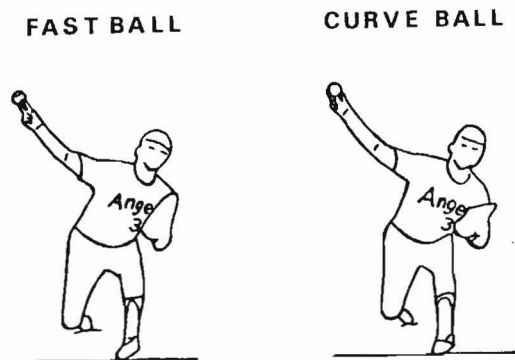
BALL RELEASE (rear view)

Fast ball (stretch)   Curve (stretch)

Figure 2.   The influence of lateral trunk inclination on ball
release height.

FAST BALL   CURVE BALL

NOLAN   RYAN   3-21-77

Figure 3.   Ball release position.

PITCH RELEASE HEIGHT

Figure 4. Ball release height (top) and lateral trunk lean (bottom) for pitches thrown from the windup and stretch positions.

STRIDE LENGTH IN BASEBALL PITCHING

Another aspect of throwing that deserves clarification, from a biomechanical point of view, is that of stride length in pitching. An investigation of this topic was conducted in 1979 and presented as a master's thesis by Lyndon Schutzler, working under my supervision at the University of Arizona. No evidence was available in the literature to quantify the actual stride distance employed by pitchers of different heights throwing different types of pitches. Also, the stride distances that a coach might refer to as "overstriding" and "understriding" had not been defined. These latter two conditions have frequently been referred to as "faults" causing pitches that are too high or too low. Yet, no one had determined the extent of variability in stride length either within or among pitchers so that excessively long or short strides could be identified and corrected.

The purpose of Schutzler's (1980) study was to quantify the stride length of major league, triple A minor league, and college varsity pitchers during a game situation. A total of 58 pitchers, approximately equally divided among the three groups, were filmed from a side view at a camera speed of 12 frames per second. The number of trials for each pitcher ranged from 7 to 22 and included pitches of different types thrown with both the windup and the stretch deliveries. A Jugs Speedgun was used to record the speed of the pitch during each filmed trial. The stride length measured from the film was defined operationally as the distance in feet from the front edge of the pitching rubber to the heel of the stride foot. In order to make comparisons among pitchers of different heights, stride length also was expressed as a percent of the pitcher's height and as a percent of his leg length measured from the greater trochanter to the sole of the shoe.

The results of this study provided answers to several basic questions.

Question 1: Are there differences in stride length between fastballs thrown from a windup compared to fastballs thrown from a stretch delivery? It was first determined that no significant difference in ball speed existed within any of the three groups of subjects when fastballs were delivered using a windup versus a stretch delivery. Likewise, no significant difference was found within any of the three groups in stride length relative to height, or in stride length relative to leg length, when fastballs thrown from a windup were compared to those thrown from a stretch delivery.

Question 2: Is there a significant difference in the average stride length for the three fastest pitches of each subject compared to his three slowest pitches, regardless of the type of pitch (i.e., curve ball, slider, fastball)? For all 58 subjects analyzed collectively, no significant difference was found in stride length expressed either in relation to height or in relation to leg length, when a pitcher's fastest pitches were compared to his slowest pitches. That is, the pitchers did not stride farther for their fastest pitches than for their slowest pitches.

Question 3: Is there a significant difference in stride length between the 15 fastest pitchers (regardless of the group to which they belong) and the 15 slowest pitchers? For this analysis, the 15 fastest and the 15 slowest pitchers, from among the total of 58 pitchers, were identified based on the average of their three fastest pitches, regardless of the type of pitch or the type of delivery. The average ball speed of the 15 fastest pitchers was 91.3 mph (40.8 m/s) compared to 83 mph (37.1 m/s) for the 15 slowest pitchers. Stride length tended to be longer for the faster pitchers than for the slower pitchers, but this difference was significant ($p < .05$) only when stride length was expressed relative to leg length rather than in relation to height.

On the basis of this study it was possible to conclude that, among pitchers, there was a tendency for longer strides to be taken by faster pitchers. However, within pitchers, stride length was not longer for a subject's fastest pitches compared to his slowest pitches or for pitches delivered from the windup versus the stretch position. An additional outcome of this study was its utility at the applied level. Data on the mean and variability of relative stride lengths could be used to help a coach define either a rather stringent range within which stride length should fall (X = 85.8 % of height, + 1 s.d. = 4.2 %; or, X = 163.7 % of leg length, + 1 s.d. = 8.9 %), or a more lenient range within which stride length could be considered "normal" (same X, + 2 s.d.). A coach should easily be able to determine a pitcher's stride length by measuring the distance between the front edge of the pitching rubber and a mark made in the dirt by the heel of the striding foot. For pitchers whose fastball velocity exceeds 80 mph (35.8 m/s), the above ranges could then be used as guides to the coach in identifying overstriding or understriding.

KINEMATICS OF SPRINTING

During 1978 and 1979, I participated with other researchers in studying physical and performance characteristics of male, national-class sprinters who were invited to attend sprint camps sponsored by the USOC Development Committee. The start of a 100 m sprint and several strides at mid-race for a total of 24 sprinters were filmed and subjected to kinematic analysis. While further analysis of these films is ongoing, preliminary results have been reported elsewhere (Atwater, 1980). Selected findings that may be of interest to coaches are presented here.

Sprint Start

In the first four strides (steps) taken by the sprinters out of the starting blocks, the average horizontal velocity of the center of gravity increased from zero to 7 m/s. By the fourth step, the toe distance from the starting line was an average of 4.5 m. An increased stride (step) length, rather than a faster stride (step) rate, was judged to be the means by which these sprinters attained their maximum speed in the 100 m sprint. The basis for this judgment was the finding that stride length increased while stride time, and therefore stride rate, remained essentially the same during the first 6 m and from 30 m to 60 m from the starting line (Figure 5). Of course, at the start, more time per stride was spent in the support phase (75% of stride time) than in the flight phase (25% of stride time). By mid-race, the percentage of stride time spent in flight had increased to approximately 55%.

Mid-race Sprinting

For the 24 sprinters in the 1978 and 1979 groups, the relationships were examined between stride (step) velocity and several stride variables (Figure 6). The only relationships reaching significance were stride time, and in particular, the portion of the stride spent in support. That is to say, for the fastest sprinters, the support portion of stride time was shortest. Sprinting speed seems to be dependent on producing a larger force against the ground in a shorter time of support. The implications of these findings for coaching would suggest that either the neuromuscular properties of the faster sprinters are superior to those of slower sprinters, or that additional strength conditioning might be useful to improve the ability to explosively apply force against the ground.
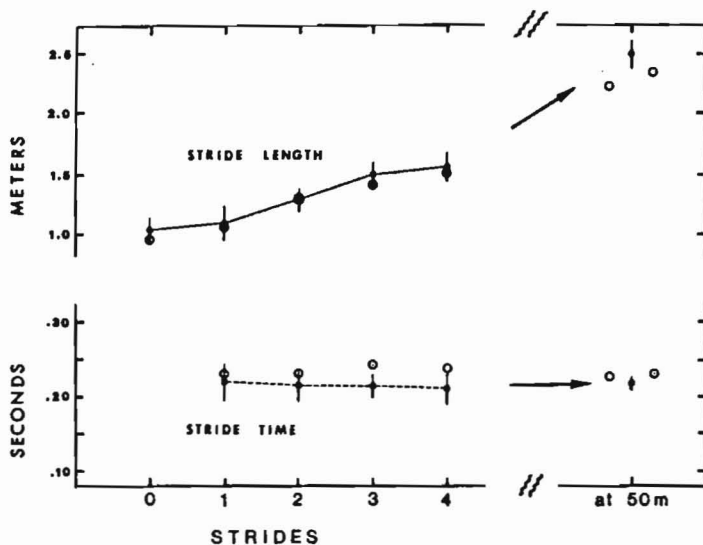
Figure 5. Stride length (top) and stride time (bottom) at the start of a 100 m sprint and at mid-race. (Legend: closed circles = 1978 group means, ± 1 s.d. (N = 12); open circles = 1979 group means (N = 12). Mid-race strides were filmed at 50 m in 1978 and at 30 m and 60 m from the start in 1979.)

STRIDE   VELOCITY

	1978	1979	
	at 50m	at 30m	at 60m
$\overline{X} \rightarrow$	11.4 m/s	9.8 m/s	10.3 m/s
STRIDE LENGTH	−.05	−.51	−.16
HEIGHT	.33	−.28	−.02
LEG LENGTH	.08	−.53	−.24
STRIDE TIME	−.62*	−.74**	−.71**
SUPPORT TIME	−.76**	−.79**	−.63*
FLIGHT TIME	−.09	−.47	−.38

Figure 6. Relationships between stride velocity and other length and time variables for 100 m sprinters filmed in 1978 (N = 12) and 1979 (N = 12). (*$p < .05$; **$p < .01$)

Arm Action

Another aspect of sprinting that we are currently studying is arm action. Some coaches, who emphasize technique and form in sprinting, believe that the arms should remain at about a right angle at the elbow as they are swung forward and backward. However, all 24 of the 100 m sprinters demonstrated considerable elbow flexion and extension causing the elbow angle to deviate approximately 50 degrees on either side of the 90 degree, or "neutral", arm position (Table 1). As the upper arm was flexed in front of a vertical line through the shoulder joint, the elbow joint flexed to an average angle of 41.9 degrees, which was 48.1 degrees less than a right angle. As the upper arm extended and reached a vertical position rotating backward, the elbow angle typically reached its point of greatest extension at 142.7 degrees, which was 52.7 degrees greater than a right angle. The shoulder joint continued to extend to an average position of 76.6 degrees behind the vertical during which time the elbow joint flexed somewhat to approach a right angle position.

As can be noted in Table 1, there was a fair amount of variability in the positions of maximum shoulder and elbow flexion and extension for the 24 sprinters. Since arm action undoubtedly has a "balancing" role in counteracting the rotation of the body caused by the alternating leg action, there are likely to be several combinations of shoulder and elbow action that can accomplish this goal of the arms. Further investigations will explore the relationships between components of arm action and other kinematic and kinetic aspects of running.

Table 1

MAXIMUM SHOULDER AND ELBOW FLEXION AND EXTENSION

AVERAGED FOR 24 SPRINTERS

Maximum Position	$\overline{X}$	s.d.
Shoulder flexion (in front of vertical)	24.0°	12.2°
Shoulder extension (behind vertical)	-76.6°	9.3°
Elbow flexion (less than a right angle)	48.1°	8.5°
Elbow extension (greater than a right angle)	52.7°	13.1°

SUMMARY

These examples that I have presented illustrate some very basic data and simple diagrams that served mainly to clarify common misconceptions and to probe certain aspects of technique that were of interest to coaches and athletes. I initially approached each of these topics with the objective of finding out what top-level performers actually do,

rather than with the goal of determining the faults of these performers. I feel that it is against a background of knowledge of what a number of good performers actually do, in combination with information on relationships between technique factors and success, that we can best judge whether or not a particular aspect of technique is deserving of correction. Even then, comparison of the performance with a mechanical model is critical to determine if there is a sound basis for technique change. And, of course, the bottom line is whether or not the athlete can, or wishes to, change his or her technique. If we are dealing with top-level athletes, there must be some good reasons why they have become successful and we should be very cautious before we recommend that a technique be changed or corrected.

REFERENCES

Atwater, A.E. 1980. Kinematic analysis of sprinting. **Biomechanics Symposium Proceedings**, 303-314, Indiana University.

Hay, J.G. 1978. **The Biomechanics of Sports Technique.** Englewood Cliffs, N.J., Prentice-Hall, Inc.

Hay, J.G. and J.G. Reid. 1982. **The Anatomical and Mechanical Bases of Human Motion.** Englewood Cliffs, N.J., Prentice-Hall, Inc.

Schutzler, L.L. 1980. A cinematographic analysis of stride length in highly skilled baseball pitchers. Unpublished master's thesis, University of Arizona.

Shaw, B. 1972. **Pitching.** New York, The Viking Press.