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Nutrition for distance events

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Abstract

The goal of training is to prepare the distance athlete to perform at his or her best during major competitions. Whatever the event, nutrition plays a major role in the achievement of various factors that will see a runner or walker take the starting line in the best possible form. Everyday eating patterns must supply fuel and nutrients needed to optimize their performance during training sessions and to recover quickly afterwards. Carbohydrate and fluid intake before, during, and after a workout may help to reduce fatigue and enhance performance. Recovery eating should also consider issues for adaptation and the immune system that may involve intakes of protein and some micronutrients. Race preparation strategies should include preparation of adequate fuel stores, including carbohydrate loading for prolonged events such as the marathon or 50-km walk. Fluid and carbohydrate intake during races lasting an hour or more should also be considered. Sports foods and supplements of value to distance athletes include sports drinks and liquid meal supplements to allow nutrition goals to be achieved when normal foods are not practical. While caffeine is an ergogenic aid of possible value to distance athletes, most other supplements are of minimal benefit.

Keywords: *Carbohydrate loading, marathon, refuelling, protein requirements, caffeine, iron deficiency*

Introduction

Many events involve prolonged effort within the IAAF umbrella of track and field, road running, cross country, and race-walking. Events commonly undertaken by elite competitors include the 5000-m and 10,000-m track events, the half-marathon and marathon, the 20-km and 50-km walks, and cross-country runs (8 km for females and 12 km for males). In addition, a vast array of "fun runs" and community events around the world attract large fields, ranging from the elite to the weekend warrior. Nutrition plays a key role in assisting distance athletes of all standards to achieve their training and competition goals.

Training for distance runners and walkers

Distance runners follow a periodized training programme (see Stellingwerff, Boit, & Res, 2007), split into base training (8 – 16 weeks), a pre-competitive period (8 – 16 weeks), and a competitive period (if track events) or a tapering phase (up to 3 weeks) before a marathon followed by a short transition/recovery phase. Heat acclimatization before competition in a hot environment and altitude training are other specialized training techniques often undertaken by distance runners and walkers. Altitude training remains a controversial area, with coaches and scientists still arguing over the benefits of periods in a hypoxic (lower oxygen) environment on performance at sea level. Distance athletes who usually reside at low altitudes have a variety of options for undertaking altitude training (see Hawley, Gibala, & Bermon, 2007).

Since athletes of East African origin (Kenya, Ethiopia and, more recently, Eritrea and Uganda) dominate distance running, the reasons for their superiority have been studied extensively (Billat *et al.*, 2003; Lucia *et al.*, 2006; Saltin *et al.*, 1995). Of the key physiological factors of distance running performance [maximal oxygen uptake ($\dot{V}O_{2max}$), the maximal fraction of $\dot{V}O_{2max}$ sustained during the event, the velocity at the lactate threshold, and the running energy cost], it would appear that East African runners have mainly a greater running economy (Lucia *et al.*, 2006) and a higher fractional utilization of $\dot{V}O_{2max}$ than Caucasian runners (Lucia

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et al., 2006; Saltin *et al.*, 1995). The underlying mechanisms of these differences are still contradictory but are a combination of social, genetic, and anthropometric/biomechanical factors. The effects of the residence/training altitude *per se* or of nutritional differences have not been identified. Although high running distances in training (80 – 150 km · week^{-1} in 3000 – 5000 m runners; 150 – 220 km · week^{-1} in marathon runners during base training) are commonly observed in all distance runners, several studies have reported that most African runners spend a greater part of their weekly training at high relative intensity. The current trend in distance running is for a "polarized training" model – that is, a large percentage (70 – 75%) at strictly aerobic intensity, a small percentage ($<$10%) of "tempo" training at around or above lactate threshold, and 15 – 20% at high intensity.

Competition in distance events

Although most distance events involve a single race, some events require heats and finals (e.g. 5000 and 10,000 m at the Olympic Games and World Championships). Most distance runners and walkers peak for several important events in a year (e.g. a Big City Marathon or the World Championships). However, there may be other times when they compete in a series of races, including the lucrative professional circuit in Europe, meets within a university circuit such as the NCAA season, or in the cross-country schedule for club athletes. In general, the main competition for track and field occurs in summer, whereas cross-country has an autumn and/or winter season. Most road races attracting large fields of both elite and community-based participants are scheduled over the warmer months from spring to late autumn when heat and hydration are more of an issue. The schedule of Big City Marathons, which includes races in Boston, Chicago, New York, London, and Paris, extends from April to November.

Aerobic metabolism typically accounts for more than 95% of the energy production of long-distance events, especially half-marathon and marathon races and the longer walking events. However, there are critical times in all distance races requiring anaerobic effort – for example, a surge, a hill, or a sprint finish – that may be the ultimate factor in determining the order of race finishers. The factors that limit the performance of distance runners and walkers vary according to the duration and environment of the race, and nutrition is an important factor in success in the event. Because many of these factors (e.g. fluid balance, the availability of carbohydrate fuel, disturbance to acid – base status arising from anaerobic glycolysis) can be manipulated by dietary strategies, nutrition is an important component of the athlete's preparation for competition.

Nutritional issues and challenges

There is a range of common nutritional issues in long-distance running and walking related to optimal physique, training, and race day performance. This review will provide an overview of the major issues.

Physique

Very low levels of body fat are a striking feature of successful distance athletes. However, it is hard to distinguish whether this is a critical factor in determining successful performance or the outcome of the high training volumes needed for successful performance. Low levels of both total mass (which determines the total energy cost of running) and fat mass (dead weight that must be transported) assist fast and economical movement. These traits become even more important when the event involves long distances or moving against gravity (e.g. running up hills in a road or cross-country race). Because the upper-body musculature is unimportant for running performance, elite runners and walkers typically exhibit minimal evidence of muscle development in their arms and upper torso. Although there is variability in the size of long-distance runners and walkers, the winners of "hot weather" races tend to be small and light. A small and compact physique offers thermoregulatory advantages, both by reducing the absolute amount of heat that is produced (smaller muscle mass) and by achieving a more efficient dissipation of heat generated by the body (enhanced ratio of surface area to volume). Data from both modelling (Dennis & Noakes, 1999) and laboratory (Marino *et al.*, 2000) sources show that lighter runners store less heat at the same running speed and enjoy an advantage in conditions where heat dissipation mechanisms are at their limit.

Some runners and walkers achieve a small and very lean frame as a result of their genetic background and training programme. However, other runners with naturally larger frames or greater adiposity feel that they must whittle themselves down to an "unnatural" size and low percentage of body fat to be competitive. Although many male runners eat and train specifically to reduce their body fat and racing weight, the battle for a low percentage of body fat and weight control is most often identified as a problem for female athletes. This may be because females generally need to push their body characteristics further from their natural shape than male runners to achieve the leanness that is considered ideal. Attempts to deviate body fat further from the apparent biological "default" can have negative effects, including "penalties" resulting from the low body fat *per se*, such as a lack of insulation against cold. Other penalties arise from the nutrition and training methods used to manipulate weight and body fat, including restricted intakes of energy, protein, carbohydrate, and micronutrients (Burke, 2007). Some athletes develop frank medical or psychiatric problems such as eating disorders, osteopaenia, and chronic menstrual dysfunction. More develop sub-clinical versions of these problems; the spectrum of restrained eating, menstrual dysfunction, and poor bone health within the "female athlete triad" is covered in greater detail by Manore and colleagues (Manore, Kam, & Loucks, 2007) and similar issues should also be considered in the evaluation of some male athletes.

The problems associated with poor bone health lie not only with the risk of a premature onset of osteoporosis but also with the immediate problem of stress fractures. Recurrent or chronic stress fractures can prevent the athlete from competing at important times and interfere with his or her ability to undertake the training volume necessary for high-level performance. Many athletes have had promising careers ended by this injury pattern. Distance runners and walkers should be encouraged to set realistic weight and body fat goals; these are specific to each athlete and must be judged by trial and error over a period of time. Further discussion on dietary strategies to assist with loss of weight and body fat is found in the review by O'Connor and colleagues (O'Connor, Olds, & Maughan, 2007).

Poor iron status

There is a common belief that endurance athletes, particularly distance runners, are at high risk of iron deficiency. This has been given apparent credibility because the target levels for iron status measures such as serum ferritin are often set well above those of normal population standards to provide a "safety margin" for athletes whose performance are underpinned by the roles of iron in oxygen transport (haemoglobin and myoglobin) and enzyme function (for a review, see Deakin, 2006).

The depletion of the body's iron stores progresses through a number of stages with different functional and diagnostic criteria (see Deakin, 2006). The literature is unclear, in part because of methodological concerns, whether iron depletion, in the absence of anaemia, impairs exercise performance (Fogelholm, 1995). Some studies of iron supplementation in iron-depleted but non-anaemic female runners (Klingshirn, Pate, Bourque, Davis, & Sargent, 1992; Newhouse *et al.*, 1989; Powell & Tucker 1991) failed to find differences in performance changes between supplementation and placebo treatment groups, even when serum ferritin increased with iron therapy (Klingshirn *et al.*, 1992; Newhouse *et al.*, 1989). However, in other studies, female runners with low ferritin levels experienced a performance improvement, albeit in conjunction with an increase in haemoglobin, after iron supplementation (Lamanca & Haymes, 1993; Schoene *et al.*, 1983). Of course, athletes are also concerned whether iron depletion affects their ability to recover between workouts or races. Brownlie and colleagues (Brownlie, Utermohlen, Hinton, & Haas, 2004) exposed previously untrained participants with non-anaemic iron depletion to a 4-week training programme and found that those with a tissue iron deficiency (based on abnormal serum transferrin receptor concentrations) had an impaired adaptation to this training compared with a similar group who received iron supplements. In contrast, iron supplementation did not affect endurance cycling performance at the end of the training programme in the iron-depleted group who were not tissue iron-depleted.

In summary, the true prevalence of iron-deficiency anaemia in distance runners and walkers is probably not greater than in the general population (Fogelholm, 1995). However, reduced iron status does occur and may be problematic for performance or adaptation to training, particularly altitude training (see Hawley *et al.*, 2007). The cause is essentially the same as that in the general population: a lower than desirable intake of high bioavailability iron. Iron requirements may be increased in distance athletes because of increased gastrointestinal or haemolytic iron losses (for a review, see Deakin, 2006). However, the most important risk factor is still the low-energy or low-iron diet. Females, vegetarians, and those following diets with restricted quantity and variety are at highest risk. Dietary interventions to reverse or prevent a decline in iron status involve strategies to increase total iron intake as well as to increase the bioavailability of this iron.

The management and prevention of iron deficiency requires careful diagnosis using a variety of clinical, haematological, dietary, and medical data. Haematological and biochemical tests that are routinely measured to indicate iron status should be undertaken in a way that minimizes or standardizes the effect of exercise on the results. In athletic populations, ferritin concentrations lower than 30–35 $\text{ng} \cdot \text{ml}^{-1}$ (Nielsen & Nachtigall, 1998) are generally marked for further consideration or review, especially where it makes a change in the established iron status history of the individual. New tests that include the measurement of serum transferrin receptors and the characteristics of reticulocytes may offer new opportunities. However, these tests are not routinely available in all laboratories and need to be evaluated carefully in relation to iron status in athletes.

Many distance athletes are tempted to self-medicate with iron supplements that can be purchased over the counter. However, there are several risks involved with the consumption of iron supplements in the absence of a confirmed iron status problem, including haemosiderosis or iron overload. Typically, a 3-month period of supplementation, in the form of a daily dose of 100 mg of elemental iron, is needed to restore depleted iron stores (Nielsen & Nachtigall, 1998). In some cases, when it is not possible to enhance dietary iron intake sufficiently, iron supplementation is continued at a lower dose to prevent ongoing iron drain. In cases of extreme iron depletion or where oral iron intake is not tolerated, intramuscular injections of iron can achieve a rapid increase in iron stores. However, there is no evidence of additional performance benefits over oral supplementation, and there are higher risks of side-effects. Iron injections will not increase haemoglobin levels or other iron parameters in people who are not otherwise suboptimal in iron status (Ashenden *et al.*, 1998).

Carbohydrate needs for optimal training and recovery

Distance runners and walkers must be able to rapidly recover their muscle fuel stores between daily or twice-daily sessions, and between races on the competition circuit. A high carbohydrate intake enhances the performance of a single bout of prolonged running as well as the recovery and performance of a subsequent running bout (Fallowfield & Williams, 1993). However, muscle glycogen concentrations might not recover completely within 24–48 h following a very strenuous running session (e.g. marathon) or unaccustomed eccentric loading, despite a plentiful carbohydrate supply (Asp, Rohde, & Richter, 1997; Sherman *et al.*, 1983). Unaccustomed muscle damage may cause a disruption to muscle cell function and could require an increase in total carbohydrate intake in the first 24 h of recovery (Doyle *et al.*, 1993) or a greater recovery time (up to 7 days) for full replacement of muscle glycogen.

Logically, the benefits from enhancing acute recovery between sessions should translate over time into better training adaptations and long-term performance gains. However, the literature, which includes three studies involving runners, is curiously unclear in showing that high carbohydrate diets provide superior training outcomes to moderate carbohydrate intakes (Burke, 2007). Kirwan *et al.* (1988) studied well-trained runners who increased their training by 150% for 5 days while consuming either high ($8\ \text{g} \cdot \text{kg}^{-1} \cdot \text{day}^{-1}$) or moderate ($4\ \text{g} \cdot \text{kg}^{-1} \cdot \text{day}^{-1}$) intakes of carbohydrate. Muscle glycogen concentration gradually declined in both treatments but was better preserved with the higher carbohydrate diet; additionally, running economy at two different running speeds was better. In contrast, Sherman and colleagues (Sherman, Doyle, Lamb, & Strauss, 1993) followed 7 days of training in two groups of runners who consumed carbohydrate intakes of either $5\ \text{g} \cdot \text{kg}^{-1} \cdot \text{day}^{-1}$ (gradually reduced muscle glycogen concentrations) or $10\ \text{g} \cdot \text{kg}^{-1} \cdot \text{day}^{-1}$ (maintained muscle glycogen concentrations). At the end of this period, the groups did not differ in their capacity to undertake two treadmill runs to exhaustion at 80% $\dot{V}\text{O}_{2\text{max}}$ with a short recovery interval at the end of a training session.

Finally, in another study well-trained runners undertook 7 days of intensified training supported by both moderate ($5.4\ \text{g} \cdot \text{kg}^{-1} \cdot \text{day}^{-1}$) and high ($8.5\ \text{g} \cdot \text{kg}^{-1} \cdot \text{day}^{-1}$) carbohydrate diets (Achten *et al.*, 2004). Muscle glycogen utilization decreased during submaximal running on the moderate carbohydrate diet and there was a decline in speed over 8-km (treadmill) and 16-km (outdoor) time-trials. However, the high carbohydrate treatment was associated with a smaller decrease in 8-km speed and maintenance of 16-km performances. The authors concluded that a high carbohydrate diet reduced symptoms of overreaching in runners during intensified training compared with a moderate carbohydrate diet but could not prevent it entirely.

n emerging interest is that of dietary periodization – the so-called "train low, compete high" approach – in which distance athletes deliberately train with low glycogen or carbohydrate availability to enhance metabolic adaptations to the training stimulus, then replete carbohydrate to enhance their competition performance (see Hawley *et al.*, 2007). Currently, there is inadequate scientific support to recommend that distance athletes should practise carbohydrate restriction for prolonged periods Indeed, the potential disadvantages of this practice include an increased risk of illness and injury (see Nimmo & Ekblom, 2007) and reduced well-being or capacity to train (see Burke & Kiens, 2006). In fact, the available study supporting a "train low" approach (Hansen *et al.*, 2005) achieved glycogen depletion for some, but not all, training sessions by manipulating the training timetable rather than dietary intake. Indeed, it is likely that elite athletes spontaneously periodize carbohydrate availability within their microcycles of training because the practicalities of their lifestyle and training mean that some sessions are taken after an overnight fast, or without complete refuelling between workouts.

Unless more sophisticated research can identify benefits from deliberately "training low", distance athletes should eat to promote carbohydrate availability, at least for the most important training sessions of the week. Recent recommendations for daily carbohydrate intake (Burke, Kiens, & Ivy, 2004) acknowledge that fuel requirements for distance athletes differ according to body size and training loads. The targets of $7-10\ \text{g} \cdot \text{kg}^{-1} \cdot \text{day}^{-1}$ for high volume training and $5-7\ \text{g} \cdot \text{kg}^{-1} \cdot \text{day}^{-1}$ for more moderate exercise loads provide a general target that must be fine-tuned according to overall nutritional goals and performance feedback from each athlete. Such recommendations may be unfeasible for runners, particularly females, whose focus on low body mass and percent body fat requires energy restriction and, by association, a lower carbohydrate intake. The compromise is to periodize nutrition goals and dietary carbohydrates intakes over the season, so that lower intakes and physique goals are the priority of training periods, whereas greater carbohydrate intakes are allowed during competition preparation and recovery to maximize glycogen stores.

Although total intake of carbohydrate is probably the most important determinant of post-exercise refuelling, during periods of high volume training the distance athlete should use other dietary strategies to promote recovery. Speedy intake of carbohydrate after exercise will maximize the period of effective refuelling time (Burke *et al.*, 2004). Carbohydrate-rich foods in recovery snacks and meals should be chosen according to the need to meet practical challenges (e.g. finding portable foods when the athlete is "on the go") or to meet additional nutritional goals (e.g. to provide a source of iron, protein or other nutrient need). It is probably useful to co-ingest protein with carbohydrate-rich recovery snacks. Although the effect of protein on glycogen resynthesis is likely to be minimal in most circumstances (see Tipton, Jeukendrup, & Hespel, 2007), various issues of recovery and adaptation require protein synthesis. Indeed, in addition to refuelling, the distance athlete needs to consider a range of recovery eating goals after training and races, including rehydration (Shirreffs, Casa, & Carter, 2007), repair and adaptation (Hawley *et al.*, 2007), and preserving the immune system (Nimmo & Ekblom, 2007).

Protein requirements during training

Data from studies of essentially recreational exercisers have led to the belief that protein requirements are not altered by any form of physical activity. However, the high volumes of training and the training intensities possible only in elite athletes result in estimated protein requirements that are nearly twice those of sedentary individuals, $1.6-1.7\ \text{g} \cdot \text{kg}^{-1} \cdot \text{day}^{-1}$ (Tarnopolsky, MacDougall, & Atkinson, 1988; Friedman & Lemon, 1989). Even for modestly trained individuals, there is an increase in protein requirements estimated from nitrogen balance experiments (Meredith, Zackin, Frontera, & Evans, 1989; Phillips, Atkinson, Tarnopolsky, & MacDougall, 1993). Although no study has specifically calculated protein requirements for elite female athletes, nitrogen balance data imply that the requirements for women are about 25% lower than those for men – that is, $1.2-1.3\ \text{g} \cdot \text{kg}^{-1} \cdot \text{day}^{-1}$ (McKenzie *et al.*, 2000; Phillips *et al.*, 1993). Most athletes will achieve these protein intakes from an everyday diet providing 10 – 15% of energy as protein and adequate energy. Nevertheless, it is important to evaluate protein intake on a grams per kilogram basis as opposed to a percentage of the diet to avoid low intakes that can be seen in energy restricting athletes. A low energy intake will also have a negative effect on protein requirements (Calloway, 1975).

There are benefits to the timing of nutrient delivery, especially when undertaking high volumes of training. When female athletes consumed a nutritional supplement immediately after each workout during a training camp, they achieved an improvement in nitrogen balance, less weight loss, and improved performance on a trial completed at the end of the week than when the supplement was consumed after breakfast (Roy, Luttmer, Bosman, & Tarnopolsky, 2002).

Fuelling up for competition

Preparation for racing should ensure that muscle carbohydrate stores are matched to the anticipated fuel needs of the event. For races of 60 – 90 min duration, normalized muscle glycogen stores are adequate and can generally be achieved by 24 – 36 h of high carbohydrate intake. Carbohydrate loading in preparation for prolonged exercise resulted from pioneering studies undertaken in the 1960s using percutaneous biopsy techniques to examine fuel utilization and enzyme activities in the muscle. These studies on healthy but untrained men produced the classic 7-day model to supercompensate muscle glycogen stores; a 3- to 4-day depletion phase of hard training and low carbohydrate intake followed by a 3- to 4-day loading phase of high carbohydrate intake and exercise taper (Bergstrom, Hermansen, Hultman, & Saltin, 1967). Early field studies of prolonged running events showed that this strategy enhanced sport performance, not by allowing the athlete to run faster but by prolonging the time that race pace could be maintained (Karlsson & Saltin, 1971).

A modified version of carbohydrate loading was developed when well-trained runners were shown to supercompensate their glycogen stores without a severe depletion or glycogen stripping phase (Sherman, Costill, Fink, & Miller, 1981). The modified protocol, consisting simply of 3 days of high carbohydrate intake and taper, was offered as a more practical competition preparation that avoided the fatigue and complexity of the extreme diet and training requirements of the previous depletion phase. More recently, muscle glycogen concentrations were measured after 1 and 3 days of rest and a high carbohydrate intake (10 g $\cdot$ kg body mass^{-1} $\cdot$ day^{-1}) in well-trained male athletes (Bussau, Fairchild, Rao, Steele, & Fournier, 2002): this study found that optimal refuelling is probably achieved within 36–48 h following the last exercise session, at least when the athlete rests and consumes adequate carbohydrate.

Theoretically, carbohydrate loading can enhance performance in distance races that would otherwise be limited by the fatigue caused by glycogen depletion. Studies in well-trained runners have failed to detect benefits of carbohydrate loading for 10-km treadmill running (Pitsiladis, Duignan, & Maughan, 1996), a 20.9-km race on an indoor track (Sherman *et al.*, 1981), and a 25-km treadmill run (Sullo *et al.*, 1998). By contrast, carbohydrate loading has been shown to enhance performance of a 30-km cross-country run (Karlsson & Saltin, 1971), a 30-km treadmill run in trained men (Williams, Brewer, & Walker, 1992), and a 25-km treadmill run in moderately trained men (Sullo *et al.*, 1998). Typically, carbohydrate loading is associated not with an increase in overall running speed but with maintenance of race pace during the last part of the run compared with the control trial or group. Therefore, runners and walkers should consider carbohydrate loading for races of 30 km and longer.

Fat adaptation – a twist on depletion prior to carbohydrate loading

Distance runners and walkers should have a high capacity for fat oxidation during exercise as a legacy of their training. However, this capacity can be further up-regulated by as little as 5 days of training while following a low carbohydrate (<2.5 g $\cdot$ kg^{-1} $\cdot$ day^{-1}), high-fat ($\sim$65–70% of energy) diet. In trained individuals, "fat adaptation" achieves a markedly increased fat oxidation and reduced utilization of muscle glycogen ("glycogen sparing") during subsequent submaximal exercise (Burke *et al.*, 2000). This effect persists even when followed by acute strategies to carbohydrate load, and eat carbohydrate before and during the bout (for a review, see Burke & Kiens, 2006). Such a combination of dietary strategies would seem the perfect preparation for a marathon or distance walking event, simultaneously optimizing carbohydrate stores while maximizing the capacity for fat oxidation. Curiously, the effect on endurance and ultra-endurance performance is unclear (Burke & Kiens, 2006).

There is now evidence that what was initially viewed as glycogen sparing may, in fact, be a down-regulation of carbohydrate metabolism or "glycogen impairment". Fat adaptation/carbohydrate restoration strategies are associated with a reduction in the activity of a key enzyme regulating carbohydrate metabolism, pyruvate dehydrogenase (Stellingwerff *et al.*, 2007). Such a change would impair rates of glycogenolysis at a time when muscle carbohydrate requirements are high. This explains the observation that when fat adaptation/carbohydrate restoration is applied to exercise protocols that mimic a real-life race – self-pacing, and the interspersing of high-intensity and moderate-intensity exercise – there is a compromised ability to performance high-intensity sprints (Havemann *et al.*, 2006) In many endurance events, the critical activities in a race – the breakaway, the surge up a hill, or the sprint to the finish line – are all dependent on the runner's ability to work at high intensities. With growing evidence that this critical ability may be impaired, it now seems clear that fat adaptation or pre-loading depletion strategies should not be undertaken by distance athletes.

Fluid and fuel intake during races

In distance running and walking events, especially road races, a network of aid stations allows competitors to consume fluids during the race. In large community participation events, a supply of water, sport drinks, and sponges is on hand, although elite competitors are usually provided with opportunities to supply their own race beverages at specially marked tables. There is still debate on the ideal hydration plans for distance events, with the observation that most top runners are conservative with fluid intake while some of the "back of the pack" participants in large community events risk serious problems from over-consumption of fluids (Noakes, 2002; Almond *et al.*, 2005). These issues are covered in greater detail by Shirreffs *et al.* (2007).

The use of carbohydrate–electrolyte drinks (sport drinks) during races of 60 min or longer provides the runner or walker with the potential to replace fluid and carbohydrate simultaneously, with the option of altering the carbohydrate concentration of the drink (typically 4–8 g $\cdot$ 100 ml^{-1}), according to the priority of rehydration or refuelling in a particular event. Sports gels and confectionery are other readily available sources of carbohydrate often consumed by distance athletes. There is good evidence of the benefits of carbohydrate intake during prolonged (>90 min) exercise (Hargreaves, 1999), with reports dating back to the Boston marathon in the 1920s that the consumption of sweets during the race prevented hypoglycaemia and enhanced running performance (Gordon *et al.*, 1925; Levine, Gordon, & Derick, 1924). Recent studies in which carbohydrate ingestion enhanced a running protocol include a 40-km outdoor run in the heat (Millard-Stafford, Sparling, Rosskopf, & Dicarlo, 1992), a 30-km road run (Tsintzas, Liu, Williams, Campbell, & Gaitanos, 1993), a marathon run on a treadmill (Tsintzas, Williams, Singh, & Wilson, 1995), and an approximately 2-h treadmill protocol to exhaustion at 70% $\dot{V}O_{2\max}$ (Tsintzas, Williams, Wilson, & Burrin, 1996b). The generally accepted mechanisms of performance enhancement include prevention of hypoglycaemia, sparing of liver glycogen, and provision of an additional muscle fuel substrate (Hargreaves, 1999). However, in the case of running, there is some evidence of muscle glycogen sparing, at least in selected fibres (Tsintzas *et al.*, 1993; Tsintzas, Williams, Boobis, & Greenhaff, 1996a).

The effect of carbohydrate intake during shorter distance events is unclear, with the potential mechanism of any performance enhancements being attributable to effects on the central nervous system rather than provision of muscle fuel (see Burke, 2007). One study involving a 15-km treadmill run in a hot environment found an improvement in speed over the last, self-paced portion of the run when carbohydrate was ingested immediately before and during the run compared with a placebo trial (Millard-Stafford, Rosskopf, Snow, & Hinson, 1997). By contrast, carbohydrate intake during an 18-km run failed to enhance performance of a large group of runners or the fastest runners in the group compared with water (Van Nieuwenhoven, Brouns, & Kovacs, 2005), and highly trained runners experienced a trivial effect on performance when carbohydrate was consumed during a half-marathon (Burke, Wood, Pyne, Telford, & Saunders, 2005). Further studies are needed to determine the full range of events that might benefit from carbohydrate intake immediately before and during the race.

Differences in nutrition strategies between the sexes

It has been assumed that dietary advice for female distance athletes would be a simple extrapolation from male athletes, scaled to their smaller size. However, numerous studies have found that females oxidize more fat and less carbohydrate than men during endurance exercise (see Tarnopolsky, 2000). An early study found that increasing dietary carbohydrate intake from 55% to 75% of habitual energy intake for 4 days neither increased glycogen storage nor enhanced cycling performance in female athletes, in stark contrast to the results seen in males (Tarnopolsky, Atkinson, Phillips, & MacDougall, 1995). Of course, the relatively low energy intake of the females limited carbohydrate intake to $< 6.5\ \mathrm{g \cdot kg^{-1} \cdot day^{-1}}$ even in the "loading" phase. A follow-up study provided an additional trial in which 75% of a higher energy intake achieved carbohydrate intakes $> 8\ \mathrm{g \cdot kg^{-1} \cdot day^{-1}}$ (Tarnopolsky *et al.*, 2001). With higher carbohydrate and extra energy, females increased muscle glycogen, albeit to levels that were about 50% of the increase seen in males. From a practical perspective, carbohydrate loading is of use to female athletes only if they are prepared to consume adequate energy and carbohydrate.

In contrast to the limited ability of women to carbohydrate load, the dietary recommendations for men and women with respect to sport drink consumption during exercise (Riddell *et al.*, 2003; Wallis, Dawson, Achten, Webber, & Jeukendrup, 2006), and for post-exercise glycogen re-synthesis (Tarnopolsky *et al.*, 1997), appear to be similar.

Sport foods and supplements

Many distance athletes, even recreational athletes, are consumers of sport foods and supplements. Products such as sports drinks and liquid meal supplements are specially designed to help a runner or walker meet specific needs for energy, fluid, and nutrients in circumstances where everyday foods are not practical to eat, although the expense must be considered (see Burke, 2007). Nutritional ergogenic aids have generally been poorly tested or have failed to live up to their claims when rigorous testing has been undertaken on distance running/walking performance. The exception is caffeine, which may enhance the performance of some runners (for a review, see Graham, 2001). Recent research has focused on the use of small doses of caffeine before and during endurance exercise, since the benefits appear to be similar to those achieved by larger doses of $6-9\ \mathrm{mg \cdot kg^{-1}}$ (see Maughan, Depiesse, & Geyer, 2007). Caffeine intakes of as little as $3\ \mathrm{mg \cdot kg^{-1}}$ have been shown to enhance running performance, including a worthwhile improvement of $\sim 1\%$ in an 8-km track protocol (Bridge & Jones, 2006). However, runners who were provided with very small amounts of caffeine ($\sim 1.3\ \mathrm{mg \cdot kg^{-1}}$) during an 18-km road race did not show a detectable improvement in performance (Van Nieuwenhoven *et al.*, 2005).

While bicarbonate supplementation is typically considered a strategy for middle-distance running (see Stellingwerff *et al.*, 2007), it has been shown to improve performance of the longer track events (e.g. 5000-m races) (Oopik *et al.*, 2003; Oopik, Saaremets, Timpmann, Medijainen, & Karelson, 2004). Creatine loading has become synonymous with the enhancement of repeated sprint training or exercise bouts (see Tipton *et al.*, 2007) and is typically considered inappropriate for use by distance athletes. In fact, runners recorded a slower time to complete a 6-km cross-country run after creatine supplementation (Balsom, Harridge, Soderlund, Sjodin, & Ekblom, 1993), presumably due to the accompanying increase in body mass. In spite of recent evidence that prior creatine loading enhances the muscle's capacity for glycogen loading or resynthesis (Nelson, Arnall, Kokkonen, Day, & Evans, 2001; van Loon *et al.*, 2004), it is likely that the increase in body mass would hinder performance in distance running events, particularly if the course is hilly. Further research is needed to test the hypothesis that glycerol hyperhydration can enhance thermoregulatory function in conditions in which thermal stress limits running performance.

Finally, the claims made in support of the majority of other supplements and compounds marketed as ergogenic aids are not supported by scientific research (see Burke, 2007). Of course, more research is needed, using rigorous control and carefully chosen protocols to test the claims for most products. In many cases, particular (proposed) ergogenic compounds that are used by distance athletes have not been tested appropriately and no further comments can be made about these products. The reader is therefore referred to the general conclusions provided by Maughan *et al.* (2007).

Summary of nutrition guidelines for distance athletes

Consensus for:

- Distance athletes should follow established guidelines to meet the carbohydrate needs for their training loads and to enhance recovery after each training session. These strategies are particularly important to promote performance and recovery for key training sessions.
- Distance athletes should consume sufficient carbohydrate to prepare fuel stores that are adequate for their event. Carbohydrate loading or glycogen supercompensation will be of benefit to longer events such as the marathon or 50-km walk. A prolonged depletion phase is unnecessary and may even impair performance.
- Carbohydrate and fluid intake during an event is possible and of probable value for races lasting longer than 60 min. Each athlete should experiment to find a plan that is practical and provides benefits for their performance.
- Iron deficiency may be a problem for some distance runners, but this is a diagnosis of exclusion and other causes need to be ruled out. Nutritional counselling to increase the intake of bioavailable iron is an important goal of prevention and therapy.
- Some sports supplements such as sports drinks and liquid meals may be useful in providing a practical way for distance athletes to meet their nutrition goals. Moderate doses of caffeine can provide an ergogenic benefit to distance running and may be useful for some runners.

Consensus against:

- Distance athletes should not practise extreme levels of energy restriction to achieve loss of body weight/body fat without considering the effect on their ability to meet goals for carbohydrate, protein, iron or other nutrients. Hormonal balance, bone health, and the immune system are also critically impaired by inadequate energy intakes.
- Routine supplementation with iron or iron injections in the belief that it enhances performance should be strongly discouraged in the absence of documented iron depletion or anaemia. Supplementation in the absence of deficiency can lead to serious medical conditions such as haemosiderosis.
- The majority of supplements that are promoted to distance athletes are unlikely to provide substantial benefits, and should not replace sound eating and training practices.

Issues that are equivocal:

- It is unclear whether distance athletes will enhance adaptations and performance outcomes by undertaking deliberate strategies to restrict carbohydrate availability during training. In the real world, elite athletes will probably achieve some level of periodization of carbohydrate status within the microcycles of their training programme. Any benefits of more prolonged carbohydrate depletion need to be balanced by the possible disadvantages.

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