CHAPTER 8

How to use biomechanical knowledge

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One of the most difficult problems which confronts coaches when they are teaching fundamental skills is that of detecting errors accurately and specifically. If the error detection is inaccurate or non-specific the quality of instruction and the consequent learning on the part of athletes will be poor.

Attempts to impart useful information to youngsters through such generalized phrases as “drive harder,” “skate,” “you are swinging up at the ball,” “jump higher” and so on are of little value. Children are perceptive. They realise that if they could “drive harder” or “jump higher” they would be more successful in their sport. Their problem is not knowing how to do what their coach is expecting them to do and so generalized urging by the coach, no matter how vigorous, is of no use to them.

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Skill coaching in Canadian sport has been retarded by an inability to distinguish among causes of errors, symptoms of errors and idiosyncracies in performance. Time is wasted trying to correct symptoms and idiosyncracies, often to the frustration of both coach and athlete.

Failure to recognize the causes of errors stems from an inadequate understanding of the mechanisms of human motion. These mechanisms dictate what is anatomically and mechanically possible and impossible. What is efficient and inefficient. The substitute for such comprehension has been the memorization of hundreds of little details of performance, many of which are irrelevant or so minor that they only confuse the performer if he/she tries to incorporate them into the skill.

Frequently, these details are a result of thinking of the correctness or incorrectness of execution in terms of body configurations. These are the static aspects of the technique - the still photograph which focuses attention unduly on the finished product or a momentary phase of the skill. Too often the coach fails to realize what body movements occurred, in what sequence and at what speed to produce that mental photograph.

Most human motion involves body segment speeds, accelerations, the exertion of muscle force across joints and the application of force from the foot to the ground or ice, the hand to a shot or uneven parallel bars. If we can stop thinking of sport skills exclusively in terms of barre, angular momentum, human movement as body segment speed, acceleration, momentum, and direction of application of force, specific and accurate error detection will be made much easier and skill coaching will improve. It is usually easier to find fault with skill coaching techniques than to offer useful alternatives. One thing is certain, however: understanding the mechanisms of human motion is critical to effective skill coaching because these mechanisms focus on the causes of errors. This understanding comes from the study of biomechanics.

BIOMECHANICS

Biomechanics is the science which deals with the effects of forces acting or being produced by living bodies. Coaches are concerned about the human body; if you owned a racehorse you might be concerned about the forces and consequent speed which could be produced by that type of living body. Impacts in sport, in car accidents, in falls and in other activities involve forces. The designer of protective equipment for such sports as hockey, football and motorcycling requires an understanding of biomechanics because it is necessary to comprehend how the human head reacts to impact forces or how a skier's leg reacts to twisting forces before the protective equipment can be adequately developed. These examples of biomechanics problems involve injury mechanisms and forces which act on the human body.

More important for the purposes of this chapter is the aspect of biomechanics which deals with forces produced by the human body. Force produces an acceleration - a change in speed. The object which is changing speed may be a person's entire body as in sprint starting, skating, or a vertical jump while blocking in volleyball. It may also be a body segment or combination of segments such as the boxer's upper arm and forearm, the golfer's arms, the soccer player's thigh and lower leg (shank) or the badminton player's hand and racket, the latter simply being an extension of a body segment. No matter what the example, the speeds of the body segments of the sprinter, figure skater, thrower and others are produced by forces. These are often internal muscle forces, and the athlete must operate within the limits of the muscle forces which he/she can generate. Like all other objects on earth he must also operate within an environment of forces which act on him such as gravity, friction and contact with objects that strike him or that he strikes: external forces. Inappropriate sizes, sequences or directions of forces are the causes of errors in technique. These underlying causes result in undesirable sizes, sequences, combinations, directions or timing of body segment speeds and produce body configurations which look wrong to the coach.

It is here that technique coaching problems arise.

Causes, symptoms and idiosyncracies

Often coaching advice is directed towards correcting a symptom of an error or an unimportant idiosyncracy in the performance. This leads to a slow and indirect approach to skill development at best, and to non-specific or even incorrect advice at worst. The advice should be directed towards the cause of the error. The problem is distinguishing causes from symptoms and idiosyncracies. Two familiar examples, one specific and one more general, illustrate this point:

Almost without exception a golfer who shoots in the low 100s playing with one who shoots in the region of 115 will give his friend a lesson. The coaching cure-all for slices, hooks and topped balls is "you lifted your head." Lifting your head does not, in itself, cause topped balls. A lifted clubhead causes topped balls and the clubhead is lifted for any one of or a combination of reasons: the legs may have straightened at the knees, the trunk may have lifted because of a straightening at the hips or, less likely, the arms may have flexed a little. Lifting the head is
In golf, the duffer frequently tries to correct symptoms of errors rather than causes. Lifting the head is usually the symptom of a mistake which results in topped shots, not the cause itself.

A symptom of an error caused by an unwanted force produced at another part of the body. Correcting the symptom by concentrating only on head stability in the absence of stabilization of other parts of the body probably will not help.

Frequently, in sports where running or skating speed is important, the coach will observe that the athlete's stride is too short. The common correction is something like "stretch out," often implying to the youngster that she should reach out farther with her lead leg. If she does this she complies with the coach's mental image, his instant body configuration snapshot of what she should look like; the coach now has the most stylish but slowest athlete on the team on his hands.

The short stride was a symptom of an error. Lengthening the stride in the way described erases the symptom but not the cause. The reason that the stride was short was because the thrust of the athlete's trail leg on the ice or ground was not strong enough and possibly partly in the wrong direction. The coaching should have been directed to the cause of the error, which was an inappropriate use of the size and timing of the muscle forces that the athlete could produce at the hip joint, knee joint and ankle joint of the thrusting leg—not the lead leg. With an increased thrust and an improved direction of thrust comes a longer stride.

Correcting the cause of a technique error will thus correct a symptom while correcting a symptom will not usually correct the cause.

Equally wasteful of time is attempting to alter idiosyncrasies of athletes' performances—aspects of their style which neither account for their success nor explain their failure. Moreover, incorporating idiosyncratic aspects of professional or world class performers' styles into the young athlete's performances obviously wastes time and effort. It is generally easier to detect idiosyncrasies in the well-honed, highly skilled athlete than to assess whether an apparently strange movement in a lower level athlete's motion pattern is harmful, helpful or neutral. Understanding the mechanisms of movement by approaching technique coaching biomechanically assists in making this distinction.

Newton's laws of motion

Human motion is governed by the same three laws of motion discovered some 300 years ago by Sir Isaac Newton that govern the movements of machines and their components and all other things that move. They say, in essence:

1. An object cannot change its speed or its direction unless a force, not offset by other forces, acts on it. That is to say, for a change in motion to occur (speed, direction of movement or both) a force must be present and also, if a force is present a change in motion will occur.

2. The size of the change in motion—the acceleration that occurs—is large if the force is large and the mass of the object is small. The larger the mass the larger the force required to produce a certain size change in speed. For an object of fixed mass such as an arm or a whole human body the larger the force the greater the change in speed.

3. If force is applied to an object, that object pushes back with an equal and opposite force. For example, if you apply a force to the ground with your feet by straightening your legs fast, the ground pushes
back with an equal and opposite force and you jump into the air — the ground reacted to the action of your body. This law has thus been termed “the law of reaction.”

To leave these laws in this form is not very helpful to the coach since there are many implications for coaching which need to be pointed out. The thing to remember is that all three deal with force and momentum, work, power, words such as acceleration, speed (velocity), momentum, work, power, energy and impulse. Coaches have most of these words in their vocabulary; consequently no change is required in vocabulary but simply a reorientation of thinking to consider sport skills in these terms so that error detection and correction are made easier and more precise.

The implications of these laws for coaching will be pointed out systematically in the following pages by describing a series of concepts which come from the laws and which, for convenience of identification, will be called “biomechanical principles.”

A BIOMECHANICS APPROACH TO ERROR DETECTION

The application of a biomechanics approach to error detection in technique is most easily understood by means of an example.

Consider first a skill which involves a thrust from the legs, such as sprint starting in track or swimming, jumps in volleyball or basketball, vaulting in gymnastics, takeoffs in diving or strides while running, speed skating, figure skating or hockey skating. Biomechanically, all these skills plus others not listed here that the reader may think of, are the same. If the coach can analyse one of these skills and accurately and specifically detect errors, he can do the same for any of them even though he may know relatively little about the particular sport. The only knowledge required is a) the purpose of the movement, and b) an understanding of the biomechanical mechanisms of human movement.

Purpose of the movement

The starting point in this approach to error detection is to establish the purpose of the movement. One way of defining this for these particular skills is to state that the athlete wants to get his body to move at the maximum possible speed during each thrust. This will give the jumper, diver or gymnast height or distance and the runner or skater overall speed.

A slightly more precise definition is to state that the athlete must produce the maximum possible thrust in the correct direction. Defining the task in this way immediately provides some hints as to possible causes of errors whereas the first definition of the purpose does not.

Let us narrow the example to skating, assuming only that speed is of immediate concern. Whether it is figure skating, speed skating or hockey skating is irrelevant. Moreover, one could substitute any of the other thrusting type skills for skating and the arguments would be the same.

The ability to skate fast forward or backward at high steady speed or to accelerate forward or backward from a standstill or slow speed to a high speed involves the same things:

1. The amount of force applied by the skate to the ice — the larger the force, the greater the change in speed;
2. The length of time that the force is applied — the longer the time of application the greater the change in speed;
3. The direction of the force applied by the skate to the ice — this should be directly opposite to the intended direction of movement.

All three points are extracted from Newton’s laws of motion: a force must be applied to change speed; the larger the force the greater the change in speed; the speed will continue to increase as long as the force is applied but the body immediately stops changing speed when the force ceases; the direction of the movement is directly opposite to the direction of the force produced by the moving body. However, to recite these points to your athletes is of academic value only and leads to tips such as “thrust harder,” “drive” and so on. These were earlier pointed out to be too general to be of any use. The athlete (and coach) must know how to increase the size of the force he/she is applying, how to increase the length of time it is applied and how to improve the direction of application. This comes from an understanding of how total body motion is produced from the combined movements of individual body segments — in this example, the movements of the thigh around the hip joint, the Shank (lower leg) around the knee joint and the foot around the ankle joint.

The linked segment human body

All human motion with the exception of free falls is produced by rotations of the body segments, regardless of whether it involves mainly the arms as in throwing, the legs as in kicking or moving the total body as in running, jumping or skating. The segments are like links in a chain, connected at the joints. They rotate around a joint because the muscles which produce the force cross the joints at some distance from the joint centre, which is the centre of rotation of the...
segment (see Figures 1 and 2). An analogy is the rotation of a screen
doors around the hinges; the force exerted by the spring crosses the
hinges (joint) off-centre in connecting the door and the door frame
(links or segments).

Figure 1 Sketch of bone structure of the leg.

Figure 2 Sketch of selected extensor muscles of the leg

The joints are considered to be simple pin joints.
Understanding is simplified if the muscles are represented simply as forces indicated by arrows. The bone links are represented by sticks and the joints by nails pinning the sticks together (Figure 3a). When the muscles at the back of the hip contract they produce a force which causes the thigh segment to rotate in the direction of arrow A and the angle between the trunk and thigh to straighten (extend). When the muscles that cross in front of the knee joint (quadriceps) produce force the shank rotates in the direction of arrow B and the angle at the knee joint straightens (extends). Similarly, contraction of the muscles on the back of the shank (calf muscles) produces rotation of the foot in the direction of arrow C and the ankle joint extends.

It is the combined action of the muscle force produced at each of these three joints (hip, knee and ankle) and the resulting change in speed of the related body segments (thigh, shank and foot) that produces the force of the foot against the starting block, ground or ice. In fact, the only way that a hand or a foot can move or push in a straight line is to have more than one body segment in motion at the same time. These movements are sketched in Figure 3b. Although not indicated here a similar arrangement can be imagined for the arm segments (upper arm, lower arm and hand) in order to understand throwing and other upper body activity.

MECHANISMS OF HUMAN MOTION

An understanding of the principles outlined so far makes it possible for the coach to deal with the mechanisms of human motion for accurate and specific error detection. This process will be subdivided into the application of "biomechanical principles," the violations of which are the true causes of errors.

Principle of summation of joint forces

The amount of force exerted by the foot on the ice depends upon how many of the three joints capable of producing this force are used and how large the force is at each of them. Because the size of the force on the ice is the sum of the three separate forces, leaving a joint force out of the movement (e.g. lack of foot extension at the ankle joint) is the cause of an error. All three joints may have been used but if the force produced at one or more of them is less than its potential the sum of the joint forces will be lower than it could have been. This is also the cause of an error.

It is easy to see whether all three joints have been used but it is more difficult to determine, without measurement, whether each has been used maximally. The best visual indication is whether the speed of the movement of each segment — the thigh, shank and foot — is fast or slow. In other words, it is not sufficient simply to "use" all joints; the segment motion produced by the muscles at each joint must be as fast as possible.

The biomechanical principle of adding the forces at each joint which is capable of contributing to the motion is called "the principle of summation of joint forces." A violation of this principle results in too small a force being exerted by the foot, an error in skating or other thrusting movements, and its cause is an inadequate "summation of joint forces." A symptom of this error could be a short stride or simply a slow skater.

Principle of continuity of joint forces

Not only must the skater use all three leg joints, he must time their use so that the motion begins at the larger segment (thigh), continues and is overlapped by motion of the shank which in turn is overlapped by motion of the foot around the ankle. There must be no pauses in the flow of motion from the thigh to the shank to the foot. It must be continuous. Pauses take up time uselessly, ultimately resulting in the foot having to be lifted in recovery before the end joints have a chance to work.

A more familiar idea may be the "timing" of coordinated joint movements. This biomechanical principle is called "the principle of continuity of joint forces." A violation of the principle not only results in too small a force being exerted by the foot but gives the athlete a visibly jerky movement pattern.

Principle of impulse

Because an object changes speed only as long as a force is applied, both a large force and a long time of application are desirable. The same skating speed can be achieved (theoretically) by applying a large force for a short time, a small force for a long time or a moderate force for a moderate time. The size of the force multiplied by its time of application is called "impulse" and it is really this force/time combination that produces a change in speed. "Impulse" and "thrust" can be thought of as the same thing.
Although compromises in the size of force and duration of application often have to be made in sport to achieve an optimum combination, one combination to be avoided is a small force applied for a short time.

The size of the force an athlete can produce is determined by his/her ability to comply with the principles of summation and continuity of joint forces. In the absence of measuring devices, assessing whether the force application time is as great as possible presents yet another problem. In general, if each joint (hip, knee and ankle) has gone through a complete range of motion one can be assured that the maximum time available has been used.

It was previously pointed out that not only must the range of motion of the joint be complete, the joint must straighten fast and the combined joint motion must be continuous. The concept of the importance of the combined effect of force and time of application of force in producing speed changes is called "the principle of impulse." Violation of this principle causes further errors in performance.

**Principle of direction of force application**

The direction of the application of force to the ice is also very important. Ideally, the thrust should be opposite to the intended line of motion. This is difficult on ice, however, because it is necessary to push off the side of the front part of the skate blade, resulting in a somewhat sideways thrust. Excessive lateral motion can be avoided by increasing the outward rotation of the entire leg at the hip, thus increasing the outward rotation of the foot and permitting a better direction of force application.

Advising a youngster to push diagonally or slightly to the side during skating is both bad biomechanics and bad motor learning. The emphasis must be on pushing straight back. He will automatically move to a diagonal thrust because of the demands of the anatomical structure of his leg. To tell him to push somewhat to the side can cause the child to focus attention on the "side" part of instruction rather than on the desired thrust opposite to the direction of motion.

The amount of lateral motion is easily observed by standing behind or in front of the player as he skates, watching the total body motion and then studying his skate marks in the ice. Excessive lateral motion reduces forward or backward speed because the total force available is fixed and divides itself into a forward part and a sideward part. Ideally, if the sideward part can be reduced to zero all of the speed is in the intended direction and none is wasted. When the direction of thrust is too vertical, speed is reduced because less force is left to produce motion in a horizontal direction. Excessive vertical motion is more obvious in running than in skating but in both cases is characterized by a bobbing or bounding appearance.

Incorrect direction of thrust can be disastrous for gymnasts and divers. It can produce fouls for basketball players and volleyball players if their horizontal thrust is too great when their intent is a vertical jump, as in a jump shot or a block. Violations of "the principle of direction of force application" are yet another cause of technique errors.

Summarizing to this point, causes of errors in skating, regardless of whether it is forward, backwards, accelerating, stopping, cross-stepping in tight circles or moving laterally, can be accounted for by the violation of one or more of the following biomechanical principles which apply to any thrusting type of movement:

1. Summation of joint forces
2. Continuity of joint forces
3. Impulse
4. Direction of force application

For example, in forward skating the most common problems are incomplete knee extension and virtually no ankle extension; in cases where there is complete extension of these joints it is often carried out too slowly. Incomplete extension of the joints reduces the time of application of force and therefore violates the principle of impulse. Failure to use the ankle joint violates both the principle of summation of joint force and the principle of impulse. Going through a joint range of motion too slowly, even though completely, reduces the size of the force on the ice. The time of force application may be increased but the drop in the size of the force more than offsets the time increase. This is a violation of both the principles of summation of joint forces and of impulse. All of these violations produce a slow skater.

When skating backwards, beginners and some advanced players commonly violate two principles. First, they lean too far forward, placing their centre of gravity, which is located in the region of the navel, over their toes. They discover very quickly that if they thrust very hard they tip over forward. Consequently they do not thrust very hard; the small thrust that they have is sideway s and they skate backwards very slowly. Their direction of thrust is wrong and they do not extend their hip, knee and ankle but merely shift their weight back and forth in a rear-end wiggle. They are also violating the principle of summation of joint forces.

The forward skating problem is one in which altering a body configuration such as the forward lean of the upper body, although frequently advised, is useless because it is only a symptom of error and has little effect on the cause. The real problem is in the way the joints and segments of the legs are used. The correction must be directed to a
specific joint or combination of joints. With an improved thrust will come a more appropriate body lean. The backward skating example is one of the few in which body configuration is partly responsible for the slow skating. Straightening the player's upper body will place his centre of gravity in a position where summation, continuity and correct direction of force can be applied. Even here, changing the body configuration alone does not mean that the player will automatically improve the thrust.

PRINCIPLES OF ERROR DETECTION

Although only four principles and one type of movement (thrusting) have been discussed, the coach should be ready now for some recommendations on how to learn to use the principles and how to observe skills.

Until you become familiar with the implications of the principles write their names on your clipboard. This will remind you of the concepts and the violations of principles to look for. It takes a bit of practice to master the technique but its value in improving the accuracy and precision of error detection beyond that possible with the currently used "body configuration detail memorization" approach makes the effort worthwhile. The principles are applicable to any sport or other form of human movement (e.g. walking) and can be entertainingly practiced while girl(boy)-watching. It puts this activity in a dynamically new light. Television and community sports, even ones that you do not coach, provide an opportunity to practice observing.

Movement observation

Some coaches see nothing but a blur when they attempt to analyze motion, particularly when they are observing visually, unaided by replays or slow motion. The reason is that they have not trained themselves to focus their attention on a specific aspect of the movement pattern. The following systematic approach helps:

1. Establish the purpose of the movement in terms of biomechanics, rather than simply telling yourself that the purpose of sprinting is to run fast. The biomechanics purpose is to maximize a thrust in a prescribed direction. In throwing a ball for speed the purpose is to produce as much hand speed at the instant of release as possible; the biomechanical purpose of a wrist shot or a slap shot in hockey, a serve in tennis or a drive in golf, is to produce as much blade, racket-head or clubhead speed as possible at impact. If distance or accuracy is involved an additional contingency is the direction of the hand at release or the clubhead at impact. Once this aspect of the skill has been established the error identification problem is reduced to determining how the athlete's body segment movements can produce these speeds.

2. Observe the movement several times at usual speed and confirm that there is a problem (something looks wrong). Usually, this is the easy part.

3. Attempt to assess the cause of the problem (which biomechanical principles have been violated) and localize its source (upper body or lower body).

4. Observe the movement a few more times watching only the identified source (lower body).

5. Attempt to further localize the source to a specific joint or, more complicated but common, the interaction of two or more joints (inadequate knee extension or knee and ankle extensions are too slow).

The idea is to zero in gradually on the cause of the problem and the body segments responsible for it.

OTHER BIOMECHANICAL PRINCIPLES

This chapter has purposely been restricted to only four biomechanical principles and an explanation of their use in detecting errors in thrusting movements. Another chapter would be required to provide sufficient explanation of the remaining principles which deal with other types of movements. A brief outline will be useful, however.

While thrusting is a part of nearly all movement patterns — if not the primary component — several other subdivisions can be identified. The classification is based largely on the biomechanical purpose of the movement.

Principle of stability

Many skills depend on the stability of the athlete for success. The football and hockey player must resist upsetting forces when receiving or delivering blocks, tackles or body checks. Gymnasts and figure skaters must maintain their equilibrium in precarious positions. Wrestlers at times must be very stable and at other times very unstable so that they can move quickly.

The principle of stability accounts for success and explains errors in events where the athlete wants to maintain or regain a position against large and sometime unpredictable forces, as in the body contact
examples just given. It also is applicable where unstable balance must be maintained or regained, as in gymnastics, figure skating and skiing; where a quick start is required, such as “ready positions” in squash, handball, tennis, badminton, baseball fielding, football line-backing and the like.

An athlete tips over when his/her line of gravity falls outside the base of support. The line of gravity is the line a plumb bob would make if it were suspended from the person’s centre of gravity; the base of support is the area contained within the boundary marked by the supports. Figure 4 illustrates these definitions.

If the base of support is large and/or the centre of gravity is low, the line of gravity must move a long way before tipping occurs. Stability is improved under these conditions. However, if one must move quickly in frequently predictable directions as in tennis, badminton and other activities the fastest way to initiate motion is to get the line of gravity outside the base of support so that one begins to fall. In these cases movement is facilitated by a relatively high centre of gravity and a relatively narrow base of support. “Feet shoulder width apart” may be too far for some purposes, too narrow for others and just right for yet other situations. Dynamic stability — balance in motion — presents some interesting apparent, but not real, contraventions of stability concepts as in skating, skiing and running.

**Principle of summation of body segment speeds**

The primary purpose of all throwing, kicking and striking events is to obtain as high a hand, foot, stick-blade, racket-head or club-head speed as possible at the instant of impact or release. The speed of an end segment in the chain is built by adding together the individual speeds of all preceding segments with appropriate timing. Leaving potentially contributive segments out or using them sub-maximally is the cause of an error. This principle is very similar to that of the summation of joint forces. The latter deals primarily with self-propulsion of the body, the former with hand, foot or club-head speed used in propelling something else.

**Principle of production of rotational motion**

Many sport skills involve rotations while in contact with the earth such as spins in figure skating, discus and hammer throwing, pivoting while playing hockey, basketball and quarterbacking in football, giant circles on a horizontal bar, hip circles on uneven parallel bars and pole vaulting. Still other rotary movements occur while the athlete is airborne, some undesirable as in long jumping and ski jumping and other highly desirable as in somersaulting and twisting dives and trampoline stunts, free exercises in gymnastics and leaping spins in figure skating.

A little less obvious but equally important in rotational considerations are activities such as golf swings, baseball pitching, javelin throwing, bowling, spiking in volleyball and various racket strokes. It has been already noted that all human motion is the product of combined body segment rotations around their respective joints and
the source of errors in performance is therefore in the use of these joints and segments.

The principle of the production of rotational motion explains how segment and total body rotations can be produced, increased and controlled. Violation of this principle is the cause of certain errors in rotational performances.

**Principles of: conservation of momentum, rotational inertia manipulation, body segment momentum manipulation**

Two principles explain how to control the speed of airborne rotations once produced and how to increase the speed of body segment rotations in throwing types of activities: the principle of conservation of momentum and the principle of rotational inertia manipulation.

The final biomechanical principle, a minor one, is a somewhat specialized concept that helps to explain how to control the undesired airborne rotations with which long jumpers, divers and ski-jumpers sometimes must cope: the principle of body segment momentum manipulation.

These last few principles sound a bit ominous in the absence of detailed explanation. Excellent references for rotational motion explanations in sport can be found in two delightful books, one by Dyson and a more recent one by Hopper, listed at the end of the chapter.

**Quantitative biomechanics**

The aspect of biomechanics which has been emphasized in this chapter has been "qualitative biomechanical analysis" of skills through biomechanical principles which refer to concepts of force generated by the contraction of muscle and the resulting body segment acceleration, velocity (speed) and impulse produced. No reference was made to actually **measuring** the size of the impulse produced, its direction, the size of the muscle forces produced at important joints, the change in speed from stride to stride, the segment speeds and accelerations, stride lengths, rate or the mechanical work done. This is "quantitative biomechanical analysis" and is capable of providing detailed inventories of the phases of performances of highly skilled athletes. The advantages of such information are that small changes in important aspects of performance as a result of coaching can be followed if the analysis is conducted frequently enough. This can provide the coach and athlete with useful feedback before overall changes in performance, such as improved times, distances, goals scored and so on, are detectable. While certain European countries have recognized the value of this aspect of biomechanics for a long time, North American sport authorities have not yet exploited it. It is being undertaken in some universities here, however.

In fact, the greatest use of quantitative biomechanics is being made in rehabilitation medicine through studies of walking of amputees and other abnormal cases. Growing interest in the role of biomechanics in protective equipment design on the part of sporting goods manufacturers is also emerging.

Aside from material presented in this chapter other biomechanics issues which are of interest to coaches are injury mechanisms and such training areas as strength, which has a large biomechanical component.

**RECOMMENDED READING**


Ecker, Tom. *Track and Field Dynamics*. Track and Field News.
