

Training Principles and Issues for Ultra-endurance Athletes

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Ultra-endurance competition is defined as events that exceed than 6 hours in duration. The longer events rely on long-term preparation, sufficient nutrition, accommodation of environmental stressors, and psychological toughness. Successful ultra-endurance performance is characterized by the ability to sustain a higher absolute speed for a given distance than other competitors. This can be achieved through a periodized training plan and by following key principles of training. Periodization is an organization of training into large, medium and small training blocks which are referred to as macro-, meso-, and microcycles, respectively. When the sequencing of training is correctly applied, athletes can achieve a high state of competition readiness and during the months of hard training, avoid the overtraining syndrome. A plan is executed in accordance with the following principles of training: all-around development, overload, specificity, individualization, consistent training, and structural tolerance. Training relies heavily on the athlete's tolerance to repetitive strain. Today's ultra-endurance athlete must also follow appropriate nutritional practices in order to recover and prepare for daily training and remain injury free and healthy. Rehydration after exercise, together with the timing and method of increased food intake to cope with heavy training, are essential for optimal performance. Furthermore, the treatment of soft tissue after training or racing is necessary to control inflammation.

Introduction

Current trends in endurance participation now include much longer athletic events. Some events, such as the 90-km Comrades ultra-endurance running race founded in 1925, have stood the test of time. Others, including Ironman triathlons, have increased in availability and popularity. Furthermore, new events have been created to appeal to those athletes who still seek longer more grueling pastimes. These include adventure racing, the

3000-mile Race Across America cycling race, multistage events (Marathon Des Sables), and Ultraman Triathlons.

Defining ultra-endurance

Some investigators identify the term *ultra-endurance* as exertion greater than 4 hours [1,2]. However, a definition of ultra-endurance could be based on physiologic or psychologic reasoning. For example, the 26.2-mile marathon is an event that is completed on average near 4 hours, and it has become popular in its association with fundraising and societies. Physiologically the marathon can be labeled as ultra-endurance, but relative to the vast number of events that exceed this duration, a marathon might be classified simply as a long-distance race. For the purpose of this article, it is proposed that ultra-endurance events refer to those that are greater than 6 hours in duration. These longer events rely more on adequate exercise management and long term preparation, optimal rate of movement, sufficient nutrition to accommodate environmental stressors, and psychological toughness. Generally, the longer the event, the more important preparation becomes in successfully finishing with functional health.

Variables of Training

There are many variables that affect the outcome of an ultra-endurance event. These variables can be considered as characteristics of preparation. The successful execution of an ultra-endurance event is dependent on preparation and attention given to nutritional requirements, injury prevention, tissue regeneration, and avoidance of acute tissue trauma and overtraining.

The training required for ultra-endurance events is no different than that required for other sports with respect to underlying principles; successive stresses must be applied to the body over time in order to provide a stimulus to initiate an adaptation so that subsequent training or performance is accomplished at a higher absolute intensity or for a longer period of time. Successful ultra-endurance performance is characterized by the ability to sustain a higher absolute speed for a given distance than other competitors. From a holistic point of view, the athlete should be considered as a living psycho-social-physiologic system [3]. This holistic approach can be expanded into five areas that, when combined, culminate in an integrated view of performance: physiology, biomechanics, psychology, tactics,

and health/lifestyle. All these components need to be functioning at near-optimal levels in order to achieve a successful performance or a maximum training adaptation.

Frequency, intensity, and duration of training

The fundamental variables of physiologic stress are the intensity, duration, and frequency of training. The intensity of effort is a qualitative component and in ultra-endurance activities where distance and time are factors, absolute intensity can be recorded as speed. Relative intensity, on the other hand, can be quantified as a proportion of an athlete's maximum speed, or by a physiologic variable such as percentage of maximum heart rate or percent heart rate reserve. Intensity is generally considered to be the most critical factor of training. Within the training process, the correct balance of low-, medium-, and high-intensity training is critical to the adaptation process and if too much moderate- or high-intensity training is undertaken, there is a significant risk of fatigue which may lead to over-reaching or overtraining. The duration of training is a quantitative component referring to the length in time of a training session. Training frequency refers to the number of training sessions within a given time frame, such as a day or a week. Athletes and coaches often refer to combinations of these variables. Training volume refers to the product of duration and frequency of training (usually in a week) and training load refers to the product of all three fundamental components, frequency, duration, and intensity. The correct sequencing of changes in volume and load throughout a training year is critical to the adaptation process.

Quantification of training load

The concept of training impulse (TRIMP), developed by Bannister [4] and Morton *et al.* [5] is determined as the product of training duration and intensity where the average heart rate of a workout is multiplied by a nonlinear metabolic adjustment factor based on the classically described blood-lactate curve. The intensity of training is calculated as a delta heart rate ratio, which equals exercise heart rate minus resting heart rate divided by maximum heart rate minus resting heart rate. Although a drawback to the TRIMP method is that only aerobic intensities eliciting heart rate response up to maximum heart rate can be determined, for the ultra-endurance athlete this is a minor limitation.

An alternative method to the TRIMP system is the rating of perceived exertion (RPE) originally proposed by Gunnar Borg in 1970. The Fitness-Category scale includes a wide range of intensities ranges (6–20) from "no exertion at all" (6) to "maximal exertion" (20) [6]. Foster *et al.* [7] used the modified Category-Ratio scale from 0 to 10 [8] as a representation of a training session RPE. Training load was defined as the product of the rating of the global intensity of an entire training session and the duration of the session. Thus, load equals session RPE multiplied by duration. The session RPE was found to be related to the

average percent heart rate reserve during an exercise session [9]. These two methods of quantifying training load (TRIMP and session RPE) allow an athlete to track his or her training in order to evaluate the effectiveness of different training sequences.

Periodization of training

The sequence in which training loads or volumes are applied, as a series of training blocks, is critical to the final outcome for an ultra-endurance athlete. Periodization, as popularized by Bompa [10], is a training concept in which the year is divided into large, medium and small training blocks referred to as macro-, meso-, and microcycles. A microcycle refers to a structure of separate training sessions or small grouping of several sessions; mesocycles (3–5 weeks) are a grouping of several microcycles with a predetermined training objective or performance goal, and macrocycles (12–16 weeks) reflect groupings of mesocycles within a semiannual or annual plan. Periodization provides a framework which allows a coach to formulate a specific program to achieve improvements in physiologic, technical, or psychologic components of performance. When the sequencing of training is correctly applied through a periodized plan, athletes can achieve a high state of competition readiness and during the months of hard training, avoid the overtraining syndrome. The underlying concept of periodization is that training should progress from general to specific with the intention of peaking at competition time. Pyne [11] listed common features of periodized training programs as follows:

1. The long-term performance goal for the season forms the basis for designing the training program.
2. There is a progressive and cyclical increase in training loads.
3. There is a logical sequence to the order of the training phases.
4. The training process is supported by a structured program of scientific monitoring in the areas of physiology, biomechanics, psychology, and physiotherapy.
5. There is intensive use of recovery or regenerative techniques throughout the training program.
6. Emphasis on skill development and refinement is maintained throughout the training program.
7. There is an underlying component of the improvement and maintenance of general athletic abilities.
8. Each part of the training program builds on the preceding phase.

The success of a periodized plan is thus determined by how the training stress is applied within the comprehensive plan while taking into consideration certain principles of training [12•].

Principles of training

Principles of training have been described by various authors, including Harre [13] and Siff and Verkhoshansky [14]. For an ultra-endurance athlete, the following principles may be considered critical to success:

1. *All-around development* suggests the need for an underlying general athletic ability that is supported by a strong psychologic platform and technical ability in the various activities in which an athlete engages. Within the training process, overcoming training and competition stresses promotes willpower, self-confidence, and tolerance for higher training and competition demands [15].
2. *Overload* addresses the concept of progressively increasing the training load and volume of physical work so that after a recovery period, an overcompensation and improved fitness is achieved. Thus, an athlete will be able to compete or train at an improved absolute intensity.
3. *Specificity* emphasizes the need for practice under similar conditions to those of competition and for the ultra-endurance athlete is fundamental to success. It recognizes that specific exercises and skills are required to compete efficiently and effectively in an event.
4. *Individualization* implies that individual athletes will react and adapt differently when presented with identical training regimes [16••]. On a continuum, there are two broad categories of athletes. At one end are those who are genetically talented and at the other end are those with a highly developed work ethic, with a system guiding their effort. Thus, there is a need for individualized training programs with monitoring systems available to evaluate individual responses to a training load.
5. *Reversibility* highlights the requirement for consistent training. As suggested by the fitness-fatigue model of Bannister [4], fitness and fatigue are never constant and interruptions to training caused by injury, illness, or social needs, break the consistency of training that is required to achieve improvements. Loss of fitness can occur through inconsistent training and fatigue may occur through nontraining stress factors and inadequate recovery.
6. *Structural tolerance* implies that the body needs time to adapt to a training load. Structural tolerance is the ability to withstand weeks or months of high-volume training without the incidence of injury, illness, or fatigue that may lead to overreaching or overtraining. Through years of general and specific training, structural tolerance can be greatly improved.

Issues for Ultra-endurance Athletes

Today, the modern ultra-endurance athlete is acutely aware of the need for sustenance in order to recover and prepare for upcoming training and racing. Rehydration and recovery of fluid balance after exercise, together with the timing and method of increased food intake to cope with heavy training, are essential for optimal performance. Furthermore, specific activities may present unique challenges in administering the appropriate strategy. During an ultramountain bike race for example, it is much more difficult to meet nutritional demands than during a road biking or running race due to the nature of the event [17].

Caloric replacement

Caloric replacement is one of the key fundamentals of sustenance for ultra-endurance athletes. Some events report caloric expenditure ranging from 8500 to 11,500 kcal [2,18]. The caloric intake must be adequate to maintain the activity. Ultra-endurance events require energy contributions from all three macronutrients (carbohydrates, protein, and fat) as indicated by the duration of the event and the lower intensity [19]. The relative contribution of these macronutrients is also affected by the intensity of the performance, or frequency of intensive bouts dictated by terrain and race strategy. The higher the intensity, the more reliance there is on carbohydrates [20]. Carbohydrate diets range from 5 to 7 g/kg/d to 7 to 10 g/kg/d 3 to 4 days before competition [21••]. During prolonged running events, usage of 40 to 80 g/h have been reported [22], whereas usage of more than 90 g/h is not uncommon during cycling events [23]. Most endurance athletes report better performances and less gastrointestinal discomfort using liquid carbohydrates. Research has shown that liquid ingestion of 30 to 70 g of carbohydrate per hour or 0.2 to 0.6 g/kg body weight/h [24] can maintain blood glucose oxidation and delay fatigue. A liquid composition prescribed at 7.5% to 12% solution has been shown to minimize the chances of hypoglycemia but maximize performance as glycogen levels deteriorate [25].

A critical factor in the rate of carbohydrate ingestion is individual gastric emptying physiology. Absorption occurs in the duodenum but particle size can affect the rate at which the substrate enters. Entry via the pylorus is gained only if the particle size is no larger than 1 mm in diameter [26]. Other factors that must be taken into consideration include dietary fiber, meal volume, meal temperature, and osmolarity [26,27]. Exercise intensity and environmental stress can affect the blood flow to the small intestine consequently affecting gastric emptying and distress. The athlete must have alternate feed plans to accommodate the state of digestion and absorption. It is important that the athletes implement these feeding strategies during training at the same relative intensity and if possible under the same environmental conditions as the race. Unfortunately, it is difficult to simulate race anxiety and the affect it may have on

the gastrointestinal system, but often, the more race experience the athlete has, the less likely he or she will be affected.

Liquid meal feeding has been shown to be superior when compared with solid food [26,28]. But for some, solid food will satisfy athlete hunger and allow for more variation, which can help ensure ingestion of caloric requirements. Again, this concept should be investigated individually as taste fatigue is a real concern in ultra-endurance events. In addition, gastric emptying can be enhanced when the feeding solution contains sodium and other electrolytes [26]. Cooler liquids tend to be more readily absorbed [26], but this element may not be controllable during longer training sessions. In some races that allow support teams or provide aid stations, athletes will freeze their feed bottles and have them several hours later ensuring better liquid temperatures.

In ultra-endurance events and training, evidence suggests that protein is an essential nutrient to assist in energy requirement [29], tissue repair, and glycogen replenishment [30]. Furthermore, Zawadzki *et al.* [31] provided evidence that a ratio of 3 g of carbohydrate to 1 g of protein can enhance glycogen resynthesis, although other studies have indicated that immediate carbohydrate ingestion remains the most important factor in recovery [32]. What seems to be the common principle for ultra-endurance training and racing is that immediate ingestion of carbohydrate or carbohydrate-protein solution is necessary to replenish muscle glycogen. Some nutritional strategies have tried to promote fat oxidation for sparing muscle glycogen in order to enhance performance [33,34]. In extreme ultra-endurance events in which tremendous caloric use occurs, foods high in fat tend to be appropriate not only to provide caloric dense options, but to satisfy taste and satiety [35]. Often athletes in these ultra-events need small rewards to maintain pace. Reward foods that do not support the tradition views of performance can be used. Variations can be used to meet the athlete's desires, such as salty fat foods, or sweet savory foods. As long as the athlete is fulfilling the fundamental requirements for continued exercise, these strategies can be quite advantageous for longer events.

Fluid replacement

Adequate fluid and electrolyte replacement is critical in ultra-endurance performance and training. Dehydration increases core temperature and cardiac drift occurs when the body loses excessive amounts of fluids due to perspiration [36]. Water loss can be as high as 2 L/h in hot weather particularly if the event pushes the athletes above 70% of VO_2max [37]. In ultra-endurance events, modifications in fluid and electrolyte ingestion have been suggested to avoid hyponatremia [38]. Researchers recommend 500 to 800 mL/h during the 180-km bike portion and 300 to 500 mL/h during the marathon run, with smaller men and women advised to drink lower rates. Oral sodium supple-

mentation has been shown to assist in maintaining hydration balance during ultra-endurance events [39].

An increasing proportion of athletes develop either hypernatremia or hyponatremia in ultra-endurance events that last 6 hours or more [40]. According to Sharwood *et al.* [41], conservative drinking policy can be advocated for those Ironman triathlons that are held in moderate environmental conditions similar to those at the South Africa Ironman Triathlon, without risking the health of the athletes.

Prevention of injuries

In order for an athlete to complete an ultra-endurance event, countless hours of physical preparation are required. Consistent training relies heavily on the athlete's tolerance to repetitive strain. According to Egermann *et al.* [42], most injuries (81.3%) occur during triathlon training hours compared with 18.7% during actual competitions. But considering the hours spent training in relation to competitions, there is a sixfold higher incidence for injury during competitions. This implies that athletes tend to push their bodies to their limits during competition even beyond structural tolerance.

Treatment of soft tissue after training and racing incorporates ice and cold water therapy to control inflammation. This practice along with proper rehydration and fuel replacement should be the focus immediately following extreme physical training. Repeated recovery care will ensure successful training sessions in the immediate future.

Overtraining

Overtraining is an additional potential problem for ultra-endurance sports performers. Athletes who exhibit performance incompetence, prolonged fatigue, or an inability to train at expected levels are said to be suffering from overtraining. Overtraining occurs when an excessive training load is not compensated by a sufficient amount of recovery for a sustained period of time. Overload training, a few days of hard training followed by short-term fatigue, is an essential part of all athletes' training [43]. Overload training can, however, result in overreaching if recovery of 3 to 5 days has not resulted in performance recovery. Overreaching is characterized by a transient performance incompetence, which is reversible within a short recovery period of 1 to 2 weeks, and can be rewarded by a state of supercompensation [44]. However, if recovery is inadequate or the training load is unmanageable, overreaching can progress to overtraining and recovery may take weeks or months [45,46]. External factors that may contribute to prolonged fatigue may include excessive intensity or volume of training, incorrect sequencing of training or competitions, a lack of training background, and inadequate structural tolerance. A progressive increase in intensive training volume with a considerable increase in training volume is the strongest cause, including an imbalance between an athlete's adaptive capacity and the recovery time required

[43•]. Furthermore, issues such as social or economic factors, food intake, or sleep may play a role in leading to overreaching or overtraining. In reality, it is likely that significant inter-individual variability in recovery potential, exercise capacity, nontraining stress factors, and stress tolerance may explain the different vulnerability of athletes to training under identical training stress conditions [46].

Diagnosis of overtraining is very difficult and no exact criterion exists. A diagnosis should be based on several points, including patient history, ruling out of other diseases, laboratory findings [43•], and careful examination of the athlete's training log, paying particular attention to the sequence and load of training. A blood marker that shows promise as an indicator of overreaching/overtraining is the glutamine/glutamate ratio [47]. A lowering of the ratio in conjunction with a decline in performance and altered mood state may be a useful tool for diagnosis [48]. A common feature of overtraining is the inability to sustain intense exercise. A performance test that has been used to distinguish overtrained athletes, involves exercise associated with the individual anaerobic threshold (IAT) [49]. The duration of this stress test, an all-out short-term duration exercise test performed at an intensity of 110% above IAT, has been observed to be one of the most sensitive single objectifiable criterion in diagnosing overtraining [50]. At this time, there are no clear early warning signs of overtraining and it is suggested that the best treatment is prevention through periodization with sufficient recovery built into the program.

Conclusions

Successful ultra-endurance performance is characterized by the ability to sustain a higher absolute speed for a given distance than other competitors. The training required is no different than for other sports with respect to the underlying principles. Successive stresses must be applied to the body over time in order to provide a stimulus to initiate adaptation so that subsequent training or performance is accomplished at a higher absolute intensity or for a longer period of time. The sequence in which a series of training blocks is applied is critical to the final outcome for an ultra-endurance athlete. How the loads are applied is dependent on training periodization, which is a training concept in which the year is divided into large, medium and small training blocks that are referred to as macro-, meso-, and microcycles. The design of a periodized plan should incorporate the following principles: all-around development, overload, specificity, individualization, and consistent training. Furthermore, structural tolerance is a concept that suggests that the body needs time to adapt to a training load and tolerance is built up through years of general and specific training. The modern ultra-endurance athlete requires sustenance in order to recover and prepare for upcoming training and racing. Rehydration and recov-

ery of fluid balance after exercise, together with the timing and method of increased food intake to cope with heavy training, are essential for optimal performance.

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