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Abstract

Distance events in Athletics include cross country, the 10,000 m track race, half marathon and marathon road races, and 20 and 50 km race walking events, over different terrain and environmental conditions. Race times for elite performers span ~26 min to >4 h, with key factors for success being a high aerobic power, the ability to exercise at a large fraction of this power, and high economy of movement. Nutrition-related contributors include body mass and anthropometry, capacity to use fuels, particularly carbohydrate (CHO) to produce ATP economically over the duration of the event, and maintenance of reasonable hydration status in the face of sweat losses induced by exercise intensity and the environment. Race nutrition strategies include CHO-rich eating in the hours/days prior to the event to store glycogen in amounts sufficient for event fuel needs, and in some cases, in-race consumption of CHO and fluid to offset event losses. Beneficial CHO intakes range from small amounts, including mouth rinsing, in the case of shorter events to high rates of intake (75-90 g/h) in the longest races. A personalized and practiced race nutrition plan should balance the benefits of fluid and CHO consumed within practical opportunities, against the time cost and risk of gut discomfort. In hot environments, pre-race hyperhydration or cooling strategies may provide a small but useful offset to the accrued thermal challenge and fluid deficit. Sports foods (drinks, gels etc) may assist in meeting training/race nutrition plans, with caffeine and, perhaps, nitrate being performance supplements with evidence-based uses.

Key words: marathon, CHO loading, CHO periodization, African runners, Track and Field

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Introduction

The International Association of Athletics Federations (IAAF) recognizes various distance events, with current World Championship and Olympic Games hosting the 10,000 m track event and road marathon (42.2 km) in running, and 20 km and 50 km events in race walking. Additionally, there are separate IAAF Road Race Label events spread throughout the year in half marathons, marathons and other distances, a half-marathon World Championship, cross-country World Championships (10 km), and various Race Walking Cups and Challenges. Many events are held as national or continental titles, and include competitions for junior athletes (e.g. under 20 or under 18 years) over shorter distances.

Table 1 summarizes characteristics of key distance running and race walking events, noting the duration and intensity of races for top competitors and elements that contribute to the physiological and nutrition challenges of these events. Meanwhile, opportunities to address these challenges via within-event nutrition strategies are summarized in Table 2. As in middle distance events, there are both tactical, technical and physiological components to successful outcomes. This paper focuses on knowledge that has emerged over the past decade on nutrition strategies to support the training and competition goals of distance runners and race walkers, translating race nutrition principles into practical recommendations.

Bio-energetic and physiological determinants of success in distance events

The distance events (from ~26 min in the 10,000 m track race to >3.5 hours in the 50 km race walk) are considered “submaximal”, with mean energy requirements of ~75-92% of maximal O_2 uptake ($\dot{V}O_{2max}$) (Londeree, 1986). They are heavily dependent on aerobic resynthesis of adenosine triphosphate (ATP) (Coyle, 2007), and require adequate delivery of oxygen (O_2) from the atmosphere to the mitochondria to oxidize carbohydrate (CHO) and lipid fuels. When energy contribution from anaerobic metabolism is minimal, performance is typically related to three key factors (Joyner and Coyle, 2008): $\dot{V}O_{2max}$, the fraction of $\dot{V}O_{2max}$ that can be sustained for the distance, and running/walking economy. For example, a $\dot{V}O_{2max}$ of 70 ml/kg/min sustained at 90% for 10,000 m (i.e. 63 ml/kg/min), and a running economy of 190 ml/kg/km, translates to a sustainable speed of 19.9 km/h ((63 x 60)/190), and an expected 10,000 m time of 30:09 min:s.

A high $\dot{V}O_{2max}$ sets the ceiling on success in 'submaximal' distance events (Saltin and Astrand, 1967). Elite female distance athletes typically possess values of 65-80 ml/kg/min; elite males are higher (70-85 ml/kg/min) [Joyner & Coyle, 2008], due to factors including higher hemoglobin concentrations, which increases O_2 delivery at maximal cardiac output (Q_{max}), and lower fat mass. The fraction of $\dot{V}O_{2max}$ that can be sustained for a given exercise duration, which is rarely >90% $\dot{V}O_{2max}$ in distance events, is related to muscle oxidative capacity (Gollnick and Saltin, 1982; Ivy et al., 1980) and, in turn, metabolic thresholds such as lactate threshold (LT; the speed corresponding to the first increase in blood lactate above resting levels; and critical speed (CS), the asymptote of the hyperbolic relationship between speed and time-to-exhaustion (Hughson et al., 1984; Poole et al., 1988). Exercise above LT incurs a nonlinear increase in metabolic, respiratory and perceptual stress and a more rapid fatigue development, due to the effects of metabolic acidosis on contractile function or an accelerated depletion of muscle glycogen (Sahlin, 1992). A rightward shift in the blood [lactate]-speed relationship with training is a clear marker of enhanced endurance capacity (Hurley et al., 1984). However, LT typically occurs between 60-80% $\dot{V}O_{2max}$ even in highly trained individuals; a lower intensity than is maintained during most distance races, except perhaps the 50 km walk. CS, representing the highest speed at which $\dot{V}O_2$ (and blood [lactate]) can be stabilized over time, may be more important. Elite athletes sustain ~96% of CS during the marathon (Jones and Vanhatalo, 2017) while a 10,000 m track event likely exceeds CS, at least for some portions of the race, such that performance depends upon the interplay between CS and the curvature constant of the speed-time relationship (D′; Jones and Vanhatalo, 2017). Physiological responses to exercise performed within moderate (<LT), heavy (>LT but <CS) and severe (>CS) intensity domains differ considerably (Poole et al., 2016) with implications for the predominant cause(s) of fatigue (Black et al., 2017). The goal of race nutrition is to address factors that would otherwise cause fatigue or suboptimal outputs during and especially towards the end of an event (Burke and Hawley, 2018). Table 1 indicates that substrate availability for the muscle (glycogen and glucose) and brain (glucose) is a key issue for many distance events, along with the offsetting of sweat loss to preserve plasma volume and cardiac output.

There is variability in running and walking economy, defined as the steady-state $\dot{V}O_2$ at a given absolute speed, even between individuals with similar $\dot{V}O_{2max}$ and/or performance characteristics (Conley and Krahenbuhl, 1980; Morgan and Craib, 1992). Better exercise economy is advantageous to endurance performance because a lower fraction of $\dot{V}O_{2max}$ is utilized for any particular speed. Running economy is associated with anthropometric (including segmental mass distribution), physiological and metabolic, and biomechanical and technical factors (Saunders et al., 2004). Endurance training may improve economy via improved muscle oxidative capacity and associated changes in motor unit recruitment patterns, reductions in exercise ventilation and heart rate for the same exercise intensity, and improved technique (Williams and Cavanagh, 1997; Saunders et al., 2004). A partial offset may occur due to increased fat utilization because of its greater O_2 requirement for ATP synthesis compared to CHO metabolism.

Support for the periodized training programs of distance athletes

"Periodized nutrition", the strategic combination of nutrition and exercise to optimize training adaptations and competition performance (Jeukendrup, 2017a), is explained in relation to Athletics by Stellingwerff and co-workers (2019). In distance events, a variety of strategies, often in apparent conflict with each other but nevertheless targeted at enhancing the specific session or training phase, should be integrated into the annual, meso and microcycles of training according to the athlete's individualized and changing goals. For example, workouts/phases targeting an enhancement of oxidative capacity should exploit the superior adaptations in fat metabolism and mitochondrial biogenesis following exercise with low CHO availability either at a whole-body level or muscle level (Burke et al., 2018b; Jeukendrup, 2017a). Conversely quality/high intensity training should be performed with high CHO availability, as it is during races (Jeukendrup 2017a). Furthermore, when intake during the event is beneficial, it may be possible to prepare the gut to optimize and tolerate this by practicing strategies with adjusted intakes of CHO and fluid within training sessions (Jeukendrup 2017b).

It is likely that the heavy training loads and habitual dietary practices of high performance distance runners/walkers, including the remarkable East African athletes (Commentary 1) already create periodization of CHO availability across a training cycle. Whether more deliberate planning can improve the outcome is of interest. In this regard, although sub-elite endurance athletes performed better after undertaking 3-w of training with strategic manipulations of CHO availability (Marquet et al., 2016), a study of elite race walkers failed to find evidence of superior race performance after an intensified training block supported by periodized CHO availability compared with constant high CHO availability (Burke et al., 2017a). Meanwhile, both dietary approaches were associated with better race outcomes than chronic (3.5 w) exposure to a ketogenic low CHO high fat (LCHF) diet, despite its achievement of substantial (~2.5 x) increases in muscle fat oxidation (Burke et al., 2017). This contrasts with claims that LCHF is the "future of elite endurance sport", but is supported by empirical (Krogh and Lindhard, 1920) and theoretical (Leverve et al., 2007) evidence of better exercise economy with CHO-dependent generation of ATP than fat oxidation pathways (see Commentary 2 for modeling of this effect). This is especially important at exercise intensities that are typical of the distance events (Hawley and Leckey, 2015). Further investigation of periodization of fuel support strategies in elite athletes is warranted, although it is clear that some areas are controversial or confusing. This is at least partly attributable to different definitions or inaccurate descriptions of the implementation or goals of these strategies. A recent commentary has promoted the case for a common terminology and understanding of this theme (Burke et al., 2018b). In the meantime, it appears that elite athletes include various versions of "train high", "train low" and "gut training" within their training programs, both accidentally and with intent (Stellingwerff, 2012; Heikura et al., 2018).

Periodization of body composition provides another example of a strategic integration of different nutrition strategies within training schedules. A recent science-based case study of an Olympic female middle-distance runner argued that it is not sustainable from a health and/or performance perspective to be at race body composition year-round (Stellingwerff, 2018). Instead, an assessment of anthropometric, hematological and performance metrics over a 9-year career demonstrated a periodized approach. During the general preparation phase (September-April), the athlete was ~2-4% over ideal race body mass (BM) and body fat (%), with optimal energy availability being prioritized. Body composition optimization for competition (May-August) included an individualized timeframe and energy deficit with various feedback metrics (BM, performance, and hunger) to guide the process. This approach supported targeted peak performances and minimized risk of injury, while maximizing training adaptation and long-term athlete health through management of energy availability. Although this concept has, arguably, been understood for many years, the concept and calculated practice is a contemporary update (Jeukendrup 2017a). Importantly, it helps the athlete to integrate the inevitability or benefits of brief periods of controlled low energy availability (LEA) within the endurance training framework. Problems associated with chronic or severe LEA, known as Relative Energy Deficiency in Sport (RED-S) are well-known (Mountjoy et al., 2018); specific issues in relation to Athletics are covered by Melin et al. (2019).

Race preparation

Race preparation should include strategies to store muscle glycogen in the amounts commensurate with the fuel needs of the event. For races < 90 min duration (e.g. 10,000 m, cross country, half marathon and 20 km walks), it is sufficient to normalize the superior glycogen concentrations associated with endurance training; this is typically achieved with CHO intakes of 7-10 g/kg body mass for 24 h (Burke et al., 2011). In the marathon and 50 km race walk where glycogen can become limiting for race performance, protocols which supercompensate glycogen are beneficial. Indeed, investigations of the original protocol devised in the 1960s involving distance runners (Karlsson and Saltin, 1971) and race walkers (Hyman, 1970) were largely responsible for the popularization of this strategy within the sports world; these studies showed that CHO loading improved performance by attenuating the decay in speed in the last portions of the race. The contemporary CHO loading protocol is an abbreviated version of the original, involving 36-48 h of CHO intakes targeting 10-12 g/kg/d (Burke et al., 2011). This is often undertaken in conjunction with a low residue (fiber) diet, which may reduce the risk of gut issues during the race, but also achieve a small reduction in BM to partially offset the mass of the additional muscle glycogen and stored water.

Further contributions to fuel availability are provided by a pre-event CHO-focused meal, and a small CHO-rich snack (e.g. sports gel or drink) during the race warm-up. This is particularly important for events undertaken in the morning where CHO intake can restore liver glycogen following an overnight fast as well as provide an ongoing supply of CHO from the gut (Burke et al., 2011). The timing, size and food choices in the pre-race meal will vary according to event characteristics and athlete preferences; these should be well-practised to develop an individualized protocol. Athletes should also consider fluid needs to achieve optimal hydration status for the event and specific race conditions (see Casa et al., 2019). As discussed in the section on racing in the heat, there may also be opportunities to address race challenges related to thermoregulation and dehydration by hyper-hydrating and/or pre-cooling in the hours prior to the event.

Race feeding: fueling and hydration update

Some distance events offer an opportunity for athletes to consume fluid and fuel during the race to address physiological limitations around these factors (Table 2). CHO ingestion during longer distance events (e.g. marathon and 50 km race walk) can improve performance by delivering additional substrate to maintain high rates of CHO oxidation in the face of dwindling endogenous stores (Coyle et al., 1986). A systematic review of the literature on CHO ingestion during endurance protocols by Stellingwerff and Cox (2014) concluded that 82% of studies (50 of 61 studies, involving 679 subjects) showed statistically significant benefits from this practice. Older guidelines (Coyle 1991) recommended that distance athlete experiment with hourly CHO intakes within the range of 30-60 g to find a beneficial strategy. More contemporary recommendations (Burke et al., 2011; Thomas et al., 2016), however, suggest smaller amounts for shorter duration events and higher rates of intake for longer events (>2.5h), based on the mechanism of likely benefits to performance as well as the recognition that higher amounts can be tolerated and utilized than previously considered.

Early investigations of CHO ingestion during exercise concluded that maximal oxidation rates plateaued at 60 g/h, even when larger amounts were ingested (120-180 g/h) [Jeukendrup, 2014]. The limiting factor was subsequently found to be intestinal absorption, particularly the sodium dependent glucose transporter (SGLT1), rather than gastric emptying, hepatic glucose extraction, muscle glucose uptake or muscle glucose oxidation (Jeukendrup, 2014). However, as reviewed by Jeukendrup (2017), SGLT1 abundance and activity in animals is increased by a CHO-rich diet; furthermore, chronic exposure to higher CHO intakes by athletes, including exercise intake, increases gut tolerance, intestinal absorption and muscle oxidation of CHO consumed during exercise (Cox et al., 2010; Costa et al., 2017). Combining glucose-based CHO sources with fructose (transported in the intestine by GLUT5) increases total exogenous carbohydrate oxidation during exercise, with rates as high as 1.75 g/min (Jeukendrup, 2010). Narrative review (Stellingwerff & Cox, 2014), meta-analysis (Vandenbogaerde & Hopkins, 2011) and dose-response (Smith et al., 2010) approaches to this topic have found that higher amounts of CHO promote better performance in longer events relevant to the marathon and 50 km race walk, with optimal intakes of ~75-90 g/h. However, in shorter events (half marathon, 20 km race walking), performance benefits may be associated with intake of smaller amounts of CHO, including central nervous system activation associated simply with mouth exposure to CHO (the so-called "mouth rinsing" effect). Indeed, there is robust evidence that the detection of CHO by receptors in the oral cavity, independent of sweetness, activates certain centers in the brain to enhance perceptions of effort and pacing decisions (see Jeukendrup and Chambers, 2010). A range of sports drinks, gels and confectionery is available to meet various targets, both in training and racing, around taste, practicality, balanced intake of fluid and CHO, inclusion of multiple transportable CHO sources, electrolyte replacement, and supplementation with caffeine, while other everyday foods and drinks may also be used

Fluid intake to address sweat losses is important during longer events and in the heat, since a fluid deficit equivalent to >2-3% BM loss is typically associated with increases in perception of effort and core temperature, and reductions in performance, especially in hot environments (Sawka et al., 2015). However, plans for fluid intake in events that permit it (as indeed for CHO intake) should involve a cost:benefit analysis, where “costs” include the availability of supplies at drink stations during the race (see Table 2), the time lost while slowing down to obtain and consume drinks/sports products, and the risk of gut upsets. Furthermore, the associated BM reduction may partially compensate for the disadvantages of dehydration. High performance runners are less able to consume fluid/CHO during races than racewalkers due to the higher speed of movement and the lower number/increased time between drink stations; e.g. ~15-18 min for marathon runners with stations ever 5 km vs 8-10 min for racewalker with stations every 2 km. Furthermore, the impracticality of drinking large volumes despite high sweat rates explains BM losses of up to 10% in race winners in hot-weather marathons (e.g. Beis et al. 2012). We recommend that athletes develop a personalized and practiced race plan that optimizes fluid and CHO status within the prevailing conditions and opportunities of each event. Despite the practical challenges, it is noted that several world records/marks in the marathon (personal observations A.E. Jeukendrup; A.M. Jones; Hutchinson; 2013; Caeser, 2017) and Olympic records in the 50 km race walk (personal observations, L.M. Burke) have involved aggressive hydration and CHO feeding plans (targeting 90 g/h). Indeed, some recent elite marathons, including the 2018 Berlin event in which the most recent world record was set, have increased the frequency of feed zones (every 2.5 km) to provide greater opportunity for race feeding. A personalized drinking plan can be adjusted to all levels of runner, including recreational competitors who may drink in volumes exceeding their sweat rates and who should be warned about the dangers of developing hyponatremia (Almond et al., 2005).

Supplements for distance athletes

The term "supplements' includes products that address a distance athlete's nutritional goals in a specialized context: medical supplements used to prevent/treat a nutrient deficiency (e.g. Vitamin D or iron supplements); sports foods providing energy, macronutrients and fluid requirements in scenarios where whole foods are impractical; and performance supplements which directly improve training or competition outcomes. Characteristics of these products and scenarios in which they contribute to a distance athlete's nutrition plan are summarized elsewhere (Castell et al., 2019; Maughan et al., 2019; Peeling et al., 2019). The specific needs of long distance races raise potential new uses of sports foods and performance supplements, based on the specific physiological, biochemical and central nervous system factors that limit performance in these race, as well as the opportunity to consume products within the event, at least for races of half-marathon and longer.

Only a handful of the multitude of performance supplements marketed to athletes have a strong evidence-base. Peeling and co-workers (2019) have separately reviewed these products (caffeine, nitrate, creatine, B-alanine and bicarbonate) and their mechanisms of action in relation to Athletics, identifying only the first two of this group as likely to achieve a performance benefit in distance events; investigations of these products in relevant scenarios are summarized in Tables 4 and 5. We note the sparsity of specific studies and the variability in findings; this may arise from differences in supplement protocols as well as the under-powering of studies due to small sample sizes and/or reliance on performance protocols lacking sufficient reliability to detect small but meaningful benefits. Indeed, the evidence-base for these performance products relies on summaries of the general endurance sports literature (McMahon et al., 2017; Southward et al., 2018a). However, the actual use of any performance supplement by endurance athletes requires its integration into a bespoke nutrition plan that accounts for the specificity of their event and/or training schedule and their experience of individual responsiveness to the plan (Burke et al., 2018d).

Table 2 summarizes the role of sports foods/drinks in achieving goals for CHO and fluid intake during distance events. While the known benefits of these strategies provide a benchmark against which the magnitude of any effects from other performance products should be compared, they also provide a potential confounder of the effectiveness of other performance supplements. For example, a meta-analysis of a heterogeneous group of studies of caffeine supplementation and endurance performance (Conger et al., 2006) found that the margin of improvement when caffeine was consumed in addition to CHO was significantly reduced (but still worthwhile) in comparison to scenarios involving a water placebo (mean effect sizes = 0.26 vs 0.52, $p = 0.006$). This illustrates why potential interactions between concurrently used supplements or nutrition strategies are high priority for scientific investigation and specific consideration when developing race plans or training uses (Burke et al., 2018d). The efficacy of caffeine during endurance sports may be correlated with its role in masking fatigue (Spriet, 2014); therefore, in situations in which another strategy reduces the onset or magnitude or fatigue, a smaller effect on performance is logical. Conversely, in scenarios of increased fatigue such as "training low" with endogenous CHO stores, caffeine may provide a greater benefit in helping to attenuate the reduction in training capacity (Lane et al., 2013). Other issues around caffeine or nitrate use in distance athletics are noted in

Tables 4 and 5. Finally, the potential for enhanced glycogen storage following creatine supplementation (Roberts et al., 2016) merits further investigation in terms of increased CHO availability for the longer distance races; however such benefits should be balanced against the likely increase in BM (Tomcik et al., 2017).

Strategies for hot environments

Major championships are often held in hot and/or humid environments, with the Doha 2019 World Championships and Tokyo 2020 Olympic Games being immediate targets at the time of preparation of this review. There are multiple and circular interactions between the hot environment and nutrition; exercise in the heat creates extra challenges in terms of increased rates of fluid loss and glycogen use (Jentjens et al., 2002), with dehydration increasing the risk of gastrointestinal discomfort/upset (Rehrer et al., 1990) and further interference with nutritional status and goals. Meanwhile, fluid intake reduces thermal stress (Montain and Coyle, 1992) and CHO intake reduces gut damage (Snipe et al., 2017). The performance and health challenges associated with racing in hot weather should be addressed by strategies such as acclimatization, appropriate pacing, and pre-cooling activities (Racinais et al., 2015). Adjustment to race nutrition strategies, if practical, may also assist (Table 2). For example, a more aggressive approach to within-race hydration strategies to address greater fluid losses may be possible, while hyperhydration during the hours before a race via consumption of large amounts of fluid together with an osmotic agent (e.g. glycerol or sodium) can reduce the net fluid deficit incurred over the race (Van Rosendal & Coombes, 2013; Goulet et al., 2007). Here, we note that glycerol has been removed from the World Anti-Doping Agency’s list of prohibited substances and may be reinstated for use in hyperhydration/rehydration strategies. The intake of ice slurries within pre-cooling strategies to reduce pre-race core temperature via the “heat sink” created by the phase change from ice to water may also be beneficial (Jay & Morris, 2018; Ross et al., 2013). Where race intake is practical, mouth sensing of cold water or menthol may provide a sense of cooling during a race to reduce ratings of perceived effort (Best & Stevens, 2017), while intake of reasonable amounts of cold/icy beverages might theoretically contribute to improved thermoregulation (Jay & Morris, 2018). The literature on specific benefits of these strategies (see Table 6) in high performance running or racewalking scenarios is sparse; investigation is required, including assessment of potential disadvantages such increase in BM or a greater risk of gut disturbances. In the meantime, athletes should practice the intended use of these strategies before implementing in a race.

Commentary 1: Dietary practices of East African Runners

East African athletes have dominated distance running for decades, with their superior performance drawing speculation about a range of potential contributing factors (Larsen & Sheel, 2015), including their striking dietary practices and specific anthropometric features (Mooses & Hackney, 2017; Burke et al., 2018a). While dietary surveys of Kenyan and Ethiopian runners have been limited to their home environments and training camps (Beis et al., 2011; Christensen et al., 2002; Fudge et al., 2006, 2008; Onywera et al., 2004), it appears that they maintain their eating practices on the competition circuit or in their Northern Hemisphere training bases due to the low cost and cultural familiarity, as well as self-belief that it might contribute to their success (personal observations, M. Mooses). A range of features, both consistent and in contrast to current sports nutrition guidelines merit comment.

The diets of East African runners contain substantially different contributions of foods and macronutrients compared with Western practices; indeed, CHO supplies 60-80% of energy, with high reliance on vegetables (80–90% of diet) rather than animal food sources (10–20%), and limited food variety (staple foods: rice, pasta, potatoes, porridge, cabbage, kidney beans, ugali maize meal, and injera flatbread). Typical fluid choices include water (0.9-1.1 l/d) and tea (~0.9 l/d) with brown sugar and (for Kenyans) milk (Onywera et al., 2004; Beis et al., 2011). Daily energy intake is distributed over a small number of meals, with prolonged moderate- to fast-paced morning runs being undertaken before breakfast and with nil/minimal intake of fluid (Fudge et al., 2006, 2008; Onywera et al., 2004; Beis et al., 2011). Meanwhile, meals are consumed soon after training sessions and high–intensity track sessions are completed as a mid-morning workout after breakfast. Indeed, many concepts of periodizing CHO availability according to the needs of the session (Burke et al., 2018) appear within these traditional practices. Although supplements are rarely used, data from observational studies (Beis et al., 2012) and accounts of recent attempts on world marathon records by male runners (Hutchinson; 2013; Caeser, 2017) note personalized race nutrition plans including pro-active intakes of fluid and CHO, often with the involvement of Western sports scientists.

Also of topical interest is the reported or suspected prevalence of acute or chronic periods of LEA among these athletes. Notwithstanding artefacts in dietary survey methodology and calculations of energy availability (Burke et al., 2018c), there are consistent reports of low energy intakes relative to calculated or expected exercise energy expenditures in various groups of East African middle- and long-distance athletes (Onywera et al., 2004; Fudge et al., 2006, 2008). Contributors to energy mismatches include cultural eating patterns (e.g., fiber-rich unvaried diet, few eating occasions in a day), food insecurity and the interaction with high training loads (e.g., lack of intake during training hours, post-exercise appetite suppression) (Burke et al., 2018a). Although, the role of deliberate manipulation of body mass/composition for performance purposes is unclear, some involvement is likely because low energy intakes have been observed during pre-competition training camps (Onywera et al., 2004) and the majority of African athletes report that their "ideal racing weight" is lower than their normal training BM (Mooses, unpublished data).

Further study is needed to consolidate our understanding of the dietary practices of these highly successful athletes and how much they contribute to, or interfere with, optimal performance. It is likely that practices include both helpful and harmful features, as well as accidental and intentional elements. As for any group of athletes, an audit of practices may identify the potential for performance improvement, but various practical and personal issues need to be taken into account.

Commentary 2: Modelling the 2 hour marathon barrier: is CHO a tool?

Nearly 100 years ago, Krogh and Lindhard (1920) reported that energy derived from the metabolic consumption of O_2 depends on whether fat or CHO is the primary source of carbon substrate. For example, increasing the respiratory quotient (RQ) from 0.85 to 0.90 (49% to 66% contribution from CHO) results in a 5% increment in released energy (4.967 vs 4.921), (Krogh and Lindhard, 1920). In the D. B. Dill lecture at the 2015 annual conference of the America College of Sports Medicine, Professor Ron Maughan identified the important implications of this finding for marathon performance; an increase in RQ improves metabolic efficiency by reducing the O_2 cost of running at a particular speed or permitting a higher speed for the same absolute $\dot{V}O_2$. This contradicts the conventional recommendation that endurance athletes should spare their finite carbohydrate reserves by maximizing the use of fat as a substrate. However, it is supported by the findings of an increased O_2 cost of race walking at speeds related to race performance when rates of fat oxidation were markedly increased by adaptation to a ketogenic LCHF diet (Burke et al., 2017).

With regard to the challenge of a sub 2 hour marathon, if we assume a running economy of 190 ml/kg/km at 21.1 km/h and BM of 55 kg, the total energy cost of running 42.2 km is calculated at ~2200 kcal (9210 kJ). Theoretically, this could be provided by CHO (550 g) in the form of supercompensated muscle and liver glycogen stores supplemented by an aggressive approach to consuming CHO during the race. The total O_2 cost of oxidizing CHO alone or fat alone would be 435 L vs 459 L, respectively (Krogh and Lindhard, 1920). In our hypothetical athlete with a $\dot{V}O_{2max}$ of 80 ml/kg/min (i.e. 4.4 L/min), $\dot{V}O_2$ during the race would correspond to 3.63 L/min (or 83% $\dot{V}O_{2max}$) and 3.83 L/min (or 87% $\dot{V}O_{2max}$) using purely CHO or fat, respectively. However, even more subtle changes in RQ can be meaningful. For example, an athlete with a sustainable $\dot{V}O_2$ of 3.75 L/min and running economy of 180 ml/kg/min would achieve a sustainable marathon running speed of 20.83 km/h, with a finishing time of 2:01:33. In this scenario, a ~0.9% increase in the energy liberated per L O_2 consumed (achieved via a 0.05 unit increment in RQ, for example from 0.85 to 0.90), could translate into a similar magnitude of increment in running speed (to 21.02 km/h) and a finishing time of 2:00:27, a 66 s improvement. For this reason, a key strategy in Nike’s 2017 ‘Breaking 2’ marathon attempt, during which Kenyan Eliud Kipchoge ran a world’s best time of 2:00:25, was to encourage CHO oxidation by supplying ~60-70 g/h CHO via regular (every ~7 min) access to high-concentration drinks (personal observations, A.M. Jones; Caeser, 2017). Further rigorous study of this concept is needed, but it may become part of the formula for further enhancement of distance running performance.

Conclusions

Distance athletes should adopt nutritional strategies that address specific physiologic and biochemical factors that otherwise limit performance. These include periodized support for specific goals of workouts or phases within the training program, and as summarized in Table 2, nutrient choices pre- and/or during the race to maintain optimal fuel and fluid status. In-race nutrition is dependent on practicalities such as the availability of aid stations as well as time and gut considerations of consuming CHO-containing fluids or other sports products. Finally, several performance supplements, particularly caffeine and nitrate, could be considered for likely and potential benefits, respectively.

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Conflicts of interest

The authors declare no conflicts of interest in the preparation of this review.

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“Contemporary Nutrition Strategies to Optimize Performance in Distance Runners and Race Walkers”
by Burke LM, Jeukendrup AE, Jones AM, Mooses M
International Journal of Sport Nutrition and Exercise Metabolism

Table 1. Characteristics of key distance events in athletics

Event	**10,000 m track race**	**Cross country**	**21.1 km half marathon**	**20 km race walk**	**42.2 km marathon**	**50 km race walk**
World record: male (h:min:sec)	26:15.53 (Kenenisa Bekele)	~12 km (No records)	58:18 (Abraham Kiptum)	1:16.36 (Yusuki Suzuki)	2:01:39 (Eliud Kipchoge)	3:32:33 (Yohann Diniz
World record: female (h:min:sec)	29:17.45 (Almaz Ayana)	~8 km (no records)	1:04:51 Joyciline Jepkkosgei)	1:24:38 (Hong Lui)	2:15:25 (Paula Radcliffe)	4:04:36 (Rui Liang)
Approximate Intensity (% VO2max)	90-95% ≥ Critical speed.	90-95% ≥ Critical speed.	85-90% ≤Critical speed.	80-90% ≤Critical speed.	80-85% < Critical speed but above lactate threshold	75-80% ≤ Lactate threshold unless during higher intensity pieces.
Surface	Track	Natural terrain, with undulating topography and variable surfaces	Road – may include changes in elevation	1-2 km circuit on road – typically flat	Road – may include changes in elevation	2 km circuit on road – typically flat
Physiological and nutritional limitations to performance	Fatigue related to peripheral factors (metabolic acidosis, Ca^{2+} handling, low PCr), plus possible localized fiber-specific glycogen depletion.	Fatigue related to peripheral factors (metabolic acidosis, Ca^{2+} handling, low PCr), plus possible localized fiber-	Fatigue related to glycogen depletion, central fatigue development, and some peripheral factors.	Fatigue related to glycogen depletion, central fatigue development, and some peripheral factors.	Fatigue related to glycogen depletion, hypoglycemia, possible dehydration and hyperthermia depending on environmental conditions, central	Fatigue related to glycogen depletion, hypoglycemia, possible dehydration and hyperthermia depending on environmental

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Event	**10,000 m track race**	**Cross country**	**21.1 km half marathon**	**20 km race walk**	**42.2 km marathon**	**50 km race walk**
		specific glycogen depletion.			fatigue, possibly muscle damage.	conditions, central fatigue.

Table 2. Nutritional strategies for high performance athletes in key distance events in Athletics*

Issue and general guidelines	10,000 m track race	10 km cross country	21.1 km half marathon	20 km race walk	42.2 km marathon	50 km race walk
Pre-race refueling: • Normalization of glycogen = 7-12 g/kg/d for 24 h • CHO loading = 10-12 g/kg/d for 36-48 h	Glycogen normalization	Glycogen normalization	Glycogen normalization	Accentuated glycogen normalization	CHO loading, especially with low residue diet	CHO loading, especially with low residue diet
Pre-race meal • 1-4 g/kg CHO in 1-4 h pre-race • Reduced fat, fiber and protein intake according to risk of gut issues during race	Familiar pre-race meal	Familiar pre-race meal	Familiar pre-race meal + CHO after warm up	Familiar pre-race meal + CHO after warm up	Familiar pre-race meal + CHO after warm up	Familiar pre-race meal + CHO after warm up
Opportunities for in-race nutrition: (availability of drink stations)	Nil. (If extremely hot, water station may be provided on outside lane of track)	Nil	Typically every 5 km in elite races. Frequency differs in large city races	Every lap of 2km loop course (sometimes course = 1 km loop)	Typically every 5 km in elite races. Frequency differs in large city marathons: may be every 1-2 miles	Every lap of 2 km loop course
In race fueling goals • 45-75 min: mouth rinse/small CHO amount	N/A	N/A	Trial CHO mouth rinse up to intake of 30-60 g from	Trial CHO mouth rinse up to intake of 30-60 g from CHO-	30-60 g/h CHO; Consider trialing intakes up to 90 g/h from mix of	Target 60-90 g/h from mix of CHO-drinks or more concentrated gels/

"Contemporary Nutrition Strategies to Optimize Performance in Distance Runners and Race Walkers"
by Burke LM, Jeukendrup AE, Jones AM, Mooses M
International Journal of Sport Nutrition and Exercise Metabolism

Issue and general guidelines	**10,000 m track race**	**10 km cross country**	**21.1 km half marathon**	**20 km race walk**	**42.2 km marathon**	**50 km race walk**
• 1-2.5 h: 30-60 g/h • >2.5 h: up to 90 g/h			CHO-drinks or gels/ confectionery	drinks or gels/ confectionery	CHO-drinks and more concentrated gels/ confectionery	confectionary according to fluid goals in race plan
In race hydration goals • Aim to keep net fluid deficit < 2-3%BM, especially in hot weather	N/A	N/A	Cost: benefit analysis may show that time cost of drinking may negate benefits in elite runners	Drink stations allow plentiful opportunities for frequent small intakes of CHO-containing fluid towards a race plan	Fast runners will find it difficult to drink large volumes	Drink stations allow plentiful opportunities for frequent small intakes of CHO-containing fluids towards a race plan
Caffeine supplementation • 3 mg/kg before/during race	Pre-race caffeine	Pre-race caffeine	Caffeine pre and/or during race	Caffeine pre and/or during race	Caffeine pre and/or during race to 3-6 mg/kg target	Caffeine pre and/or during race to 3-6 mg/kg target
Special issues for hot weather events	Consider pre-race pre-cooling with ice slurry in addition to external cooling strategies if significant thermal challenge is anticipated.		Consider pre-race pre-cooling with ice slurry in addition to external cooling strategies if significant thermal challenge is anticipated. Consider pre-race hyperhydration if large fluid deficit is anticipated. Adjust fluid intake during event where possible in view of increased sweat losses.		Consider pre-race pre-cooling with ice slurry in addition to external cooling strategies, but take care with pacing strategies. Consider pre-race hyperhydration if large fluid deficit is anticipated. Adjust fluid intakes during event where possible in view of increased sweat losses.	

Issue and general guidelines	10,000 m track race	10 km cross country	21.1 km half marathon	20 km race walk	42.2 km marathon	50 km race walk
Special comments for non-elite competitors			Do not overdrink by consuming fluid in excess of sweat losses			Do not overdrink by consuming fluid in excess of sweat losses

*Note that all strategies should involve a personalized and well-practiced plan that is suited to the specific needs of the events. General guidelines can be found in more detail in Thomas et al., 2016

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Table 3. Summary of a "low residue" (low fiber) diet)

Characteristic	Comment
Background	• Used as a more acceptable alternative to a "clear liquid" diet or pharmaceutical preparation to reduce intestinal fecal matter and secretions prior to bowel investigations or surgery (Vanhauwaert et al., 2015) • Although the terms "low residue" and "low fiber" are often used interchangeably to describe this dietary practice, it has been argued that it is best described as low fiber, with daily intakes < 10 g fiber (Vanhauwaert et al., 2015)
Application to athlete practice	• The implementation and outcomes have not been subjected to rigorous scientific investigation in sporting scenarios. However, the acute use of low fiber diets is often observed in weight division sports (Reale et al., 2017). Here, the athlete suddenly reduces their fiber consumption in the days before weigh-in, in the belief or experience that a reduction in bowel contents contributes a small but potentially valuable loss of body mass, with fewer disadvantages to the dietary preparation for competition than food restriction. • The reduction in BM associated with this dietary practice in athletes is highly variable and individual (Reale et al., 2017), but an average response of ~ 500 g might be expected (personal observations Louise M Burke). • Additional benefits of a pre-race reduction in intestinal fiber content for distance runners and walkers include a lowered risk of gut discomfort/upset during the race, and simplification of the logistics of bowel evacuations in the hours prior to a race. • The optimal period of implementation of the pre-race low fiber diet is also highly variable and ranges from 24-72 h depending on individual gut transit times (Reale et al., 2017). • Disadvantages of the low fiber pre-race diet include a lack of food variety, a (short-term) reduction in dietary quality/micronutrient density and discomfort due to lower satiety/hunger

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Characteristic	Comment

Suggested implementation of pre-race low	• The distance athlete should experiment with the duration of the low fiber diet to determine an optimal plan according to their usual fiber intake, gut transit time and personal tolerance of limited food variety and reduced satiety/hunger
	• The diet can be integrated with a carbohydrate-loading protocol, and may even assist with the achievement of targets for large amounts of carbohydrate intake due to the increased energy density of food choices
	• Meals and snacks should be based on low-fibre CHO-rich foods and the avoidance of significant sources of resistant starch. Suitable foods include
	  ○ "White" breads
	  ○ "White" breakfast cereals (e.g. rice puffs)
	  ○ Sweetened dairy products
	  ○ "White" rice, pasta, noodles and potato: these should be well-cooked and consumed hot to avoid creation of resistant starch with cooling
	  ○ Pulp free fruit juice, sugary drinks (soda etc)
	  ○ Confectionary, jelly preserves, honey
	  ○ Cakes and desserts based on white flours (e.g. cakes, puddings) and sugar (e.g. jello) but the avoidance of dried or fresh fruit
	  ○ Sports products (e.g. sports drinks, gels, confectionary)
	• Meats, milk, cheese, poultry, fish, eggs and other protein-rich foods can be added to meals and snack menus
	• Uncooked fruits and vegetables should be avoided, especially where they contain skin or pips. Cooked versions can be added in modest amounts to make up meals or menu items; these include:
	  ○ Pureed fruit, apple sauce

Characteristic	Comment
	○ Mashed/pureed vegetables with preference for "ketchup" style sauces and canned/mashed vegetables

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Table 4 Summary of caffeine supplementation and performance of distance events

Overview (see Burke 2008; Southward et al., 2018a; Spriet, 2014)					
Mechanism of action	• Adenosine receptor antagonist with large range of effects • Major effects during endurance exercise include masking of perception of effort, fatigue and pain, increase in vigilance and alertness				
Best practice protocol	• ~ 3 mg/kg (up to 6 mg/kg) taken before and/or during distance events, with sources including food (e.g. coffee, cola drinks, energy drinks), sports foods (e.g. caffeinated gels) or pharmaceutical products (e.g. caffeine tablets) • Greater responsiveness to small amounts of caffeine (2-3 mg/kg) may be seen when it is taken during a race, around the onset of fatigue (Spriet, 2014)				
Issues for future study	• Individual responsiveness to caffeine supplementation in distance running, including genetic causes (Southward et al., 2018b) • Interaction with other supplements – CHO, nitrate • Effect of caffeine on heat storage and performance in hot, humid environments (Hanson et al. 2018) • Use of caffeine to support training capacity/quality, especially when training in fatigued state (e.g. altitude training, training with low CHO availability) [Lane et al., 2013]				
Investigations	**Study design**	**Caffeine protocol**	**Performance protocol**	**Effect**	**Comments**
Cohen et al. 1996	• Competitive distance runners (5 M + 2 F) • Crossover design with different caffeine doses vs placebo	• 5 and 9 mg/kg taken pre-race	• Half-marathon (field study) • Hot conditions • Water during run	No benefit detected	No effects on RPE or performance at either dose compared with placebo.
Van Nieuwenhoven et al. 2005	• Trained to well-trained runners (90 M + 8 F) • Crossover design with caffeine +	• ~1.3 mg/kg in 7% CHO drink vs. CHO drink alone	• 18 km road race (field study) • CHO drink during run	No benefit detected	No differences in performance of whole group between caffeinated sport drink (78:03 ± 8:42 [min:s]), sport drink (78:23 ± 8:47), or water (78:03 ± 8:30) or for 10 fastest runners (63:41, 63:54 vs. 63:50 for caffeine sport

	CHO vs CHO vs water placebo	• 600 ml drink consumed in equal portions before and at 4.5, 9, and 13.5 km race			drink, sport drink, and water, respectively).
Bridge and Jones 2006	• Distance runners (8 M) • Crossover design with caffeine vs placebo vs control	• 3 mg/kg taken 60 min pre-race •	• 8 km race on track (field study) • No intake during run	Benefit detected	Relative to the mean time of the control and placebo trials, caffeine supplementation resulted in a 23.8 s or 1.2% improvement in run time ($P < .05$) with individual results ranging from 10 to 61 s improvement. HR was significantly higher in caffeine trial, with trend to lower RPE despite faster running speed.
Potgeiter et al. 2018	• Well-trained triathletes (14 M, 12 F); • Crossover design with caffeine vs placebo	• 6 mg/kg taken 60 min pre-race	• 10 km run at end of Olympic distance triathlon (field study)	Benefit detected	Caffeine associated with a 1.3% improvement in race time (149.6 ± 19.8 vs. 151.5 ± 18.6 min, $p < .05$), with effect great in male subjects. No difference in RPE despite faster time. Caffeine associated with greater blood lactate and cortisol concentrations
Hanson et al., 2018	• Moderately trained distance runners (6 M, 4F) • Crossover design with caffeine vs placebo vs control	• 3 mg/kg or 6 mg/kg taken 60 min pre-trial	• 10 km treadmill TT in hot conditions (30 degrees C and 50% r.h.) • No intake during run	No benefit detected	No difference in 10 km time (53.2 ± 8.2; 53.4 ± 8.4; 52.7 ± 8.2 for placebo, 3 and 6 mg/kg doses). However, greater increase in core temperature with higher caffeine dose suggesting greater heat storage

Abbreviations: TT = time trial; M = male, F = female, HR = heart rate, RPE = ratings of perceived exertion

Table 5. Summary of nitrate supplementation and effect on performance of distance events

Overview (for review, see Jones et al., 2018; McMahon et al., 2017)					
Mechanism of action	• Improves exercise economy (reduces the oxygen cost of submaximal exercise) to improve endurance exercise performance • Enhances skeletal muscle contractile function to improve muscle power and sprint exercise performance				
Best practice protocol	• ~8 mmol nitrate taken 2-3 h pre-race, especially with chronic intake for 3+ d pre-trial • Usually taken in form of beetroot juice concentrate				
Issues for future study	• Individual responsiveness to nitrate supplementation in distance running, including effect of caliber of athlete since it seems less effective in elite athletes (Jonvik et al., 2015) • Effect of protocols involving intake *during* distance events to maintain elevated plasma nitrite concentrations (Tan et al., 2018) • Interaction with other supplements – CHO, caffeine etc • Effect of nitrate on heat storage and performance in hot, humid environments (Kent et al., 2018) • Use of nitrate to promote training capacity/quality, including use during altitude training				
Investigations	**Study design**	**Nitrate protocol**	**Performance protocol**	**Effect**	**Comments**
Shannon et al., 2017	• Well-trained runners/triathletes (8M) • Crossover design with nitrate vs placebo	• ~12.5 mmol (Beetroot juice) taken 3 h pre-trial	• 10 km treadmill TT	No benefit detected	No difference in 10,000 m TT between nitrate vs placebo (2643 ± 324. vs. 2650 ± 320 s, $P > 0.05$), although the same athletes performed better on a 1500 m test in the same study.
De Castro et al., 2018	• Recreational runners (14M) • Crossover design with nitrate vs placebo	• ~8 mmol (Beetroot juice) taken for 3 d and 2 h pre-trial	• 10 km treadmill TT	No benefit detected	No difference between nitrate and placebo (50.1 ± 5.3 vs 51.0 ± 5.1 min, $p = 0.391$) for 10 km although time to complete the first 5 km was lower in the nitrate group ($P = 0.027$).

Abbreviations: M = male, TT = time trial, CHO = carbohydrate

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Table 6. Summary of hyperhydration and cooling strategies with relevance to events in distance athletics

Pre-race hyperhydration (for review, see Van Rosendal & Coombes, 2013; Goulet et al., 2007).	
Mechanism of action	• Fluid retention achieved by use of an osmotic agent (glycerol or sodium) in fluids consumed in hours before exercise increases body fluid stores; allows greater sweat losses during exercise to occur before the net fluid deficit becomes physiologically significant and impairs performance
Best practice protocol	• 25 ml/kg fluid consumed ~2 h pre-exercise with ~ 1 g/kg glycerol or 7 g sodium chloride; typically aids in the short-term retention of ~ 600 ml fluid to add to body water stores
Issues for future study	• Which is the most effective osmotic agent? Can a combination of osmotic agents increase fluid retention? • Does the gain in BM associated with fluid gain create a performance disadvantage? • What are the other side-effects (e.g. headache, gut upsets) are associated with hyperhydration strategies
Ice slurry for pre-cooling and within race cooling (for review, see Jay and Morris et al., 2018; Ross et al., 2013)	
Mechanism of action	• Internal heat transfer from cold drink or the enthalpy of fusion of ice (phase change from solid to liquid) may reduce total body heat content and allow greater duration or intensity of exercise before thermoregulatory challenges becomes significant and impairs performance
Best practice protocol	• Ice slurry: ~ 14 ml/kg consumed in two servings in the 30-60 min pre-exercise (i.e. immediately before abbreviated race warm up) to allow time to excrete excess fluid if needed. Should be combined with external cooling strategy (e.g. cold water immersion or ice towels/vest) to provide addition effect which might be continued during/after warm up
Issues for future study	• What is the most effective combination of internal and external cooling for each specific event, taking into account the logistical issues (of timing of warm up and race, facilities in race setting) as well as thermal challenges? • What is the effect of pre-cooling on pacing strategies? Can pre-cooling be detrimental if athlete misjudges perception of effort in the early party of race and chooses an unsustainable intensity causing a higher thermal load than can be tolerated?
Mouth sensing of "cool" during race with menthol (for review, see Stevens & Best, 2017)	
Mechanism of action	• Exposure of L-Menthol in the oral cavity activates transient receptor potential channels eliciting a cold sensory perception in the brain • Offers the opportunity to reduce thermal sensation/discomfort without changing body heat load to improve performance in the heat

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Best practice protocol	• Mouth rinsing or consumption of L-menthol in fluid or other agent (e.g. confectionery) • May be potentiated when combined with cool fluid
Issues for future study	• What is the optimal concentration and vehicle for mouth rinsing with Menthol? • Is the effect on thermal sensations repeatable throughout the race? • Is there a danger, to health or performance, of using artificial sensations of "cooling" during exercise in the heat if the athlete chooses a pace that leads to higher thermal load

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