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BASIC PRINCIPLES FOR IMPROVING SPORT PERFORMANCE*

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KEY POINTS

1. For most sports, the top competitor is generally the one who can appropriately sustain the greatest power output to overcome resistance or drag.
2. It is not sufficient for championship performance to simply have the ability to produce great power. The champion must be able to sustain power output in an efficient and skillful manner for the duration of the competition.
3. During maximal exercise lasting a few seconds, the anaerobic breakdown of phosphocreatine and glycogen in muscles can provide energy at rates many times greater than can be supplied by the aerobic breakdown of carbohydrate and fat. However, this high rate of anaerobic energy production cannot be sustained for more than about 20 seconds.
4. For exercise lasting more than a few minutes, an athlete who has a high lactate threshold, that is, one who can produce a large amount of energy aerobically without a major accumulation of lactic acid in the blood, will be better able to sustain a higher rate of energy expenditure than will a competitor who has a lower lactate threshold.
5. A high level of mechanical efficiency, which is the ratio of the mechanical power output to the total energy expended to produce that power, is vital if an athlete is to make the most of his or her sustainable rate of energy expenditure. Mechanical efficiency depends upon the extent to which the athlete can recruit slow–twitch muscle fibers, which are more efficient at converting chemical energy into muscle contraction than are fast–twitch fibers.
6. Neuromuscular skill is also critical to mechanical efficiency because the more skillful athlete will activate only those muscle fibers required to produce the appropriate movements. Extraneous muscle contractions require more energy expenditure but do not contribute to effective power output.

INTRODUCTION

The criterion for success in many sports, including those involving running, swimming, bicycling, speed skating, rowing, and cross–country skiing, is simply the time required to propel the athlete's body (and essential equipment such as a bicycle, rowing shell, or skis) for a given distance. In the case of Olympic weightlifting and power lifting, success is determined by how much weight can be lifted in the appropriate movements, whereas a wrestler is judged by the degree of physical control over the opponent. These sports are quite different in terms of the patterns of muscle recruitment, the force and power produced, and the equipment used; nevertheless, success in all of these seemingly diverse sports depends on a complicated application of a simple principle—the champion is the athlete best able to reduce the resistance or drag that must be overcome in competition and best able to sustain an efficient power output to overcome that resistance or drag (Figure 1)(Coyle et al., 1994). This review provides an analysis of the major factors that contribute to an athlete's ability to produce power appropriately to overcome resistance or drag and a number of important applied principles designed to help trainers, coaches, physiologists, and others assist athletes in achieving their goals in sport.

FIGURE 1. Model of the interrelationship of major factors determining sport performance. Performance is determined by how effectively the athlete can sustain sufficient power output to overcome various types of resistance or drag, depending upon the sport event. Sustainable power output depends on the rate of energy expenditure that can be sustained throughout the event and the efficiency with which that energy can be converted into mechanical power. Depending on the sport event, sustainable energy expenditure will be a function of the ability to sustain the production of energy by anaerobic and/or aerobic means. Mechanical efficiency is dependent on muscle efficiency, i.e., the efficiency with which muscles convert the energy stored in carbohydrate and fat into muscle shortening, and the neuromuscular skill with which the athlete performs the event, i.e., the degree to which the athlete has learned to recruit only those motor units required to produce maximal power output in a skillful way.

RESISTANCE AND DRAG: EXAMPLES IN SPORT

Examples of resistance in sport include the mass of a barbell in Olympic lifting or power lifting, the muscular efforts of an opponent in wrestling or judo that are used to offset the movements of a competitor, and the effect of gravity on resisting a marathon runner's ability to move up a hill. A lifter who can sustain adequate power output long enough to correctly lift a greater weight than a competitor will beat that competitor. Likewise, a competitor in wrestling or judo who can sustain power sufficient to overcome the resistance provided by the opponent throughout the match will be the winner.

Drag is a special case of resistance in which the friction of air or water around a competitor retards forward motion. Obvious examples of drag are the adverse effects of a headwind on the forward velocity of a competitive cyclist and the retarding effects of water drag on the efforts of a swimmer to move quickly ahead. In cycling on a flat course at speeds greater than 13 km/h (8 mph), most of the resistance to the power generated by a bicyclist is created by the air through which the cyclist's body moves; relatively little bicycling power is lost to friction of the moving components of the bicycle or to the rolling resistance of the contact between the tire and road (Kale, 1991). It is also important to realize that the air drag increases as the square of the velocity of the moving object, i.e., if speed is doubled, the drag increases by four–fold (Kale, 1991).

Air drag offers great resistance in any sport requiring the athlete to move at relatively high velocities; such sports include speed skating—30–40 km/h (19–25 mph) at distances of 0.5–10 km (3–6 mi)—and sprint running—25–35 km/h (15–22 mph) at distances of 100–400 m. In fact, the air creates so much resistance in speed skating that the skaters must assume a tightly crouched posture to reduce their frontal areas exposed to air. Although this posture reduces leg power, it reduces air drag to an even greater extent and thus produces higher skating velocities. Swimmers move at relatively low velocities because they encounter large drag forces from the water as well as from the turbulence at the surface of the water. This drag encountered by a swimmer is not simply a function of body mass, but also of the geometry of the body as it moves through the water.

It is obvious that in events such as bicycling, speed skating, and possibly sprint running, each of which requires the athlete to move through the air at high speeds, the ultimate race time will be determined by the power generated relative to the air resistance. The same is true for the swimmer who must overcome the drag of the water at lower speeds. The main point is that the race velocity in these sports is a function of power production relative to the drag encountered at racing speeds. Therefore, velocity (performance) can be increased by improving power output and/or by reducing drag.

REDUCING RESISTANCE AND DRAG

In some sports, such as Olympic lifting, power lifting, and the shot put, the very nature of the competition makes it impossible to reduce resistance. If a competitive lifter chooses a low resistance—a lightweight barbell, that athlete is unlikely to win the competition. Likewise, the rules do not allow a shot putter to choose a lightweight shot. However, there are methods that can be used in many sports to reduce resistance or drag. Here are a few examples:

Use Skillful Technique. Competitors in wrestling, judo, rugby, American football, and other "contact" sports can reduce the resistance applied by opponents by skillful misdirection movements that trick the opponents into resisting in the wrong direction. These techniques are learned through many years of practice under the instruction of skillful coaches.

Use Aerodynamic and Hydrodynamic Equipment and Body Postures. In some sports, effective techniques have been employed to reduce resistance and drag in air and water. The designs of golf balls and javelins have become more aerodynamic over the years, and the resulting reductions in air drag have improved the flight characteristics of both. In cycling, riders wear aerodynamic helmets and skintight clothing and assume crouch positions over the handle bars ("aero bars") to minimize wind resistance. In swimming, body position in the water and stroke mechanics are optimized by careful study of underwater videos so that the swimmer reduces water drag as much as possible. Also, engineers have successfully modified the designs of rowing shells, canoes, kayaks, sailboats, oars, and paddles to minimize water drag in competitive events.

Reduce Body Mass. Athletes should carefully consider whether they can effectively reduce resistance or drag by reducing body weight. For pole vaulters, high jumpers, long jumpers, and triple jumpers, gravity is the principal resistance that must be overcome, and body weight is responsible for nearly all of this effect of gravity. Therefore, if these athletes can reduce their body weights without equivalent reductions in their abilities to skillfully generate muscular power, their performances should improve. Of course, if the body weight loss leads to a serious loss of muscular power, performance may well be worsened, not improved. Competing at an effectively low body weight is also critical for distance runners, endurance cyclists, and cross–country skiers. In these sports, the resistance of gravity is a crucial factor in determining performance; in addition, at the higher velocities of cycling, air drag is a major type of resistance that must be overcome, and a smaller frontal body surface area can reduce that resistance.

Weight reduction is not so much of an issue in swimming because the body mass is buoyed up by being immersed in water. However, to the extent that reductions in body weight help reduce water drag, weight loss could be of benefit in swimming, too. Differences in swimmers' individual body builds could play a significant role in determining whether or not weight loss improves swim performance. For example, weight loss may be quite ineffective in a swimmer who already presents a small frontal area and who tends to lose weight mostly in the thighs. However, if a swimmer has exceptionally large shoulders and a large chest, and if the mass of these areas can be reduced effectively through a weight loss program, such an approach could shave time off that swimmer's personal records.

PROVIDING EFFICIENT SUSTAINED POWER OUTPUT TO OVERCOME RESISTANCE AND DRAG

Power is the ability to apply force through a distance quickly. In other words, power can be thought of as a combination of strength and speed. Interestingly, the sport of power lifting is misnamed because only strength, not speed, is required to be successful; as long as the barbell is moved appropriately, time is of no importance. On the other hand, a person could have exceptionally strong leg muscles and be a pitiful high jumper, sprinter, or long jumper if that strength could not be brought to bear quickly.

Unfortunately, absolute maximal muscular power can be sustained for only a fraction of a second. Thus, assuming equal resistance or drag, the champion in a sport event will not necessarily be the competitor who can produce the greatest maximal power, but instead will be the one who can sustain the greatest power output to overcome the resistance or drag for the duration of the event. This duration may be only a second or two, such as in power lifting, or many hours, such as in an Ironman triathlon.

The ability to sustain a high power output to efficiently overcome resistance or drag involves two major factors—the ability to sustain energy production by the muscles and the ability to apply that muscular energy efficiently to overcome resistance or drag.

SUSTAINING ENERGY PRODUCTION BY THE MUSCLES

When energy requirements are extremely high, such as during a sprint in track or swimming or during an Olympic weightlifting event, most of the muscular energy is supplied by two fuels, phosphocreatine (PCr) and glycogen, that are stored in small amounts in the muscles. Because these two fuels can be broken down for energy without the use of oxygen, this is known as anaerobic (without air) energy production. Aerobic energy production occurs at a much slower rate as fats and carbohydrates are broken down with the aid of oxygen in the muscles.

Sustainable Energy Expenditure in Brief, High–Power Events

Brief, high–power activities such as weightlifting and sprinting rely largely on the anaerobic breakdown of PCr and muscle glycogen for energy. When estimates of anaerobic energy production are coupled with simultaneous measurements of aerobic energy production, the approximate relative contributions of these two energy sources during various phases of exercise lasting from 0–180 s are as shown in Table 1. It is clear from the table that the percentage anaerobic contribution to energy production falls off rapidly as the exercise duration increases.

Contributions of Anaerobic and Aerobic Energy During Sequential Phases of Exercise

Phase	Time	Anaerobic	Aerobic
1	0 – 30 s	80%	20%
2	30 – 60 s	60%	40%
3	60 – 90 s	42%	58%
4	90 – 120 s	36%	64%
5	120 – 180 s	30%	70%

Contributions of Anaerobic and Aerobic Energy During Cumulative Periods of Exercise

Period	Anaerobic	Aerobic
0 – 60 s	70%	30%
0 – 90 s	61%	39%
0 – 120 s	55%	45%
0 – 180 s	45%	55%

TABLE 1. Relative contributions of anaerobic and aerobic energy production during sequential phases and cumulative periods of exhausting exercise lasting 180 s. Data from Bangsbo et al. (1990)

Both PCr degradation and anaerobic glycolysis are activated instantaneously at the onset of high–intensity exercise. Measurements of PCr and lactate from muscle biopsies taken following as little as 1–10 s of electrical stimulation (Hultman & Sjoholm, 1983) and after sprint cycling (Boobis et al., 1982; Gaitanos et al., 1993; Jacobs et al., 1983) confirm the rapid breakdown of PCr and rapid accumulation of lactate. At the onset of less intense exercise, a similar instantaneous activation of both PCr degradation and anaerobic glycolysis occurs but at a much slower rate because the mismatch between energy demand and aerobic supply is reduced during submaximal exertion.

Rate of Anaerobic Energy Production During Exercise

The rate of anaerobic energy provision is critical to success in sports that require the development and short–term maintenance of high power outputs. World–class power lifters and weightlifters can produce power outputs that are 10–20 times that required to elicit the maximal rate of aerobic energy provision, which is estimated by the maximal rate at which the athlete can consume oxygen (VO$_2$max). However, such high power outputs can be maintained for only a fraction of a second. Sprinters can achieve power outputs that are 3–5 times the power output that elicits VO$_2$max, but they can sustain that power output for only about 10 s. However, power output over a 30–40 s sprint can still be sustained at twice the power output at VO$_2$max. Estimates of the rates of anaerobic provision of energy have been calculated from biochemical changes in muscles following intense exercise lasting from 1.3 to 200 s (Spriet, 1994). These studies used non–elite athletes who performed sprint cycling, sprint running, or repeated knee extensions or who underwent electrical stimulation of their muscles. The highest measured rates for energy production from PCr and anaerobic glycolysis during various types of exercise lasting from 1.3–10 s were each approximately 250–500% of the estimated maximal rate of energy provision from aerobic metabolism. In other studies of sprint cycling for 6–10 s, energy production rates from PCr and anaerobic glycolysis combined were about 400–750% of that during maximal aerobic metabolism (Boobis et al., 1982; Jacobs et al., 1983).

The anaerobic energy provision rates decrease when averaged over longer periods of time. In studies that examined intense exercise for 30 s, the average energy provision rate from PCr was about 70–100% of that from maximal aerobic metabolism; anaerobic glycolysis provided energy at a rate estimated to be 220–330% of that from maximal aerobic metabolism (Spriet, 1994). The large decrease in energy produced from PCr when averaged over 30 s, as compared to less than 10 s, indicates that the PCr store becomes depleted between 10 and 30 s of intense exercise. Thus, for maximal exertion lasting longer than about 30 s, it appears that only glycolysis can provide for further anaerobic energy production.

Anaerobic Energy Production During Intermittent High–Power Exercise

Many athletes repeatedly engage in bursts of high–intensity exercise with varying amounts of recovery time between exercise bouts. Examples include a wide receiver in American football, a basketball player in repeated fast break situations, or a swimmer or track athlete during interval training. Most of the energy for short bouts of high–intensity exercise is derived from anaerobic sources; therefore, the ability to recover during rest periods is essential for success in this type of activity. Many studies have examined the performance effects of intermittent high intensity exercise, but few have examined the anaerobic metabolism associated with this type of metabolic stress. Examples of the exercise models that have been studied and provided some conclusions include: 10 bouts of sprint cycling, each lasting 6 s with rest periods of 30 s; four bouts of sprint cycling for 30 s with 4–min rest periods; and two bouts of knee extension exercise to exhaustion in 3 min with 10–60 min of recovery (Bangsbo et al., 1992; Gaitanos et al., 1993; McCartney et al., 1986). Muscle biopsy measurements demonstrated that PCr was decreased by approximately 50% after 6 s and by 75–80% during longer sprints. The PCr is quickly resynthesized during recovery, reaching 50% of rest values by 30–60 s and about 80% by 2–4 min. With repeated sprinting, energy production from anaerobic glycolysis is progressively more difficult to achieve. Presumably, the accumulation of lactic acid in the active muscles plays a major role in the inability to continue producing energy by anaerobic glycolysis. Therefore, after repeated bursts of exercise, PCr is the only potential anaerobic energy source that can be relied upon. However, as described above, it is essential that adequate rest be provided in between intermittent exercise bouts to allow PCr stores to be replenished in the muscles.

Sustained Aerobic Energy Production

The maximal rate of aerobic energy production (VO_2max) can be sustained for only about 8–10 min by elite athletes. In events lasting longer than 8–10 min, the best competitor among those with similar values for VO_2max is usually the one who can sustain aerobic energy production at the greatest proportion of his or her maximal rate, that is, at the greatest percentage of the VO_2max. This in turn is largely dependent on the extent to which the athlete can produce energy aerobically at a high rate without accumulating a large amount of lactic acid in the blood. In other words, the athlete who produces a large amount of lactic acid at a given speed of running, swimming, or cycling cannot continue to perform at that pace for as long as the athlete who does not accumulate as much lactic acid. An athlete who has the ability to exercise at a high intensity before blood lactic acid begins to accumulate is said to have a high lactate threshold (Coyle et al., 1988; Holloszy & Coyle, 1984). An athlete's lactate threshold seems to be a better indicator of endurance performance lasting 30 min to 4 h than does the VO_2max (Coyle et al., 1988, 1991). This is because the lactate threshold is a better index of the athlete's ability to sustain a high rate of energy expenditure for the duration of the competition.

Role of Nutrition in Determining Sustainable Energy Production

Two nutrients, carbohydrate and water, are the dietary constituents that have repeatedly been shown to be most important for optimizing endurance performance. Muscles obviously cannot produce energy without fuels derived from nutrients obtained in the diet, and carbohydrate is an obligatory fuel for high–caliber sport performance. It is well established that dietary carbohydrate consumption before, during, and after exercise can make an important contribution to performance. Carbohydrate consumption acts primarily by increasing the body's stores of glycogen in muscles and in the liver before exercise and by increasing the availability of glucose for use by the muscles during exercise (Coggan & Swanson, 1992; Costill & Hargreaves, 1992; Coyle, 1991; Williams, 1993). Fluid intake during prolonged exercise is also required to counteract the debilitating effects of exercise and heat on cardiovascular function and on body temperature regulation. When dehydration reduces blood volume, oxygen delivery to the muscles by the blood can be compromised, and this reduces the ability of the muscles to produce energy aerobically. Dehydration also compromises the ability of the body to regulate its temperature, resulting in eventual lethargy and potential heat illness, both of which adversely affect the athlete's ability to sustain a high rate of energy production. Carbohydrate–electrolyte beverages are advocated as the most effective way to supply both carbohydrate and fluid to the body during exercise (Coggan & Swanson, 1992; Gisolfi & Duchman, 1992).

IMPROVING THE ABILITY TO SUSTAIN ENERGY PRODUCTION AT A HIGH RATE

Here are some ways that athletes may be able to improve their abilities to sustain high rates of energy production so they can sustain greater power output to overcome resistance and drag:

At the onset of a training season, the athlete should establish a solid aerobic training foundation by training at relatively low intensities for long durations. This will help develop a greater blood volume, an improved ability of the heart to pump blood, and better networks of capillaries in the trained muscles. These cardiovascular adaptations will lead to an improved delivery of oxygen to the muscles and an enhanced ability of the muscles to sustain high rates of aerobic energy production.

For the bulk of the athlete's training, the specific muscle groups involved in the competitive event should be overloaded, and the athlete should train at a pace or intensity similar to that used in competition (Hickson, 1977, 1985). Such training can lead to improved stores of glycogen and PCr in the trained muscles so that greater energy reserves will be present in the muscles before competition begins. Furthermore, metabolic adaptations to this type of training are likely to enhance the ability of the muscles to utilize fat for energy and to spare muscle glycogen, resulting in less lactic acid production and less accumulation of lactic acid in the blood at a given pace or intensity (Holloszy & Coyle, 1984). This means that the athlete's lactate threshold will be increased so that aerobic energy production can be sustained longer at a greater rate than was possible before training.

During high intensity, anaerobic interval training, the duration of recovery intervals should be sufficient—usually between 30 s and 4 min—to allow the muscles to replenish most of the PCr depleted in the previous exercise interval. If these recovery intervals are too brief, the supply of PCr in the exercising muscles will be inadequate to provide energy anaerobically at a high rate (Gaitanos et al., 1993; McCartney et al., 1986). This means that the athlete will be forced to exercise at a lower intensity (slower pace) and that inappropriate muscle groups may be recruited to accomplish subsequent exercise intervals. If these events occur, the athlete will be learning incorrect movement patterns during training that may adversely affect competitive performance.

The athlete should receive adequate rest—approximately 24 h—between exhaustive training sessions to allow for total replenishment of depleted glycogen stores in the muscles prior to the next training session (Coyle, 1991). Otherwise, the quality of the next training session may be compromised because the athlete's muscles will be easily depleted of one of their main fuels. In addition, training intensity and duration should be gradually reduced during the week before a competitive event so that the athlete's energy reserves are fully loaded before competition.

The athlete should drink plenty of fluids before, during, and after exercise to avoid becoming dehydrated. Dehydration can lead to a diminished ability to deliver oxygen to the muscles, heat cramps, heat exhaustion, and even heat stroke, all of which can impair muscular energy production.

On a daily basis, the athlete should consume a diet high in carbohydrate, about 8 g of carbohydrate per kilogram of body weight (4 g/lb). This will ensure that the muscles can store extra glycogen and may help sustain energy production during competition.

Preliminary evidence suggests that dietary creatine supplementation may increase PCr stores in muscles (Dalsom et al., 1995) and perhaps improve performance in events such as fastbreak basketball that require repeated brief exertions. The extent to which creatine supplementation proves to be useful in actual sport settings remains to be seen.

During prolonged exercise, the athlete should consume carbohydrate–electrolyte drinks containing approximately 6% carbohydrate (glucose, sucrose, or maltodextrins) and a small amount of sodium to help maintain an adequate carbohydrate energy supply to the muscles and to minimize dehydration. Volumes of 150–250 mL (5–8 oz) should be consumed every 15–20 min to replace most, if not all, of the sweat lost by the athlete during exercise (Montain & Coyle, 1992).

MECHANICAL EFFICIENCY: A MAJOR DETERMINANT OF EFFECTIVE POWER OUTPUT

Mechanical efficiency for a sporting event is the ratio of the mechanical power output to the total energy expended to produce that power. Typically, both power output and energy expenditure are expressed in watts (W), and the ratio is expressed as a percentage. For example, if a cyclist expends energy at the rate equivalent to 5 L of oxygen per minute (1745 W) to produce 400 W of power on a bicycle ergometer, the mechanical efficiency would be (400/1745) 100 = 23%. Two of the principal factors that determine the mechanical efficiency of an athlete in a sport event are 1) the efficiency with which the active muscles convert the chemical energy stored in carbohydrate and fat to the mechanical energy required to shorten the contractile elements in the muscles, and 2) the neuromuscular skill with which the athlete performs the event.

Role of Muscle Efficiency in Determining Mechanical Efficiency

Muscle efficiency has two components, the first of which is the efficiency with which chemical energy from carbohydrate and fat is converted to adenosine triphosphate (ATP), the only form of chemical energy that can power muscle contraction. The process of ATP synthesis is about 40% efficient, i.e., 40% of the metabolic energy in carbohydrate and fat is transferred into ATP synthesis, whereas 60% of the energy is lost as heat (Kushmerick, 1983; Kushmerick & Davies, 1969). This efficiency of ATP synthesis is fairly constant among individuals.

The second component of muscle efficiency, i.e., the efficiency with which the energy released during ATP hydrolysis is converted to muscle fiber shortening, is more variable than is the efficiency of converting stored fuels to ATP. The efficiency of ATP hydrolysis is dependent on the velocities of muscle contraction (Goldspink, 1978; Kushmerick & Davies, 1969). A peak efficiency of approximately 60% or more can be elicited from myofilaments contracting at one– third of maximal velocity; i.e., the velocity of peak efficiency (Kushmerick, 1983; Kushmerick & Davies, 1969). Thus, slow–twitch muscle fibers obviously have slower velocities of peak efficiency than do fast–twitch fibers (Fitts et al., 1989).

Mechanical efficiency when cycling at 80 rpm is directly related to the percentage of slow– twitch muscle fibers in the vastus lateralis muscles (Coyle et al., 1992). It seems that when cycling at this cadence, the velocity of muscle fiber shortening in the vastus lateralis is close to one–third maximal velocity of the slow–twitch fibers (Coyle et al., 1992). This makes slow–twitch muscle fibers substantially more efficient than fast–twitch muscle fibers at converting ATP into muscular power when cycling at 80 rpm (Coyle et al., 1992; Goldspink, 1978).

Muscle fiber type has a large effect on mechanical efficiency, which in turn has a large influence on sustainable power output as measured during a 60–min bout of cycling in a homogeneous group of cyclists (Horowitz et al., 1994). The cyclists in this study were paired and divided into two groups based upon the percentage (i.e., above or below 56%) of slow–twitch muscle fibers in their vastus lateralis muscles. One group possessed a normal distribution of fiber types, with an average of 48% slow twitch fibers. The other group had 72% slow–twitch fibers on average. These two groups were identical in VO_2 max as well as in the VO_2 maintained during the ride. Therefore, they possessed the same aerobic energy expenditure potential for this type of task. However, the cyclists with a high percentage of slow–twitch fibers displayed significantly higher mechanical efficiencies and were therefore able to sustain a 9% greater power output (342 W vs. 315 W) during the 60–min ride. Clearly, endurance cycling performance is heavily influenced by mechanical efficiency, which in turn appears to be dependent on the rider's muscle fiber type profile and the efficiency of ATP hydrolysis by the muscle.

Role of Neuromuscular Skill in Determining Mechanical Efficiency

No matter how efficiently one can transform chemical energy into mechanical energy in a given muscle fiber, the overall mechanical efficiency in a sports event will be poor if the athlete is poorly skilled. A good example of the importance of skill is the contrast in the freestyle swimming performances of novice and elite swimmers. The novice may produce a great deal of power, but because the swimmer is so unskillful, the power output is misdirected so that lots of thrashing about occurs with little forward velocity. The elite swimmer, on the other hand, has learned to swim rapidly and gracefully, using only those muscle fibers required to execute the stroke effectively. Neuromuscular skill obviously plays a greater role in determining the mechanical efficiency for some sports, e.g., swimming and wrestling, than it does for others, e.g., running and power lifting, but even small differences in skill can have a major impact on performance in any sport at the elite level.

IMPROVING THE ATHLETE'S ABILITY TO PROVIDE POWER OUTPUT IN AN EFFICIENT MANNER

There is little that the athlete can do to improve muscle efficiency because the chemical efficiency of converting fuels to ATP and the proportion of slow–twitch fibers involved in various movements are largely determined by heredity. An exception may be that athletes over many months of training may learn to recruit more of the efficient slow–twitch muscle fibers and fewer of the less efficient fast–twitch fibers. In addition, there are three important steps that can be taken to improve the skill with which power output is applied.

The athlete should obtain the technical advice of competent coaches who can explain how movement patterns should be altered to become more skillful. Often the coach can rely upon personal experience and observation to make critical improvements in an athlete's technique.

Video analysis of the athlete's performance can provide clues about changes in movement patterns that can be made to improve efficiency. The assistance of a sport biomechanist or a coach well–educated in biomechanics could be important in this phase of the athlete's preparation.

The athlete must repeat the appropriate movement patterns in a skillful manner many thousands of times during practice so the nervous system learns to perform the movement correctly every time throughout the entire duration of competition. There is no substitute for skillful repetition of muscular activities to ensure that such activities are likely to remain skillful in the heat of competition.

SUMMARY

For most competitive sports, improving the performance of an athlete can be accomplished by reducing the resistance or drag that must be overcome or by increasing the athlete's ability to sustain a high power output to overcome that resistance or drag. Reducing air resistance or water drag typically involves improving body position in the air or water by minimizing the frontal surface area of the athlete that is exposed to the air or water. Sometimes the apparel or equipment used in the sport, e.g., helmets, swimwear, bicycles, and rowing shells, can be made more aerodynamic or hydrodynamic to reduce resistance or drag.

Increasing sustainable power output requires that the athlete undergo a carefully designed training program that will improve the athlete's abilities to: 1) produce metabolic energy by both aerobic and anaerobic means, 2) sustain aerobic energy production at high levels before lactic acid accumulates excessively in the blood, 3) recruit more of the efficient slow–twitch muscle fibers at exercise intensities used in competition, and 4) become more skillful by recruiting fewer non– essential muscle fibers during competition. Careful attention to maintaining a sufficient intake of fluids and carbohydrate before, during, and after strenuous competition and training sessions is also important.

Although it is apparent that some uniquely gifted athletes are able to win consistently even when their approaches to training are obviously not optimal for reducing resistance or drag and for enhancing their sustainable power outputs, it is clear that such athletes cannot achieve their full potentials in sport without addressing these two basic principles.

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