The 3 Players Of Distance Running

An In-Depth Look At Running Economy

This is the third and final article by Jason Karp on "the three players of distance running." The two previous articles dealt with VO_2max and lactate threshold.

Although most of your athletes' running is at submaximum speeds, consuming oxygen at submaximum rates, maximum oxygen consumption (VO_2max) has historically received the most attention as a physiological indicator of aerobic fitness and endurance performance. When a group of heterogeneous subjects are studied, VO_2max does indeed correlate highly with endurance performance. However, when a homogeneous group of subjects are studied, such as a group of highly trained runners, VO_2max becomes a far less sensitive indicator of performance. How, then, are differences in endurance capabilities among individuals with similar VO_2max values explained?

In 1930, David Dill and his colleagues were among the first physiologists to suggest that there are marked differences in the amount of oxygen different athletes use when running at the same speeds, and that these differences in "economy" of oxygen utilization could be a major factor explaining differences in running performance in athletes with similar VO_2max values. Running economy is the volume of oxygen (VO_2) consumed at submaximum running speeds.

Running economy is likely more important than either VO_2max or lactate threshold in determining distance running performance because it indicates the fraction of the VO_2max that is needed to run at a given speed. For example, if two runners have the same VO_2max, but Runner A uses 70% and Runner B uses 80% of that VO_2max while running at 7:00 pace, the pace feels easier for Runner A because Runner A is more economical. Therefore, Runner A can run at a faster pace before feeling the same amount of fatigue as Runner B.

WHAT INFLUENCES ECONOMY?

There are many things that can influence how much oxygen is consumed to run at a given pace, including biomechanics, muscle fiber type, leg mass, clothing, shoe weight, wind and air resistance, and terrain. The more optimal your athletes' biomechanics (e.g., proper foot placement on the ground with just the right amount of pronation to absorb shock upon landing), the more economical they'll be. In addition, runners with a greater proportion of slow-twitch muscle

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fibers (typically long-distance runners) are more economical because slow-twitch fibers are more suited for aerobic activities. Anatomically, slim, non-muscular legs, like those of the Kenyans and Ethiopians, are more economical since it takes less energy to lift a light leg off the ground.

ECONOMY VS. EFFICIENCY

Often, the terms "economy" and "efficiency" are wrongly used synonymously. Economy refers to the relationship between oxygen consumption and running velocity, while efficiency is the ratio between the mechanical energy produced during exercise and the energy cost of the exercise. Since calculating efficiency requires calculating the amount of work done, the term "efficiency" has little meaning to running over flat ground, since in order to calculate work there must be a force produced against gravity. Although a runner's center of gravity moves vertically while running, this movement is relatively difficult and time consuming to quantify. Therefore, to calculate efficiency while running, the run must either include a grade, or it must be possible to measure the horizontal and/or vertical forces applied by the runner by using a suspended weight or strain gauge. While economy can differ greatly between runners, efficiency is similar as a result of the constant efficiency of the metabolic pathways (i.e., for a specific amount of carbohydrates or fat, the metabolic pathways produce a specific amount of energy (ATP)).

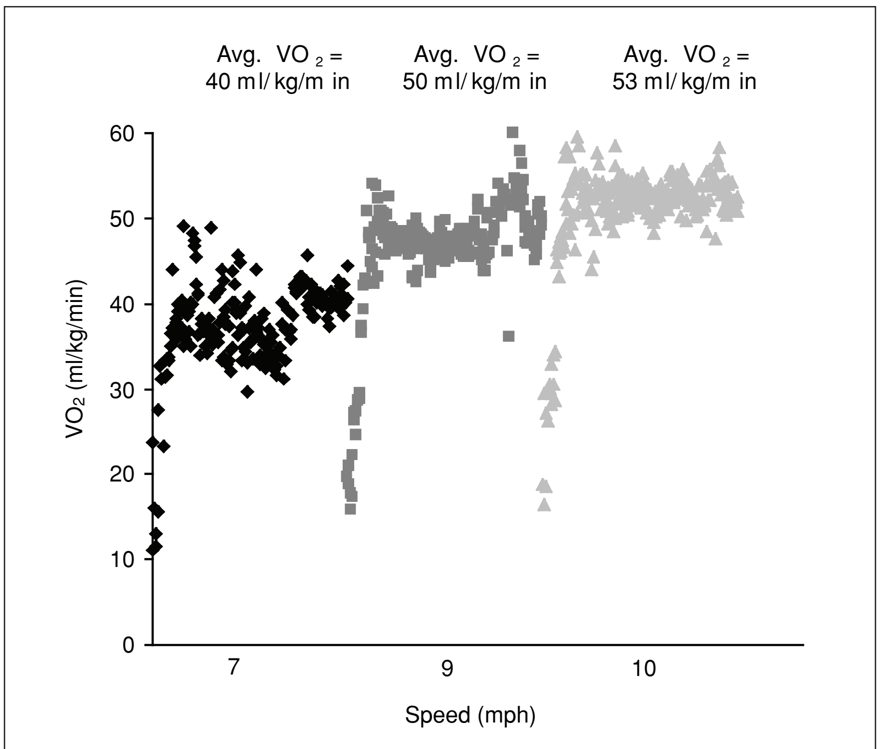

Figure 1: When running at a speed below the lactate threshold, VO_2 initially rises rapidly and then plateaus (each point on the graph represents a single breath). As the running speed increases, VO_2 increases to a larger value before plateauing. Economy is determined by averaging the VO_2 over the last couple of minutes of each run, after VO_2 has plateaued. The average VO_2 value represents the oxygen cost of maintaining that speed and can be compared among runners. The less oxygen used to maintain a given speed, the more economical the runner.

HOW IS RUNNING ECONOMY MEASURED?

Measuring aerobic economy requires all of the same laboratory equipment necessary to measure VO_2max, including oxygen and carbon dioxide gas analyzers, an expiratory air flow probe, an air mixing chamber, a dehumidifier, a vacuum pump, and a data acquisition system. Some computerized systems contain all of these things in one unit.

The treadmill test typically includes a series of five- to six-minute runs at submaximum speeds (at and below the lactate threshold) with a few minutes rest between each run (Figure 1). The athlete runs while breathing through a snorkel-like mouthpiece that connects him or her to respiratory gas analyzers and wearing a nose clip to prevent breathing through his or her nose. VO_2 is typically measured in milliliters of oxygen per kilogram of body weight per minute (ml/kg/min), but can be expressed as a function of distance traveled (ml/kg/km) rather than of time to compare the economy of athletes being tested at different speeds.

With the measurement of VO_2max, lactate threshold, and running economy, the aerobic profile of the athlete is complete. Knowing all three of these physiological variables gives you an edge over your coaching competitors. With this information, you can prescribe training speeds for a variety of workouts (Figure 2), isolate your athletes' weaknesses and subsequently tailor their training to strengthen those weaknesses, and

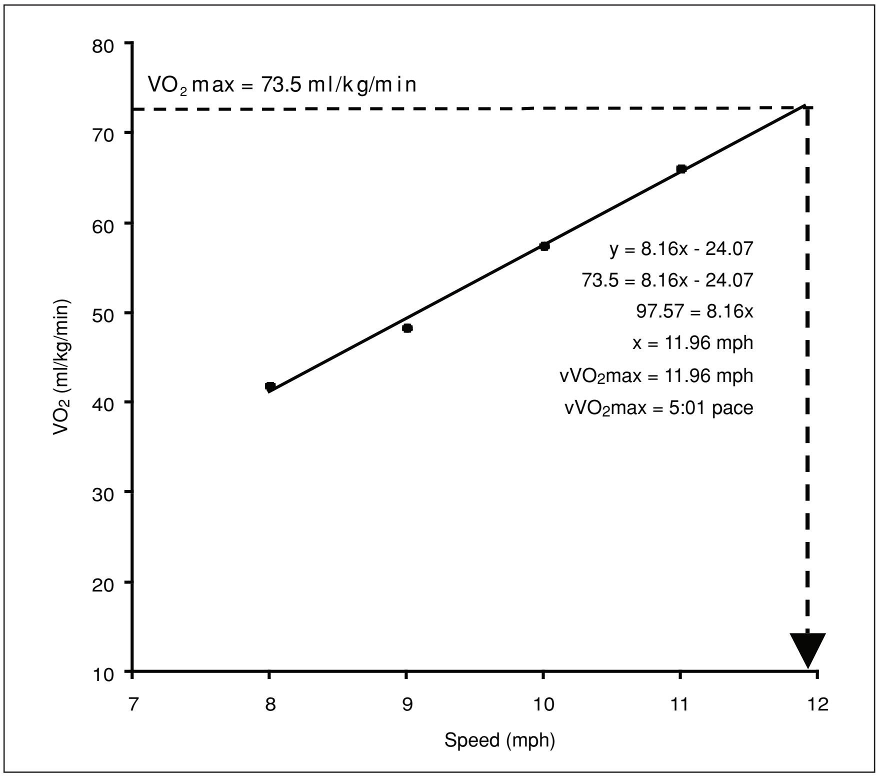

Figure 2: The results of an economy test can be used together with the results of a VO_2max test to determine the "velocity at VO_2max" (vVO_2max), the speed at which your athletes should run long intervals to improve VO_2max. First graph the average VO_2 for each speed of the economy test. Fit the points with a regression line and extrapolate the regression line out to VO_2max. From the equation of the regression line, calculate vVO_2max by substituting the VO_2max value in for y and solving the equation for x. In this same way, any speed associated with a given fraction of VO_2max can also be determined.

predict your athletes' performances (accounting for such things as the terrain and the weather) and therefore more precisely advise them on race pace.

THE COST OF BREATHING

Of course, the muscles involved in running are not the only muscles that need oxygen. Both the heart and the muscles responsible for breathing—the diaphragm and the internal and external intercostals—also need oxygen. A major consequence to the athlete of the high level of ventilatory work that accompanies intense exercise is the high oxygen cost associated with that ventilation, representing a potentially significant "steal" of blood flow from the main exercising muscles. During moderate exercise (70% VO_2max), the oxygen cost of ventilation has been estimated to equal 3 to 6 percent of total body oxygen consumption, while during maximal exercise, it equals 10 to 15 percent of VO_2max. So, if your athlete has a VO_2max of 60 ml/kg/min, 6 to 9 ml/kg/min are being used by the ventilatory muscles.

One of the more elegant effects of training may be that the body learns how to most effectively ventilate the lungs to minimize the oxygen cost of breathing, improving running economy and, thus, performance. Interestingly, the improvement in economy with training has been shown to correlate with a decrease in exercise ventilation, suggesting that improved economy may result from decreasing the oxygen cost of breathing. If your athletes can decrease how much oxygen is needed by their respiratory muscles to support breathing, more oxygen will be available for their leg muscles to support running.

One strategy that the body may adopt to maximize its economy is to coordinate, or entrain, the rhythm of breathing to the rhythm of movement. As I wrote in the Fall, 2005 issue of *Track Coach* (#173), this entrainment is done by many animals, including humans. While entraining breathing rhythm to stride rate has been shown to improve economy, it is not clear what causes this improved economy, as research on human runners has only measured whole-body oxygen consumption and has not linked improvements in economy with a decreased oxygen cost of ventilation. Whatever the precise mechanism for improved economy, coordinating the breathing and stride rhythms may be something that is subconsciously learned with many miles of running, since breathing has been found to be more tightly coupled to stride rate in trained athletes compared to untrained people.

IMPROVING ECONOMY: MILEAGE

Despite the obvious significance and performance implications of how much oxygen is needed to maintain a given speed, running economy is the most difficult of the three players to specifically train. Research has shown that runners who perform high volumes of endurance training tend to be

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more economical, which has led to the suggestion among scientists that running high mileage (greater than 70 miles per week) improves running economy. Economy is improved largely from increases to mitochondrial and capillary density, which are both enhanced with high mileage.

Runners also tend to be most economical at the speed at which they train the most, so your athletes should train at race pace to improve economy at race pace. It is possible that the greater repetition of the movements of running results in better biomechanics and muscle fiber recruitment patterns. Additionally, economy may be improved by the weight loss that usually accompanies high mileage, which leads to a lower oxygen cost.

Since VO_2max plateaus with about 70 to 75 miles per week, improved economy may be the most significant attribute gained from running high mileage. Because it's hard to prove cause and effect, it is not entirely clear whether high mileage runners become more economical by running more miles or are innately more economical and can therefore handle higher mileage without getting injured.

In addition to running lots of miles, both tempo running (e.g., 20 to 30 minutes at lactate threshold pace) and long interval training (e.g., 4 to 6 x 4:00 with 2:00 recovery) have been shown to improve economy, which is no surprise since, as VO_2max and lactate threshold improve, the oxygen cost of any submaximal speed is also likely to improve. However, it is also possible to become more economical without improving VO_2max or lactate threshold.

IMPROVING ECONOMY: WEIGHT TRAINING AND PLYOMETRICS

An important factor in distance running, as in most sports, is to produce and apply muscle force as quickly as possible. One of the keys to becoming a more economical runner is to enhance the steps involved in muscle fiber recruitment and contraction, improving the speed at which muscles produce force. A number of studies have shown that power training with heavy weights or plyometric exercises improves running economy, possibly by a neuromuscular mechanism.

MAXIMAL/EXPLOSIVE STRENGTH TRAINING

Research has shown that running economy is improved when athletes include explosive or heavy weight training in their training programs. Two studies published in *Scandinavian Journal of Medicine and Science in Sports* and *Medicine and Science in Sports and Exercise* had their subjects perform lower body exercises using heavy weights (greater than 85 percent of one-rep max, the maximal amount of weight that can be lifted once) with fast speeds for 3 or 4 sets of 5 or 6 repetitions. Other studies have used 3 to 5 sets of 3 to 5 reps to muscular failure with greater than 90 percent one-rep max. In addition to improving running economy, the subjects got stronger without gaining weight.

This type of strength training, which is ironically similar to what football players do, may be intimidating at first since it is different from what runners are typically told to do. Unlike a muscular endurance training program, which incorporates many repetitions of a moderately light weight, lifting very heavy weights will overload the force-producing characteristics of muscles.

Table 1: Sample Plyometric Training Program

To get the most out of plyometric training, it is important to concentrically contract your muscles immediately after eccentrically contracting them. To do this, try to spend as little time on the ground as possible between hops/bounds/jumps. Do exercises on a soft surface, such as grass, a rubber track, or a gymnastic mat. Begin with two sessions per week of two sets of ten repetitions (2 x 10) with full recovery between sets.

Week	Single leg hops	Bleacher hops	Double leg bound	Alternate leg bound	Squat jumps	Depth jumps	Box jumps
1	2 x 10	2 x 10					
2	2 x 10	2 x 10					
3	2 x 10	2 x 10	2 x 10	2 x 10			
4	2 x 10	2 x 10	2 x 10	2 x 10	2 x 10		
5	2 x 10	2 x 10	2 x 10	2 x 10	2 x 10	2 x 10	2 x 10
6	2 x 10	2 x 10	2 x 10	2 x 10	2 x 10	2 x 10	2 x 10

Single leg hops: 1) On one leg, hop up and down; 2) hop forward and back; 3) hop side-to-side.

Bleacher hops: Standing at the bottom of the bleacher steps on one leg, hop up the steps. Walk back down and hop up again on the other leg.

Double leg bound: From a squat position with both legs, jump forward as far as you can.

Alternate leg bound: In an exaggerated running motion, bound (which looks like a combination of running and jumping) forward from one leg to the other.

Squat jumps: With hands on hips in a squat position, jump straight up as high as you can. Upon landing, lower back into a squat position in one smooth motion, and immediately jump up again.

Depth jumps: From a standing position on a one-foot tall box, jump onto the ground and land in a squat position. From this squat position, jump straight up as high as you can.

Box jumps: From the ground, jump with two feet onto a box about one foot high, and then immediately jump into the air and back down to the ground. As you get experienced with the exercise, try jumping with one foot at a time.

PLYOMETRICS

Contrary to heavy weight training, which focuses on the strength component of power, plyometric training focuses on the speed component. Plyometric training, which includes jumping and bounding exercises involving repeated rapid eccentric and concentric muscle contractions, has also been shown to improve running economy. Muscles produce more force during the concentric (shortening) contraction if the contraction is immediately preceded by an eccentric (lengthening) contraction.

In a study from the Australian Institute of Sport, a group of highly trained runners who added nine weeks of plyometrics to their running training improved running economy and leg power more than did a control group that only ran. In another study from Finland published in *Journal of Applied Physiology*, one group of runners combined their endurance training with plyometric exercises (5 to 10 reps of 20- to 100-meter sprints and jumping exercises) and lower body weight training with light weights (0 to 40 percent one-rep max) lifted quickly, while another group did only endurance training. Only the runners who did both the plyometric and endurance training improved their economy and 5K time.

None of the research examining the effects of heavy weight training or plyometrics on economy has found changes in the other two major players of distance running—VO_2max and lactate threshold. This is an important finding because it suggests that the improvements in running economy from power training do not result from cardiovascular or metabolic changes, but rather from some other (probably neural) mechanism. When lifting maximal weights (strength), or when performing quick, plyometric movements (speed), you recruit nearly all of your muscle fibers, which serves as a training stimulus for the central nervous system. The result is that the muscles increase their rate of force development, becoming stronger, quicker, and more powerful, without the negative side effect (for a distance runner) of increasing muscle size (which would only increase oxygen cost with the added body weight). The more effective muscle force production translates into better running economy.

While all runners can certainly benefit from an improved economy of movement, only a couple of studies have actually measured whether racing performance improved after power training. These studies found that performance did improve, using either a 3K or 5K time trial. The muscle power needed for these races, which are run at or close to VO_2max, is important. However, it is unknown whether power training will improve performance for longer races, such as the marathon.

If you plan on adding this type of weight training to your athletes' programs, periodize their annual training plans to emphasize different traits (e.g., power and endurance) at different times of the year. Your athletes should do the bulk of their strength training during their speed (anaerobic) phase of training rather than during their aerobic endurance phase, since speed, strength, and power are more closely related physiological traits than are strength and endurance. Likewise, have them do their strength/power workouts on their speedwork days rather than on their recovery run or long run days.

So if you want your runners to perform at the highest level they can, they need to improve their economy. Not only will they set new personal records on the track, the shot putters won't be the only ones grunting in the weight room.

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