A Multidisciplinary Approach to Long Distance Running Training

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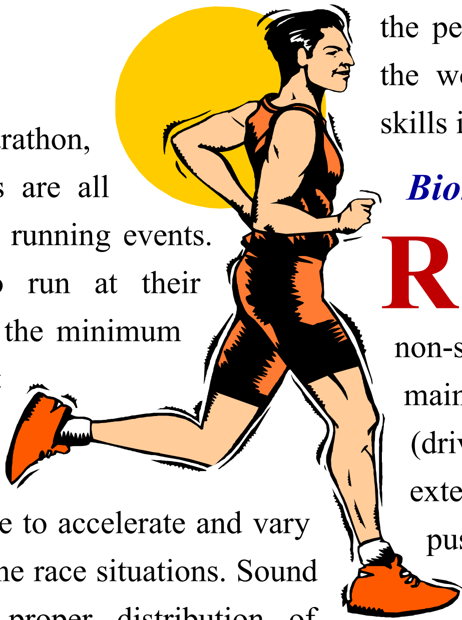
Introduction



The 10 Km, Half-Marathon, and Marathon races are all classified as long distance running events. They require athletes to run at their predetermined paces with the minimum expenditure of energy at the same time. At higher levels of competitions, athletes should also be able to accelerate and vary their speeds according to the race situations. Sound running techniques and proper distribution of efforts throughout the race are undoubtedly important for outstanding performance in these running events. On the whole, performance of such events is the combined results of technical, physical, mental, and nutritional preparation.

Training is a systematic process of preparing athletes for the highest level of performance. As an old Latin proverb says: "Many roads lead to Rome", which means that many ways can lead to the same goal. The following sections will try to use a multidisciplinary approach to discuss the training for these long distance running events.

Technical Considerations

The long distance running events require athletes to run at a relaxed and coordinated manner because only in this way can energy be conserved. As Zimkin (1959) stated almost fifty years ago, "The better the coordination of movements and the fewer muscles are involved in the performance of a given movement, the longer the work can be pursued". Correct execution of skills is definitely the heart of running economy.

Biomechanical Aspects of Running

Running is cyclic movements composed of two main phases: the supporting and non-supporting phases. Forward movement is mainly achieved by the alternating push-off (driving) action in the rear support phase. By extending the hip-, knee-, and ankle-joints of the push-off leg, a force greater than that of the body weight is applied backward and downward against the ground (i.e., action). The frictional force exerted back from the ground, which is in the opposite direction (i.e., reaction), acts on the body and propels it forward.

Running Economy

A running action is considered as economic when the runner's energy is expended solely on overcoming the forces of resistance he encounters. The greatest expenditure of energy undoubtedly takes place during the push-off phase. Energy is further required for overcoming air resistance, which increases with the running speed, and for coordinating the various parts of the body.

Running involves a rapid change of muscular contraction and relaxation. A skillful runner should be able to avoid unnecessary muscular tension so that she can apply her energy more effectively. "The ability to relax is therefore of vital importance in an economic running movement." (Schmolinsky, 1983)

The Running Technique

Body Position

1. Almost erect position of the upper body or lean slightly forward.
2. Head aligns naturally with body; eyes look forward at a distance far away.
3. Relax muscles of the face and the neck.

Drive and Swing

1. As the swinging leg moves forward and upward, the driving leg impulsively extends its hip joint, followed by the knee and ankle joints.
2. The small muscles of the sole also need to contract actively.
3. Finally, push-off the ground with the toes.

4. The lower leg of the swinging leg should be relaxed all the time, hanging loosely from the knee.
5. At the end of the drive phase, the driving leg (i.e., the support leg) extends almost completely. The lower leg of the swinging leg is almost parallel with the driving leg.
6. The longer the distance, the lower the knee of the swinging leg raised.

Recovery

1. As the driving leg breaks ground-contact, the heel of this foot rises towards the hip.
2. The knee of the other leg (i.e., the swinging leg) has to relax, getting ready for the landing.

Landing and Support

1. The foot forward of the body should make ground-contact (with knee slightly bent) about 15 to 30 cm in front of the projection of the body's centre of gravity (C.G.).

2. The outer edge of the ball of the foot makes ground-contact first. Immediately afterward, the foot rolls inward and the heel comes to the ground to bear the full weight of the body.
   - The ground-contact can also be made with flatted foot.
   - Do not deliberately avoid the heel from making contact with the ground.
   - The knee is slightly bent when the foot rest flat on the ground.

Arm Movement

1. Hold the fists lightly, with the thumbs resting on the index fingers.
2. Elbows bend at 90 degrees or smaller.
3. Arms keep close to the body.
4. Shoulders and chest should be relaxed, and arms should be swinging naturally just to counterbalance the momentum of the leg movements.
5. No forceful arm actions should be emphasized.

Components of Running Speed

Running speed is the product of stride length and stride frequency, and their relationship can be expressed as follows:

Speed = Stride Length × Stride Frequency

Stride length and stride frequency are always interdependent, and maximum running efficiency exists only when they are in the right proportion. Although speed can be improved by either increasing the stride length or stride frequency, or both, the increase in one component should never sacrifice the other.

Biomechanical Analysis of the Running Technique

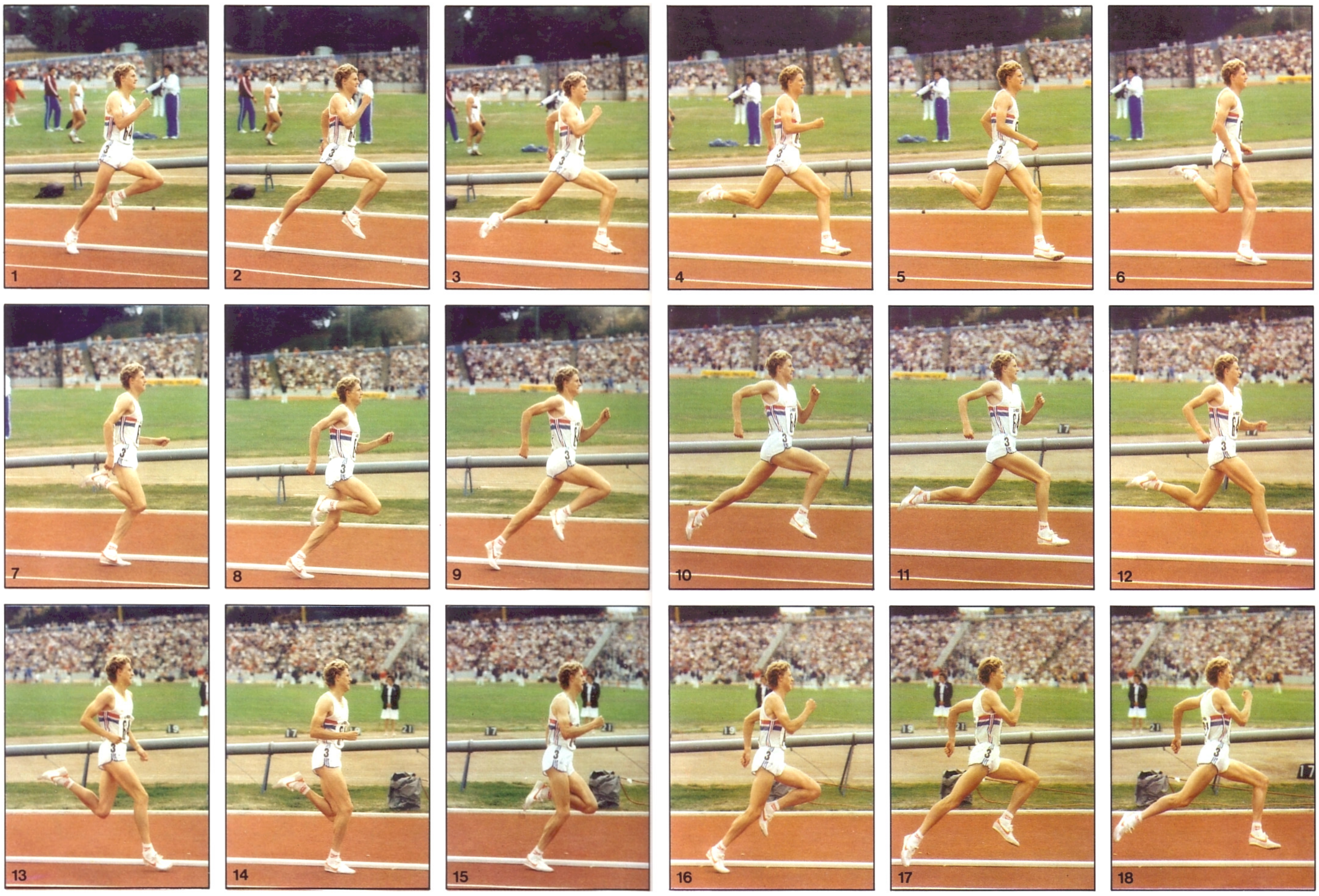
Leg Movement

For the purpose of analysis, the complete cycle of leg movement can be divided into three phases: support, drive, and recovery.

Support Phase (Photos 6-7; 13-14)

The support phase starts once the foot makes contact with the ground and ends as the C.G. of the athletes passes forward of it. The function of the support phase is twofold: (1) to absorb the shock of impact (through the flexion of the hip-, knee-, and ankle-joints) caused by the downward motion imparted by gravity at the end of the recovery phase; and (2) to prepare the athlete for the next stride with the minimum loss of forward momentum.

The method of making foot contact (i.e., landing) is the most controversial part of the long distance running techniques. Many coaches and authors advocate the "heel-ball-toes" approach, during which the athlete lands with her heel on the ground, and then rolls to the ball of the foot, and finally pushes off with the toes. Actually, however, at the moment the heel makes contact with the ground, the forward motion of the foot will continue to move forward (Newton's first law),



Steve Cram (Great Britain): Silver medalist of 1984 Olympic 1500 m (3:33.40) and world record holder of 1500 m in 1985 (3:29.67).

exerting a force on the ground (i.e., action). At the same time, the ground will response by giving back a force of "reaction", which is equal in magnitude but opposite in direction (Newton's third law) that retards the athlete's forward speed. Similar situation also occurs when the athlete overstrides by swinging the lower leg forward just before the foot lands.

A more reasonable approach (normally referred as the "ball-heel-ball" approach by track coaches) is to make ground-contact with the outer edge of the ball of the foot first, and immediately afterward, the foot rolls inward and the heel comes to the ground to bear the full weight of the body. Besides, the foot continues to move backward so that a forward horizontal reaction is evoked and the athlete's forward momentum (and thus, speed) is increased. Nett (1964) also pointed out that for longer runs at slower paces; the contact point shifted a bit further back toward the heel. Moreover, even the heels of sprinters made contact with the ground. Payne (1983) found that in a group of 18 international sprinters competing in events up to 200 m, only one did not lower the heel to the track. In another group of 41 international runners competing over 400-1500 m, only 6 used the same technique. Therefore, it is unnatural to deliberately prevent the heel from dropping onto the ground. Deshon and Nelson (1964) also concluded from their study that efficient running was characterized by the placement of the foot as closely as possible beneath the C.G. of the runner.

<u>Drive Phase</u> (Photos 7-9; 15-17)

The drive phase commences as the support phase ends, and terminates as the foot (i.e., the toes) leaves the ground. The athlete should forcefully extend the hip-, knee-, and ankle-joints, exerting the force downward and backward, which causes the body to be projected forward and upward into the next stride. The athlete's speed as the foot leaves the ground (and thus the stride length) is a function of the work done by the extensor muscles of the hip-, knee-, and ankle joints.

<u>Recovery Phase</u> (Photos 2-5; 10-13)

The recovery phase starts as soon as the toes leave the ground and comes to an end when the foot is brought forward for the next landing.

As soon as the foot leaves the ground, the lower leg is brought closer to the hip axis, reducing the leg's moment of inertia, and thus, increasing the angular velocity to move the leg forward for the next stride. When the athlete's thigh reaches a horizontal or near-horizontal position, the lower leg swings naturally forward, and prepares for the landing.

Arm Movement

Hinrichs (1982) concluded from his study that the main function of the arm movement was to cancel out the angular momentum resulted from the leg movement. The weaker leg drive and slower leg swing during the recovery phase for long distance runners actually develop less twisting angular momentum than sprinters; and a reduced striding frequency (about 3 strides per second for long distance runners and 4.5 to 5 strides per seconds for sprinters) also give the trunk time to take up the reaction to this angular momentum without recourse to forceful and exhausting arm movement (Dyson, 1986). Therefore, long distance runners should conserve their energy by avoiding vigorous arm movement.

Air Resistance

For all running events, some energy is always wasted in overcoming air resistance, which varies directly with the square of the speed of the athlete. The faster the athlete runs, the greater will be the air resistance. Dyson (1986) has estimated that when running in still air, if the athlete's speed is 10.67 m/s (i.e., the maximum speed of most elite sprinters), the air resistance acting on the athlete is 15.93 N, or 3.58 lb. Thus, long distance runners should avoid taking the lead, particularly on windy days. On such occasions, they should try to run behind or beside other runners, letting others to withstand the head-wind or side-wind for them.

Running Speed and Aging

According to Anderson (n.d.), after having videotaped 162 international runners (83 males and 79 females) and digitized the images for biomechanical analysis, Dr. Nancy Hamilton of the University of Northern Iowa found that the change in stride frequency with aging was not significant. The stride frequency of runners in their 80s was only about 4 to 5% slower than their 35-year-old counterparts. On the other hand, stride length declined dramatically by 40% for runners of 35- to 39-year-old versus those of 90-year-old (from 2.36 m per step to 1.42 m per step). Therefore, she concluded that "even though the legs of older runners were still moving quickly, they were not gaining as much distance per step".

The fall in stride length was found to be more related to the decrease in range of motion at the hips and knees. For example, Hamilton found that knee flexion during running decreased by 33% (from 123 degrees to just 95 degrees) between the ages of 35 and 90. Decreased knee flexion during the recovery phase (i.e., less tucked up by the buttock) increases moment of inertia of the leg, and thus, decreases the angular velocity of swinging the leg forward for the next stride. In addition, Hamilton found that the loss in range of motion at the hip was even greater (dropped by 38% between the ages of 35 and 90). Therefore, good flexibility of the hip- and knee-joints, as well as the quadriceps (i.e., the big muscle in the front of the upper leg) are key factors in preserving stride length (and thus speed) for runners of older ages.

Another discovery in Hamilton's study was that older runners tended to spend more time with their feet "planted" to the ground. The longer the foot is on the ground, the more speed is lost. Thus, decreasing the foot strike time by making it brief yet very explosive in terms of force production is another technique to improve speed. For someone who finishes 5 Km in 30 minutes, the overall race time can be improved by almost one minute if each foot strike time can be snipped just by $1/100^{th}$ of a second.[1]

Physiological Considerations

Movements in sports are the results of muscular contractions. Energy must be continually supplied to muscles in order to perform work. However, energy liberated from the breakdown of food cannot be used "directly" by muscles. It must be used to manufacture another high-energy chemical compound called adenosine triphosphate (ATP), which is stored in all muscle cells. When ATP is broken down, energy is released, which can then be used by the muscle cells to perform work.

Unfortunately, the total storage of ATP in the human body is very limited—just enough for a few seconds of maximal efforts. ATP is constantly being used up and regenerated, and the regeneration of ATP also requires energy. There are three energy systems in the human body for the resynthesis of ATP. Two of them are anaerobic systems, and the other one is an aerobic system.

[1] Assuming that the runner makes 180 steps in a minute, she would have made $180 \times 30 = 5{,}400$ steps in her 30-minute run. If she saves $1/100^{th}$ second for each foot strike, then she would have saved $5{,}400 \times 1/100 = 54$ seconds.

The Energy Systems

The ATP-PC system and the lactic acid system are anaerobic energy systems because they do not require oxygen for the resynthesis of ATP. The oxygen system, on the other hand, is an aerobic energy system because oxygen must be present during the process of ATP resynthesis.

ATP-PC System

Another high-energy chemical compound stored inside the muscle cells is creatine phosphate (PC). When PC is broken down, the energy released can be used to resynthesize ATP. Unfortunately, the total stores of PC in the human body is also limited—just for another few seconds of maximal efforts. Besides, the resynthesis of PC also requires ATP. When the PC stores are depleted, they cannot be replenished effectively until the recovery process starts. The total energy supply from the ATP-PC system would probably be exhausted after only about 10 seconds of maximal efforts, such as sprinting 100 meters. However, the ATP-PC system represents the most rapidly available source of ATP for use by the muscles.

Lactic Acid System

Under anaerobic condition, carbohydrate[2] is broken down incompletely to release energy for the resynthesis of ATP. However, the total amount of ATP produced is very much less than that when broken down completely under aerobic condition. Besides, lactic acid, which is the by-product of anaerobic metabolism, is also a limiting factor of human performance. Holloszy (1982) stated that there appeared to be an upper limit to the amount of lactic acid that can accumulate before a performer must stop with severe muscular fatigue. Nevertheless, the lactic acid system is still a relatively rapid supply of ATP energy, and is particularly important for maximal efforts that can be lasted between 1 to 3 minutes, such as the 400 m and 800 m runs.

Oxygen System

The total amount of energy that can be manufactured through the oxygen system is difficult to estimate because not just carbohydrates, but also fats[3] and proteins[4] can be used as "fuels". Thus, the oxygen system is particularly important for ATP resynthesis during prolonged exercises such as running a Marathon.

Energy Supply during Rest and Exercise

At Rest

Under resting conditions, oxygen supply is abundant. Energy is mainly supplied by the aerobic system. About two-thirds of the food fuel is contributed by fats, and the other one-third is contributed by carbohydrates. The contribution by proteins is again, negligible.

Exercises of High-intensity but Short Duration

Any exercise that can only be lasted up to 2 to 3 minutes such as the 100 m, 200 m, 400 m, and 800 m runs is classified under this category. The major food fuel is carbohydrates, with fats minor and proteins—once again negligible. Energy requirement is so rapid that it cannot be supplied from the aerobic system alone. All such exercises require the organism to produce energy for

[2] In the human body, all carbohydrates are converted to the simple sugar glucose, which can either be used immediately in that form or stored in the liver and muscles as glycogen for use later.

[3] It requires about 15% more oxygen to generate the same amount of ATP from the aerobic breakdown of fat than from glycogen, which is not a favorable condition during exercise.

[4] The contribution of proteins for energy production is normally negligible, unless during starvation and conditions of severe carbohydrates deprivation.

muscular work under an oxygen deficit. Thus, the anaerobic systems (i.e., the ATP-PC system and the lactic acid system) are the predominant energy systems for these events.

For exercises of very high intensity and brief duration, the ATP-PC system is the predominant energy system. For exercises that last between 2 to 10 minutes, the lactic acid system gradually and eventually replaces the ATP-PC system to become the predominant energy system. However, with the rapidly increased level of blood lactic acid (as a result of anaerobic glycolysis[5]), the activity needs to be stopped or continued at a much lower intensity.

Prolonged Exercises of Submaximal-intensity

Any exercise that can be lasted for 10 minutes or longer is classified under this category. The oxygen system is the predominant system for energy production. The major food fuels are carbohydrates and fats. For exercises that last up to 20 minutes, carbohydrates are the dominant fuel for energy production. As the time of performance proceeds past an hour, the glycogen stores decrease significantly, and fats become more important as a fuel for energy production. For this kind of prolonged exercises, the ATP-PC system and the lactic acid system mainly contribute at the beginning of the exercise, or when the athlete accelerates at the middle or at the end of the race.

For exercises of longer duration (such as Marathon running), lactic acid level in blood at the end of the race is only 2 to 3 times of resting level[6] (Costill & Fox, 1969). Factors leading to fatigue include: (1) low blood glucose levels due to depletion of liver glycogen stores; (2) local muscular fatigue due to depletion of muscle glycogen stores; (3) high body temperature due to loss of water (dehydration) and electrolytes; and (4) feeling of boredom. (Costill, 1974)

Implications for Long Distance Runners

For competitors in the long distance running events, one of the most important concerns is pacing. If an athlete starts out too fast or begins her final kick too soon, lactic acid will accumulate to very high levels and the muscle glycogen stores will be depleted early in the race. Consequently, the race may be lost, owing to the early onset of fatigue. Therefore, long distance runners should maintain a steady, but sufficient pace throughout most of the race, and then finish with an all-out-effort.

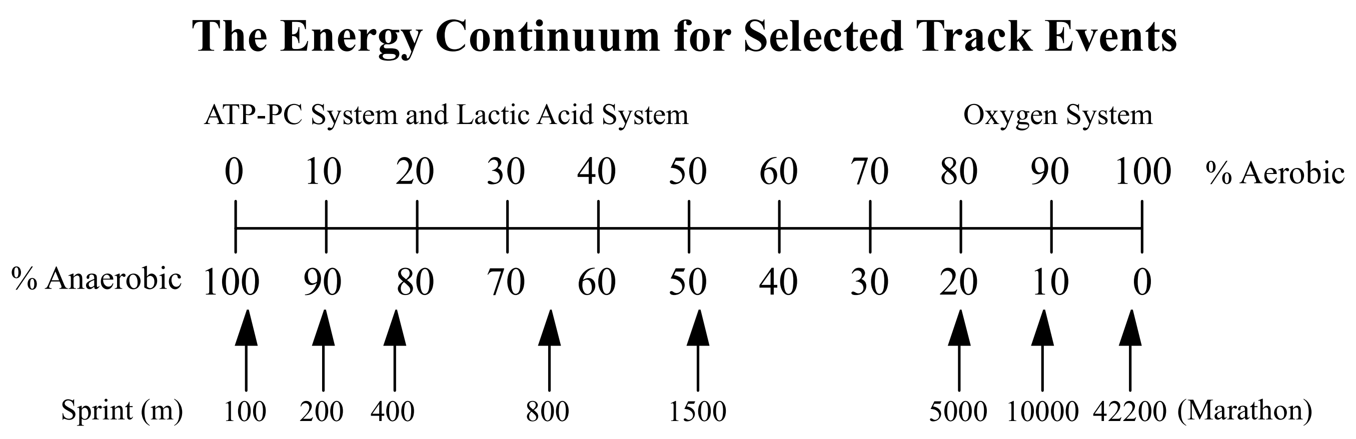


Figure 1. The approximate percentage of contribution of anaerobic and aerobic energy sources in selected track events. (Fox, Bowers, & Foss, 1993)

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5 That is, the anaerobic breakdown of carbohydrates.

6 The resting level of blood lactic acid is about 10 mg%.

Training Methods for the Long Distance Running Events

Long distance running training aims at improving both the anaerobic and aerobic capacities of athletes. The longer the running distance, the more important aerobic capacity with related to performance, and vice versa.

Most long distance running training programs include both anaerobic and aerobic running training. Running training that raises the heart rate to about 80% of the athlete's maximal heart rate (HR_{max})[7] is mainly for the development of aerobic capacity. Running training that raises the athlete's heart rate to 90% of her HR_{max} or higher aims at anaerobic development. The proportion of anaerobic and aerobic training depends on the athlete's major event. The longer the race distance, the more aerobic running training should be emphasized, and vice versa.

Different Types of Running Training

Long distance runners usually employ two main types of running training: continuous running training, and interval running training. Besides, repetition running training and fartlek training are also utilized by many long distance runners in their training programs.

A. Continuous Running Training

Continuous running training involves running continuously for relatively long distances. Wilt (1968) also classified continuous running training into two categories: continuous slow-running training and continuous fast-running training.

(1) Continuous Slow-running Training

Continuous slow-running means running for long distances at a slow pace. This type of running is also referred to as LSD (long, slow distance) by some runners. Generally, athletes should cover from 2 to 5 times of their race distance at a pace that can bring their heart rate to 80 to 85% of the HR_{max} (Fox, Bowers, & Foss, 1993). Continuous slow-running training is mainly used by long distance runners as foundation training before moving up to continuous fast-running training, or as easy running sessions on recovery days.

(2) Continuous Fast-running Training

When compared with continuous slow-running training, continuous fast-running training is conducted at a faster pace, resulting in earlier fatigue and less distance is covered. The intensity of the run should bring the athlete's heart rate to 85 to 95% of the HR_{max} (Fox et al., 1993). Continuous fast-running training also simulates the race situation better than continuous slow-running training.

B. Interval Running Training

Interval running training refers to a series of repeated bouts of runs alternated with periods of recovery. The intensity or speed of the runs is usually greater or faster than that can be done continuously for the whole training session. The recovery periods are usually occupied by light or mild exercise (e.g., walking or jogging) rather than complete rest.

C. Repetition Running Training

Repetition running training is similar to interval running training. However, the length of the runs is usually longer (e.g., 800 m or more), and the recovery between repetitions is more complete (e.g., a recovery heart rate well below 120 beats per minute). Repetition running training is usually employed by the competitive track athletes to simulate the type of stress they normally encounter under race situations. Two basic forms of repetition running are:

[7] HR_{max} = 220 – Age (beats/minute)

(1) Running one-half the race distance at race pace or faster than race pace. This is repeated so as to accumulate from 1.5 to 2 times the race distance.

(2) Running three-quarters of the race distance at slightly slower than race pace. Again, repetitions should accumulate from 1.5 to 2 times the race distance.

No matter which form of repetition running training is being used, the recovery between repetitions should be almost complete.

D. Fartlek Training

Fartlek is a Swedish word meaning "speed play". It is interval running training without the use of a stopwatch or measured track. Fartlek usually involves alternating fast- and slow-running over natural terrain, and can be thought of as an informal interval running training program in that neither the runs nor the recovery periods are precisely timed. An example fartlek training sessions may be conducted as below (Gardner & Purdy, 1970):

1. Jog 15 to 20 minutes until warmed-up.
2. Run one set of 200 m and 300 m fast-slow interval at 400 m pace.
3. Follow without stopping by using 3000 m pace to run 800 m to 1200 m continuously.
4. Jog until breathing becomes comfortable again.
5. Sprint 300 m (preferably uphill).
6. Continuous running for 800 m to 1200 m.

The athlete may continue to run as above until a distance of 5 to 15 Km is covered. The actual speed and length of the run depends on the athlete's fitness, major event, and purpose of the run. However, athletes employing fartlek training must have very good self-control or discipline; otherwise, the fartlek training session may eventually become a "fooling-around" session.

Interval Running Training

It is not difficult to understand that in a single training session, the athlete cannot repeat the complete race distance at race pace for more than once. The longer the race distance, the longer the recovery takes, or the quality of the subsequent runs has to drop. The advantage of interval running training is that quantity of the runs can be increased while quality can be maintained.

A. Physiological Foundation of Interval Running Training

Åstrand et al. (1960) found from their cycling test that a workload (350 W) that could originally be tolerated continuously for 9 minutes, if changed to be performed intermittently, could be executed for 30 minutes within an hour[8].

Christensen et al. (1960) also obtained similar results with their treadmill test. In their experiment, when the treadmill was set at a speed of 20 Km/hr, the subject could only run continuously for 4 minutes (covering a distance of about 1300 m), and the blood lactic acid level at the end of the test was 16.5 mM. When the activity was conducted as alternating periods of 10-second run and 5-second

[8] They also found that the longer the work intervals, the more exhausting the exercise appeared, even though the rest periods were correspondingly increased. For instance, at the same workload of 350 W, when the activity was conducted as alternating periods of 3-minute cycling and 3-minute rest, the subject completed 30 minutes of cycling within one hour, and become totally exhausted at the end of the test. However, when the activity was conducted as alternating periods of 30-second cycling and 30-second rest, the subject still completed 30 minutes of cycling within one hour, but was not that exhausted. The blood lactic acid level after the test (2.2 mM) was only a little higher than resting level (1 mM), and was far lower than 9 minutes of cycling continuously (16.5 mM) and alternating periods of 3-minute cycling and 3-minute rest (13.2 mM).

rest, the subject completed 20 minutes of running at 20 Km/hr in a 30-minute period (covering a distance of 6670 m) without undue fatigue, and the blood lactic acid level at the end of the test was only 4.8 mM.

The low blood lactic acid level at the end of the test indicates that anaerobic glycolysis was not the predominant source of energy supply. It should also be noted that the oxygen uptake and pulmonary ventilation were also high during the interspersed resting periods (Åstrand & Rodahl, 1986).

Implications for Long Distance Runners

From the results of the experiments conducted above, it is clear that interval running training allows the completion of total work at higher work rate than would be possible during continuous exercise alone. By adjusting the speed and length of the runs, number of repetitions, duration and type of recovery, it is possible to stress either (1) the aerobic system without significantly mobilizing the anaerobic systems, or (2) the anaerobic systems without maximally taxing the aerobic system, or (3) both the aerobic and anaerobic systems at the same time (Åstrand & Rodahl, 1986).

B. *Methods of Conducting Interval Running Training Programs*

Classical interval running training was developed in Germany in the 1930s, and the complete workout is fairly tightly structured and monitored by stopwatches (Reilly, 1981). The original form of interval running as conceived by the German coach Gerschler and physiologist Reindall was to repeat a set distance in a set time with a fixed recovery jog between (Watts & Wilson, n.d.). A typical session for a 1500-meter runner with a personal best of 3:40 could be 8 repetitions of 400 meters in 57 to 58 seconds, with a recovery jog of 300 meters covered in 3 minutes (Alford, Holmes, Hill & Wilson, 1985). The famous long distance runner Emil Zatopek of Czechoslovakia (Olympic gold medalist of the 5000 m, 10000 m, and Marathon in 1952) once completed a series of 20 × 200 m, 40 × 400 m, and 20 × 200 m in an interval running training session.

Heart rate can be used as the "yardstick" for measuring the intensity of the work and rest intervals. Traditionally, distance of 100, 200, 300, and 400 meters were favored, and athletes should look for a pulse of 180 beats/minute after the fast effort and approximately 120 beats/minute after the recovery jog (Alford et al., 1985; Reilly, 1981; Watts & Wilson, n.d.). Watts and Wilson also suggested distance of 100, 200 or 300 meters to be used for 800-meter runners; similar distance plus 400 meters for 1500-meter runners; 200, 400, or 600 meters for 5000- and 10000-meter runners.

Based on Fox et al. (1993), when conducting an interval training program, one must decide which energy system or systems is/are to be improved. Then the appropriate type of exercise (e.g., running, in the case of improving running performance) is selected and used during the work interval (i.e., the portion of the interval training program that consists of the high intensity work). The intensity and length of the work interval should be based upon the primary energy system being used in the sport event. For example, sprinters should have short but high-intensity intervals, whereas Marathon runners may run intervals of 3 miles at race pace or slower (Jensen & Fisher, 1979). To determine the proper intensity of the work interval, Fox et al. suggested that the training heart rate should be between 85 and 95% of the HR_{max} for high-school and college athletes and students. Previous research such as that conducted by Sharkey and Holleman (1967) also supported that there was a need for exertion prompting the heart rates above 150 beats per minute in order to obtain significant training effects.

Sharkey (1986), based on previous studies, stated that approximately equal work and rest intervals between 2 to 5 minutes seemed to produce the greatest aerobic improvements. In addition, shorter work intervals (e.g., 15 seconds) with a work-rest ratio of 1:1 are also effective in developing the aerobic system. For anaerobic training, the maximum duration for any work interval should not exceed 90 seconds, or the body might switch to the aerobic system to support the ongoing activity. Moreover, investigation conducted by Gaiga and Docherty (1995) indicated that aerobic interval training program might even enhance performance in repeated high intensity, short duration work.

For most interval training sessions, Fox et al. (1993) recommended that the number of repetitions of the work interval should provide a total working distance of between 1.5 and 2 miles to achieve maximum improvement. With longer work intervals (e.g., 800 yards and over), usually a 1:1 or 1:1.5 work-rest ratio is prescribed; with moderate duration intervals (e.g., 400 to 600 yards), a 1:2 work-rest ratio is used; and with shorter work intervals, a 1:3 work-rest ratio is prescribed. More recently, Babineau and Leger (1997) also showed that aerobic interval running using either 400, 800, or 1600 meters as the working distance with a work-rest ratio of 5:1 was also a good simulator and indicator of endurance performance (at least true for the 5000-meter time trial in their study). Besides, the 5:1 work-rest ratio made the training more intense and reduced the total training time when compared to the traditional intermittent training ratio of 1:1 or 1:1.5.

Finally, active recovery rather than passive recovery during the rest intervals is preferred because most studies indicated that subsequent performance was enhanced when low-intensity exercise instead of complete rest was performed during the rest intervals (Bogdanis, Nevill, Lakomy, Graham & Louis 1996; Signorile, Ingalls & Tremblay, 1993).

Wilt (1968) has also worked out a method for conducting interval running training. According to Wilt, the times for training distances between 55 and 220 yards should be between 1.5 and 5 seconds slower, respectively, than the best time for those distances measured from running starts (e.g., for training distances of 110 and 220 yards, add 3 and 5 seconds, respectively to the best times taken from running starts). For training distances of 440 yards, the rate of work would be 1 to 4 seconds less than one-fourth the time required to run a mile. If the training distance is over 440 yards, each 440 yards of that distance should be run at an average speed of 3 to 4 seconds slower than the average 440-yard time in the mile run.

C. Computerized Running Training Programs

Another approach to quantify the intensity, number of work intervals, and rest periods between the work intervals is using the computerized running training tables developed by Gardner and Purdy (1970). The first step involves timing the athlete for her best event, and then determines the "point level' for the athlete from the "Scoring Tables." The corresponding "Point Level Pacing Table" then shows various combinations of repetitions and times, as well as the recommended rest intervals between work intervals appropriate to be used by the athlete. It was reported that there was a close correlation between the programs generated in the book, and the actual workouts of world-class runners (Jensen & Fisher, 1979).

There had also been an electronic version of the computerized running training tables distributed on the Web. The program was called Quintessential Sophistry Point and Pace Calculator and was developed by Michael Sargent, based on Gardner and Purdy's formulae. Unfortunately, the program is no longer available for download due to some copyright issues.

Principles of Running Training

It is generally accepted that "Practice makes perfect." Sharkey (1986) even stated that sport consisted of about 99% preparation and 1% performance. However, as clarified by Vernacchia, McGuire, and Cook (1992), practice does not necessarily make perfect; because only perfect, planned, purposeful practice makes perfect. Peak performances and lifetime bests seldom occur by chance. Very often, they are the results of careful preparation. Furthermore, training programs must be tailored to fit individual athletes, with their positions (as in team games) or events be taken into consideration. Thus, how to determine the proper training workout for each athlete has become an important concern in this matter. Not surprisingly, many guidelines for conducting training programs have been provided by exercise physiologists (e.g., Astrand & Rodahl, 1986; Fox et al., 1993) who study the acute and long-term effects of training and sport participation on physical responses.

The principles of running training are not much different from the more general sport training principles, and several of the more important sport training principles are summarized as below.

Principle of Specificity

All sport training programs must be specific in order to develop the appropriate energy systems and muscle groups used during sport performance (Fox et al., 1993). As stated in Hewson and Hopkins (1996), in distance running, training could consist of a variety of workouts that appeared to differ in specificity for events of different duration. For example, they suggested that continuous running at moderate intensity would appear to have the most specificity for the aerobic system and the longest running events, whereas strength training would seem to be more appropriate for sprinters than for endurance athletes. Results from their study also showed that there was a significant correlation between performance and seasonal mean weekly duration of moderate continuous running for runners specialized in longer distances.

Another concern about specificity is a maximal training effect can be achieved only when the mode of exercise is the same as that used during the skill performance. Actually, it simply means that cyclists should pedal, swimmers should swim, and runners should run. For this respect, Foster et al. (1995) found that although muscularly non-similar cross training (i.e., swimming, in their study) might contribute to improved running performance, such improvement was significantly less than that produced with increased running training.

Principle of Progressive Overload

This general principle states that the intensity of the workload required to produce a training effect increases as the performance is improved in the course of training, and in order to achieve further improvement, the training intensity has to be increased (Astrand & Rodahl, 1986). That is, once the athlete has adapted to a workload of the training program, the workload should be increased. Besides, the workload should be increased throughout the training program whenever the condition of the athlete has been improved so that the workload is always near to the maximal fitness capacity of the athlete (Fox et al., 1993). As cited in Astrand and Rodahl, the need for a gradual increase in training load with improved performance was demonstrated by Christensen in as early as 1931. In another study conducted by Foster et al. (1995), it was also found that the enhanced running group which increased their running training by about 10% per week improved significantly greater than the control group which continued running 60 minutes daily at a moderate pace, 5 days weekly.

Principle of Hard and Easy Days

Progressive overload does not necessary mean that one should train hard "every day". The body needs rest for recovery particularly after the tough training days or competitions. Repeated days of hard endurance training not only interfere with glycogen restoration, but also delay the recovery of muscle damage[9]. If the exercise involves a large eccentric component, such as downhill running, damage is generally more severe (Knitter et al., 2000). Gómez et al. (2002) found that it took about 48 hours to recover from a 10-Km race. Races over 20 Km, such as the Marathon took even longer to recover. Evidence suggested that the repairing process after a 42.2 Km Marathon race might take 1 to 10 weeks to be completed (Grobler et al., 2004). Therefore, there must be easy days in between so that recovery is possible. On the easy days, the athlete may take complete rest or do some easy runs (e.g., LSD). Even if the athlete insists to run every day, the principle of hard and easy days must still be followed.

[9] It is well established that prolonged, exhaustive endurance exercise can induce skeletal muscle damage and temporary impairment of muscle function. Numerous case studies suggest a link between chronic skeletal muscle damage and impaired training and racing performance in endurance athletes with a history of high volume endurance training and racing (Grobler et al., 2004).

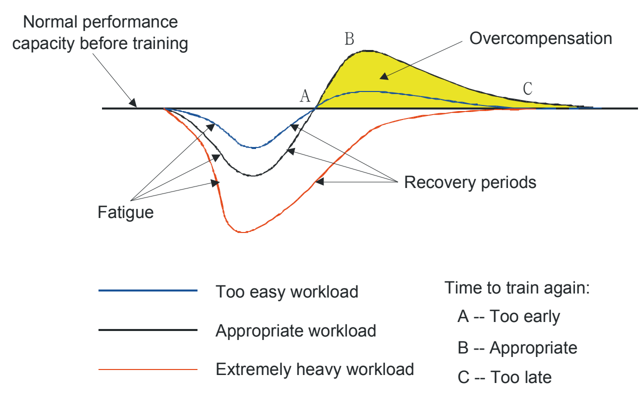

Figure 2A. After each training session, the performance capacity of the athlete drops below the initial value. With sufficient recovery, the performance capacity not just returns to its initial state, but also reaches a higher level (i.e., the overcompensation stage). The higher the intensity or/and the volume of training, the longer the recovery required.

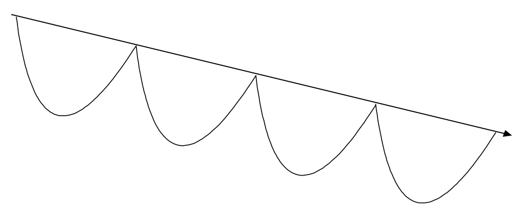

Figure 2B. If the consecutive training sessions start too early (i.e., incomplete recovery), deterioration in performance may occur.

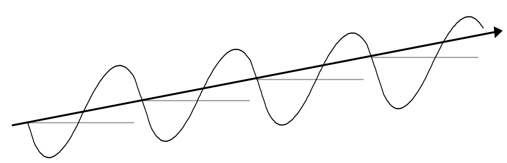

Figure 2C. If every consecutive effort takes place during the "overcompensation phase" (the closer to B the better), with a gradually increasing workload, the performance capacity will increase accordingly.

Remarks: *If the consecutive efforts take place when the "remains" of the preceding effort almost disappears (i.e., somewhere close to point C), there will be not much gain in the performance capacity.*

Principle of Individual Differences

Athletes, even of similar performance levels, may respond differently to the same training program. Sport training and coaching is actually an art even it is science based. Athletes should never blindly copy others' training programs and follow them as blueprints. All training programs should aim at improving or "fine-tuning" the technical, physical and mental qualities of individual athletes.

Principle of Periodization

Developing the athlete for top performances generally requires 6 to 8 years (Schmolinsky, 1983). Training plans for international athletes may extend over years. For most athletes, they will divide their yearly plan into three periods (assuming that there is one important competition in a year):

1. Preparatory Period (Pre-competitive Period),
2. Competition Period, and
3. Transition Period.

During the Preparatory Period and at the beginning of the Competitive Period, the quantity of training (i.e., distances for runners) is more important. When the major competition is near, quality of training (i.e., speed endurance and timing for long distance runners) should be emphasized. During the Transition Period, only light training should be carried out so that the body can have sufficient recovery from the stress of competitions.

Nutritional Considerations

Energy for rest and daily activities mainly comes from the nutrients (i.e., food) consumed every day. Such nutrients are usually classified into six categories:

1. Carbohydrates,
2. Fats,
3. Proteins,
4. Vitamins,
5. Minerals, and
6. Water.

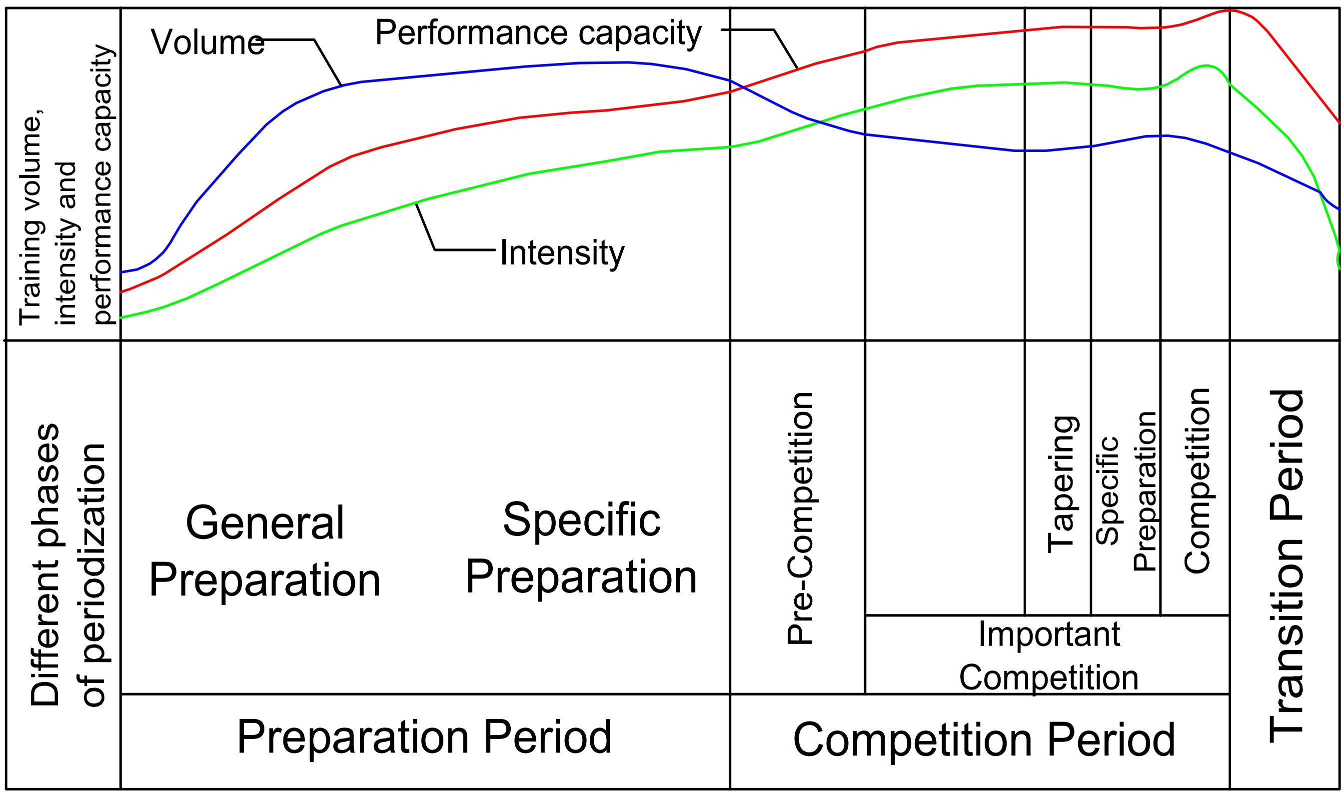

Figure 3. Variation in the quantity and quality of training during the different phases of periodization.

Under normal circumstances, energy for rest, daily activities, and exercise mainly comes from carbohydrates and fats, with very little contribution from proteins. Although vitamins and minerals provide no calories, they are important to maintain normal functions and metabolism of the body. However, vitamin and mineral supplementation above the daily consumption from a balanced diet does not increase exercise performance (Fox et al., 1993). Water is important for health and exercise. Dehydration not just decreases performance, but can also be hazardous to health. Adequate water supply must be ensured, particularly when taking part in endurance events (e.g., long distance running) in hot weather conditions.

Nutrition for Athletes

The biggest difference in food requirements for the athlete versus the non-athlete is the total number of calories consumed; and the athlete will require more (Fox et al., 1993). In the 1989 Recommended Dietary Allowances (RDAs) published by the US National Research Council, average energy requirements for slightly to moderately active female and male are 2200 and 2900 kcal per day, respectively. Actual energy expenditure is influenced by heredity, age, sex, body size, fat-free mass, and the intensity, frequency, and duration of exercise[10]. For instance, a 70-kg male runner who runs 10 miles per day at a 6-minnute pace would require an additional 1063 kcal per day just to cover the energy expenditure of the run (Katch & McArdle, 1993). A very active person who consumes more than 5000 to 6000 kcal per day may also need to eat four to five meals every day.

[10] More data concerning energy expenditure of different physical activities can be obtained from Ainsworth, B. E. (2002, January). *The Compendium of Physical Activities Tracking Guide*.

The Joint Position Statement from the American College of Sports Medicine, American Dietetic Association, and Dietitians of Canada (2000) clearly pointed out that physical activity, athletic performance, and recovery from exercise were enhanced by optimal nutrition. They recommended athletes to consume 6 to 10 g/kg body weight of carbohydrates per day. For proteins consumptions, they recommended endurance athletes 1.2 to 1.4 g/kg body weight per day. Besides, diets should provide moderate amounts of energy from fats (20 to 25% of energy). For vitamins and nutrients, unless athletes restrict themselves from energy intake or eliminate one or more food groups from their diet, supplementation of vitamin and minerals is generally not required. Once again, water must be adequately consumed before, during, and after exercise.

Pre-game Meal

The meal consumed before exercise should prepare the athlete for the upcoming activity, and leave her neither hungry nor filled with undigested food in the stomach. Therefore, the pre-game meal should be sufficient in fluid to maintain hydration, low in fat and fiber to facilitate gastric emptying and minimize gastrointestinal distress, high in carbohydrate to maintain blood glucose and maximize glycogen stores, moderate in protein, and composed of foods familiar to the athlete (ACSM, ADA, & DC, 2000).

According to Wilmore & Costill (1994), carbohydrates consumed either 5 minutes or 2 hours before, or during exercise enhance endurance performance (lasting over 1 hour). However, athletes should keep away from carbohydrates 15 to 45 minutes before exercise to avoid the secretion of insulin, which reduces blood glucose level and leads to premature fatigue.

Carbohydrate Loading

Under normal condition, muscle glycogen levels are about 15g/kg of wet muscle, which can be used for endurance activities. The total glycogen stores in the body are sufficient to supply energy for about one and a half hour of continuous work (Jensen and Fisher, 1979). Any technique that can increase the total glycogen stores inside the body should enhance endurance performance because the activity can be performed at a higher intensity (i.e., at faster speed) for a longer period of time. Endurance athletes (e.g., Marathon runners) very often employ the following carbohydrate loading techniques as described by Fox et al. (1993) to enhance their total glycogen stores.

1. Method One
   Consume a high-carbohydrate diet for 3 or 4 days after several days on a normal mixed diet may increase the glycogen stores from the normal 15 g to 25 g/kg of muscle. No exhausting exercise is performed during the period of high-carbohydrate diet.

2. Method Two
   The muscles that are to be loaded are first exhausted of their glycogen stores through exercise (e.g., running); the athlete then follows a high-carbohydrate diet for a few days. This procedure has been shown to double the glycogen stores. Again, no exhausting exercise is performed during the high-carbohydrate diet.

3. Method Three
   Exercise is used to induce glycogen depletion first. The athlete then follows a diet very low in carbohydrates but high in fat and protein for 3 days, after which a high-carbohydrate diet is followed for an additional 3 days. Exhausting exercise can be performed during the period of low-carbohydrate diet but not during the period of high-carbohydrate diet. Such procedure has been shown to increase the glycogen stores to levels approaching 50 g/kg of wet muscle.

Pre-game Meal at Different Times of a Day

If the competition is held in the morning

Consume a high-carbohydrate dinner the night before and eat only a light breakfast or some snacks in the morning on the race day.

If the competition is held in the afternoon

Consume high-carbohydrate diets the night before and in the morning of the race day. Eat a light meal or some snacks only for lunch.

If the competition is held in the evening

Consume high-carbohydrate breakfast and lunch on the race day. Eat some snacks only in the afternoon.

However, athletes must be cautious that no matter which carbohydrate loading procedure is used, it also results in an increased muscular storage of water. Each gram of muscle glycogen store is accompanied with about 3 grams of water storage. For instance, increasing the glycogen stores from 15 to 40 g/kg of muscle, a 70-kg athlete who normally has 30 kg of muscle[11] would have an extra 750 g (i.e., 1.65 lb) of glycogen and 2.25 kg (i.e., 4.95 lb) of water stored inside the muscles. This can lead to a feeling of heaviness or stiffness, which may hinder rather than help performance.

Carbohydrate Consumption during Exercise

For endurance events which last over one hour, consuming 0.7 g carbohydrate per kg body weight per hour (about 30 to 60 g/hr) has been found to enhance endurance performance. This is

[11] The human body consists of about 40% muscles by weight.

particularly true for those who have not carbohydrate-loaded or consumed pre-game meals. Besides, carbohydrates consumed at 15- to 20-minute intervals during the first 2 hours of exercise was also found to be more effective than consuming the same amount 2 hours after the exercise. Furthermore, the carbohydrate consumed should yield primarily glucose because fructose alone may lead to diarrhea, although mixtures of glucose and fructose seem to be effective. Carbohydrate consumed either as sport drink, or solid or gel plus water does not seem to matter (ACSM, ADA, & DC, 2000).

Post-exercise Meal

Glycogen stores can usually return to normal values in one or two days following strenuous exercise or competition, provided that a balanced diet is consumed. For athletes who have to compete or train several times a day, or continuously for days, high-carbohydrate diet consumed after training sessions or competitions becomes very important for glycogen restoration. Consumption of carbohydrates (e.g., 1.5 g carbohydrate per kg body weight) starting immediately after exercise at 2-hour intervals helps to restore glycogen to a higher levels than when consumption is delayed for 2 hours (ACSM, ADA, & DC, 2000). However, timing for carbohydrate consumption after exercise becomes less important when intensive training sessions or competitions are separated by one or more days, provided that sufficient carbohydrate is provided over a 24-hour period.

Hydration and Dehydration

Although water has no caloric value, it is an important medium for different kinds of reactions and metabolism inside the human body. Water makes up almost 40 to 60% of body weight and it can be obtained from drinks and food consumed as well as from metabolism. On the other hand, water can be lost through urination, defecation, perspiration, and respiration. Urine contains about 96% of water. Adults normally discharge 1000 to 1500 mL of urine daily. There is also about 70% of water in the feces, and around 100 mL of water will be lost through defecation. However, water loss as high as 1500 to 5000 mL may occur due to diarrhea alone.

Water is also important for body temperature regulation. Under normal condition, 500 to 700 mL of water will be lost through perspiration. However, sweat loss can be as high as 8 to 12 L when exercising in extremely hot weathers for prolonged periods of time. For example, a Marathon runner may lose 6 to 10% of her body weight simply due to perspiration in a race. Moreover, 250 to 300 mL of water will be lost during respiration every day. Therefore, the replenishment of water before, during, and after prolonged endurance events is particularly important.

Dehydration decreases endurance performance and heat tolerance. Long distance runners often have to reduce their speed because of dehydration. Wilmore and Costill (1994) found that a runner, who had finished the 10000 m in 35 minutes before, could run 2:48 slower due to dehydration (by 4%). Thus, it is important for endurance athletes to ensure adequate hydration before, during and after exercise. According to the joint position statement provided by the ACSM, ADA, and DC (2000):

Before Exercise

Twenty-four hours before exercise, in addition to drinking the normal amount of water (i.e., eight cups of water daily), the athlete should drink an extra 400 to 600 mL of water within the 2 to 3 hours before exercise starts.

During Exercise

The athlete should consume 150 to 350 mL of water at 15- to 20-minute intervals, beginning at the start of exercise. It is also better for the drink to contain 4 to 8% of carbohydrate if the event lasts over one hour. Adding sodium in amounts between 0.5 to 0.7 g/L may also enhance palatability and the drive to drink.

After Exercise

Since most athletes do not consume enough water during exercise to replace fluid loss, athletes should continue to drink water up to 150% of their body weight loss in order to prevent dehydration.

Implications for Long Distance Runners

Nutrition is always overlooked by athletes in their training programs. The longer the race distance, the more nutritional aspects contributes to race performance. For athletes who are planning to use any of the carbohydrate loading techniques, or to consume any kind of "power bar/gel" during the race, they had better try it out themselves some days before the race. Different persons may react differently to the carbohydrate loading technique used or to the energy-yielding food consumed. Athletes who are planning to run in 10 Km or longer races should also practice drinking water during their training runs. It takes some times for the stomach to get used to the fluid inside during exercise. Consumption of food and drink during exercise also takes time to practice.

Psychological Considerations

At the highest level of sport performance where physiological attributes and conditioning of athletes are normally evenly matched, winning and losing are often determined by millimeters and thousandths of a second. Physical preparation alone is no longer adequate to assure victory because it is most probably a matter of who are tougher in their minds that distinguishes between winners and losers. Orlick and Partington (1988) had also found that of the three major readiness factors: technical, physical, and mental; only mental readiness was significantly related to final Olympic ranking of athletes. In the same study, many highly successful athletes felt that they could have reached their peaks much sooner if they had worked on strengthening their mental skills earlier in their careers.

Cognitive Strategies of Long Distance Runners

What do middle and long distance runners think along their ways and whether cognitive strategies may help to improve their performances are some of the concerns among coaches and athletes. Research dealing with cognitive strategies and running mostly investigated the effects of associative and dissociative thinking on marathon running (Masters & Lambert, 1989; Silva & Appelbaum, 1989). As originally defined by Morgan and Pollock (1977), association referred to those mental process involved in monitoring the body and certain aspects of the exercise activity itself, such as the running pace and the distance remaining. The term dissociation referred to any thought that served to distract the runner from associative thoughts (as cited in Goode & Roth, 1993), such as listening to music, conversations with others, thinking about far-away places, or imagining pleasant situations (Tammen, 1996).

In studying how marathoners use association and dissociation in an actual race, Masters and Lambert (1989) found that their subjects showed a preference for the associative strategy while running in the marathon but were more inclined to dissociate or use both strategies while in training. In another study conducted by Silva and Appelbaum

(1989), it was found that top finishers employed cognitive strategies that utilized both associative and dissociative techniques, and lower finishers demonstrated a composite that indicated the early adoption and maintenance of a dissociative strategy. For novice runners taking part in a shorter running distance (a 1.5-mile run), Okwumabua, Meyers, Schleser and Cooke (1983) found that novice runners who employed relatively more dissociative cognitive strategies demonstrated a greater reduction in running time over trials when compared with those who reported using more associative strategies. Their results, thus, indicated that novice runners might profit from the use of dissociative cognitive strategies. In a more recent study, Tammen (1996) found that as the running pace increased, subjects who were elite middle and long distance runners reported stronger associative rather than dissociative coping strategy. In addition, all of the subjects also reported that they noticed their thoughts changed, from dissociation to association, as the running pace became more difficult.

Implications for Long Distance Runners

Concluding the research studies above, it seems that athletes tend to use association in competitions or whenever the paces of running increase. This is particularly true among athletes of higher competitive levels. Athletes must always pay attention to their bodies (for instances, difficulty and rate of breathing, coordination of paces, relaxation of muscles, etc.) in order to assess whether the paces are reasonable and suitable. On the other hand, dissociation seems to help beginning runners to reduce the tension of intensive training and competitions.

Conclusion

One may argue that "Athletes are born, not made." To a certain degree, this is true. For example, maximum oxygen consumption (max VO_2), percentage distribution of slow-twitch and fast-twitch fibers in skeletal muscles, capacity of the lactic acid system, and maximal heart rate have been found to be genetically determined to a large extent (Fox et al., 1993). However, as pointed out by Singer (1986), genetics helped because they set the machinery in motion, but there was no substitution for labor in order to become the best. Williams (1989) also said that although we could not modify our genetic potential, we could maximize what we did have through training.

Through systematic training and constant repetition, movements become more automatic and require less concentration by the higher nerve centers. As a result, the amount of energy expended is reduced (since unnecessary movements for performance of the desired task are eliminated). However, it is important to note that training is a slow and subtle process that cannot be rushed. Athletes generally need several years to achieve top results (Astrand & Rodahl, 1986) and it has also been stated that champion athletes typically train 8 to 10 years before reaching their peak performances (Sharkey, 1986). Training if done correctly, leads to impressive changes in body tissues and systems, which are normally associated with improved sport performance. On the other hand, doing too much too soon very often leads to injuries that impairs performance. For example, in a review study on running conducted by Hopkins (1991), it was found that injury rates generally increased with training volume, and more than half of the injuries were attributed either to excessive training or to an increase in training that did not give the body time to adapt. Therefore, "PATIENCE" is always the most important keyword for successful sports performance.

References

1. Ainsworth, B. E. (2002, January). *The Compendium of Physical Activities Tracking Guide*. Prevention Research Center, Norman J. Arnold School of Public Health, University of South Carolina. Retrieved 2006-12-30 from the World Wide Web. http://prevention.sph.sc.edu/tools/docs/documents_compendium.pdf.
2. Alford, J., Holmes, B., Hill, R., and Wilson, H. (1985). *Complete Guide to Running*. London: Hamlyn.

3. American College of Sports Medicine, American Dietetic Association, and Dietitians of Canada. (2000). Joint position statement: Nutrition and athletic performance. *Medicine & Science in Sports & Exercise, **32***(12), 2130-2145.

4. Åstrand, I., Astrand, P.-O., Christensen, E. H., and Hedman, R. (1960). Intermittent muscular work. *Acta Physiologica Scandinavica, **48**,* 448-453.

5. Åstrand, P.-O., and Rodahl, K. (1986). *Textbook of Work Physiology: Physiological Bases of Exercise* (3rd ed.). Singapore: McGraw-Hill.

6. Babineau, C., and Leger, L. (1997). Physiological response of 5/1 intermittent aerobic exercise and its relationship to 5 km endurance performance. *International Journal of Sports Medicine, **18***(1), 13-19.

7. Bogdanis, G. C., Nevill, M. E., Lakomy, H. K. A., Graham, C. M., and Louis, G. (1996). Effects of active recovery on power output during repeated maximal sprint cycling. *European Journal of Applied Physiology, **74**,* 461-469.

8. Christensen, E. H., Hedman, R., and Saltin, B. (1960). Intermittent and continuous running. *Acta Physiologica Scandinavica, **50**,* 269-287.

9. Costill, D. L. (1974). Muscular exhaustion during distance running. *Phys Sportsmed., **2***(10), 36-41.

10. Costill, D. L., and Fox, E. L. (1969). Energetics of marathon running. *Med Sci Sports, **1**,* 81-86.

11. Deshon, D. E., and Nelson, R. C. (1964). A cinematographical analysis of sprint running. *Research Quartery, **35***, 453-454.

12. Dyson, G. (1986). *Dyson's Mechanics of Athletics (8th Ed.).* London, Hodder and Stoughton.

13. Foster, C., Hector, L. L., Welsh, R., Schrager, M., Green, M. A., and Snyder, A. C. (1995). Effects of specific versus cross-training on running performance. *European Journal of Applied Physiology, **70**,* 367-372.

14. Fox, E. L., Bowers, R. W., and Foss, M. L. (1993). *The Physiological Basis for Exercise and Sport* (5th ed.). Dubuque, IA: Wm. C. Brown.

15. Gaiga, M. C., and Docherty, D. (1995). The effect of an aerobic interval training program on intermittent anaerobic performance. *Canadian Journal of Applied Physiology, **20***(4), 452-464.

16. Gardner, J. B., & Purdy, J. G. (1970). *Computerized Running Training Programs*. Los Altos: Tafnews Press.

17. Gómez, A. L., Radzwich, R. J., Denegar, C. R., Volek, J. S., & Rubin, M. R. et al. (2002). The effects of a 10-kilometer run on muscle strength and power. *The Journal of Strength and Conditioning Reasearch, **16***(2), 184-191.

18. Goode, K. T., & Roth, D. L. (1993). Factor analysis of cognitions during running: Association with mood change. *Journal of Sport and Exercise Psychology, **15***, 375-389.

19. Grobler, L. A., Collins, M., Lambert, M. I., Sinclair-Smith, C., Derman, W., St Clair Gibson, A., and Noakes, T. D. (2004). Skeletal muscle pathology in endurance athletes with acquired training intolerance. *British Journal of Sports Medicine, **38***, 697-703.

20. Hewson, D. J., and Hopkins, W. G. (1984). Specificity of training and its relation to the performance of distance runners. *International Journal of Sport Medicine, **17***(3), 199-204.

21. Hinrichs, R. N. (1982). *Upper extremity function in running*. Ph.D. dissertation, Pennsylvania State University.

22. Holloszy, J. O. (1982). Muscle metabolism during exercise. *Arch Physical Med Rehab, **63***, 231-234.

23. Hopkins, W.G. (1991). Quantification of training in competitive sports: Methods and application. *Sports Medicine, **12***(3), 161-183.

24. Jensen, C. R., and Fisher, A. G. (1979). *Scientific Basis of Athletic Conditioning* (2nd ed.). Philadelphia: Lea & Febiger.

25. Katch, F. I., and McArdle, W. D. (1993). *Introduction to Nutrition, Exercise, and Health* (4th ed.). Philadelphia, PA: Lea & Febiger.

26. Knitter, A. E., Panton, L., Ratmacher, J. A., Petersen, A., and Sharp, R. (2000). Effects of β-hydroxy-β-methyl butyrate on muscle damage after a prolonged run. *Journal of Applied Physiology, **89***, 1340-1344.

27. Masters, K. S., & Lambert, M. J. (1989). The relations between cognitive coping strategies, reasons for running, injury, and performance of marathon runners. *Journal of Sport and Exercise Psychology, **11***, 161-170.

28. National Research Council. (1989). *Recommended Dietary Allowances* (10th ed). Washington, DC: National Academy Press.

29. Nett, T. (1964). Foot plant in running. *Track Technique, **15**,* 462-463.

30. Okwumabua, T. M., Meyers, A. W., Schleser, R., & Cooke, C. J. (1983). Cognitive strategies and running performance: An exploratory study. *Cognitive Therapy and Research, **7***(4), 363-370.

31. Orlick, T., & Partington, J. (1988). Mental links to excellence. *The Sport Psychologist, **2**,* 105-130.

32. Payne, A. H. (1983). Foot to ground contact forces of elite runners. In H. Matsui and K. Kobayashi (Eds.), *Biomechanics VII-B*, pp. 746-753. Champaign, Il: Human Kinetics.

33. Payne, H. (1985). Athletes in Action: The Official International Amateur Athletic Federation Book on Track and Field Techniques. London, Pelham Books.

34. Reilly, T. (1981). Considerations in endurance training. In T. Reilly (Ed.), *Sports Fitness and Sports Injuries* (pp. 79-90). London: Faber and Faber.

35. Schmolinsky, G. (1983). *Track and Field*. Berlin: Sportverlag.

36. Sharkey, B. J. (1986). *Coaches Guide to Sport Physiology*. Champaign, IL: Human Kinetics.

37. Sharkey, B.J., and Holleman, J. P. (1967). Cardiorespiratory adaptatons to training at specified intensities. *The Research Quarterly, **38***(4), 698-704.

38. Signorile, J. F., Ingalls, C., and Tremblay, L. M. (1993). The effects of active and passive recovery on short-term, high intensity power output. *Canadian Journal of Applied Physiology, **18***(1), 31-42.

39. Silva, J. M., & Appelbaum, M. I. (1989). Association-dissociation patterns of United States Olympic Marathon Trial contestants. *Cognitive Therapy and Research, 13*(2), 185-192.

40. Singer, R.N. (1986). *Peak Performance... and More*. New York: Mouvement.

41. Tammen, V. V. (1996). Elite middle and long distance runners associative/dissociative coping. *Journal of Applied Sport Psychology, **8***, 1-8.

42. Vernacchia, R., McGuire, R., and Cook, D. (1992). *Coaching Mental Excellence*. Dubuque, IA: Wm. C. Brown Communications.

43. Watts, D. C. V., and Wilson, H. (n.d.). *Middle and Long Distance, Marathon and Steeplechase*. London: British Amateur Athletic Board.

44. Williams, M. H. (1989). *Beyond Training: How Athletes Enhance Performance Legally and Illegally*. Champaign, IL: Leisure Press.

45. Wilt, F. (1968). Training for competitive running. In H. Falls (ed), *Exercise Physiology*. New York: Academic Press, pp. 395-414.

46. Zimkin, N.V. (1959). *Physiological Characteristics of Strength, Speed and Endurance.* Berlin: Sportverlag.

47. 圖多・博姆帕（1990）。*運動訓練理論與方法*（馬鐵，郭小燕，周豐，馬挺譯）。北京：人民體育出版社。