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Nutrition for Ultramarathon Running: Trail, Track, and Road

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Title: Nutrition for ultra-endurance running: trail, track, and road ultramarathon.

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Abstract

Ultramarathon running events and participation numbers have increased progressively over the past three decades. Besides the exertion of prolonged running with or without a loaded pack, such events are often associated with challenging topography, environmental conditions, acute transient lifestyle discomforts, and/or event related health complications. These factors create a scenario for greater nutritional needs, whilst predisposing ultramarathon runners to multiple nutritional intake barriers. The current review aims to explore the physiological and nutritional demands of ultramarathon running, and provide general guidance on nutritional requirements for ultramarathon training and competition, including aspects of race nutrition logistics. Research outcomes suggest that daily dietary carbohydrates (up to 12 $g \cdot kg^{-1} \cdot day^{-1}$), and multiple-transportable carbohydrate intake (~90 $g \cdot h^{-1}$ for running distances ≥3 h) during exercise, supports endurance training adaptations and enhances real-time endurance performance. Whether these intake rates are tolerable during ultramarathon competition is questionable from a practical and gastrointestinal perspective. Dietary protocols, such as glycogen manipulation or low-carbohydrate high-fat diets, are currently popular amongst ultramarathon runners. Despite the latter dietary manipulation showing increased total fat oxidation rates during sub-maximal exercise, the role in enhancing ultramarathon running performance is currently not supported. Ultramarathon runners may develop varying degrees of both hypohydration or hyperhydration (with accompanying exercise-associated hyponatremia), dependent on event duration and environmental conditions. To avoid these two extremes, euhydration can generally be maintained through '*drinking to thirs*t'. A well-practiced and individualized nutrition strategy is required to optimize training and competition performance in ultramarathon running events, whether they are single- or multi-stage.

Key words: Energy requirement, carbohydrate, protein, fat oxidation, hydration, gastrointestinal.

Introduction

Ultramarathon running events and participation numbers have increased progressively over the past three decades (Deutsche Ultramarathon Vereinigung, 2018). Anecdotally, there has been growing interest from both amateur and elite endurance runners looking for new adventurous courses and challenges resulting in a wide range of competitive levels among ultramarathon participants; which also includes the substantial growing numbers of recreational ultramarathon participants targeting pleasure, tourisms, health and wellbeing outcomes. The increased participation has resulted in the internationalization of ultramarathon and trail-running events, with established championship races (www.iaaf.org/disciplines/ultra-running/ultra-running). Ultramarathons are defined as running events longer than the traditional marathon, and are hosted on either trail, track, or road. Most are, however, performed as trail events, and are typically either distance or time specific (Hoffman *et al*., 2010). Trail-running, constituting any off-road running event and can range from short distance fun-runs to ultramarathon distance competitions. By nature, trail-running is often associated with more harsh and challenging course topography (e.g., total elevation and descent, irregular running surfaces and obstacles) and environmental conditions (e.g., cold, heat, humidity, and altitude) compared with track and road based endurance running events, and may require running with a loaded pack (i.e., day-pack or self-sufficient load).

Another ultramarathon category is the multi-stage event, which has fixed distances or running time periods over multiple and consecutive days. Such ultramarathon types can be classified as either semi-supported (i.e., event organizers transport participants' necessities between stages, with *ad libitum* food and fluid provisions) or self-sufficient (i.e., runners must carry all necessities, with minimal food requirement regulations ($\geq$2000 kcal$\cdot$day^{-1}) and water ration provisions (~12 L·day^{-1})); and are normally accompanied by harsh trail course topographies, challenging environmental conditions (e.g., sub-zero, hot humid climates (≥30.0°C with 50-90% relative humidity), and altitude attainment of ≥3000 m), loaded running (e.g., up to 15 kg pack weight), and rough sleeping conditions (e.g., confined and/or crowded, unfamiliar, indoor or outdoor floor, tent, bivouac shelter or hammock). These additional challenges may contribute to the difficulty of multi-stage ultramarathon events, suggesting that lifestyle and mental management strategies (i.e., self-preservation, emotional adaptation, and ability to cope with these additional stressors) will affect performance outcomes.

With regards to the physiological demands of competitive ultramarathon training and event participation, an optimal nutritional intake is essential to support optimal performance. This applies during running, and in the preparation and recovery periods. Potential health complications associated with such extreme endurance exercise also need to be prevented or managed. With this in mind, the aims of the current review are to: 1) explore the physiological and nutritional demands of ultramarathon running; 2) provide general guidance on nutritional requirements for training periodization respective to ultramarathon running; and 3) provide general guidance on race nutrition logistics, including the prevention and management of running-associated gastrointestinal symptoms.

Physiological demands

Considering the multi-factorial demands and challenges of competitive ultramarathon running, a wide array of factors underpin performance outcome (Figure 1). Important physiological and psychophysiological characteristics for performance success in ultramarathon running have previously been reported (Nikolaidis & Knechtle, 2018). These include, but are not limited to: aerobic capacity and lactate responses, running economy and skill (e.g., ascending and descending, uneven and multi-textured footing, and obstacle management), pacing strategies, exogenous and endogenous energy substrate availability and utilization kinetics, thermoregulation, gastrointestinal integrity and functional responses. In addition, lifestyle (e.g., pack-weight, equipment, sleep, food and fluid preparation) and health management (e.g., injury, illness, infection, signs and symptoms), mental attitude (e.g., motivation, drive and toughness) and cognitive function (e.g., decision making under stress and fatigue) are also important factors to consider.

[Insert Figure 1 near here]

The assessment of performance predictors in single-stage mountain ultramarathon events (i.e., 65 km and 75 km, with 4000 m and 3930 m cumulative elevation, respectively) suggested that pre-determined $\dot{V}O_{2max}$ values can predict performance outcomes, such as event completion time (Balducci *et al.*, 2017; Fornasiero *et al.*, 2018). Whereas, energy and fuel utilization and efficiency does not necessarily contribute directly towards enhancing performance outcomes, despite clear changes in endogenous energy substrate being observed, albeit in extreme ultramarathon events (Schütz *et al.*, 2013). Additionally, pacing strategy (e.g., maintenance of consistent pace throught distance/time), running economy, skill and ability to adjust running technique to suit the terrain (e.g., contact and aerial time, step frequency, running velocity, and changes in these variable across distance/time), taking into consideration associated muscle functional responses (e.g., maximal aerobic speed and sustainable fraction, knee extensor force, and/or peak power output) appear to be strong predictors of performance outcomes in single-stage mountain trail ultramarathons (Balducci et al., 2017; Bossi *et al.,* 2017; Degache *et al.*, 2016; Fornasiero *et al.*, 2018; Hoffman, 2014;

Vernillo *et al*., 2017). It is, however, important to note that individual variables such as oxygen kinetics, power application and sustainability variables reported in laboratory experimental models only contributed to a fraction of performance outcomes; therefore emphasizing the multifaceted character of ultramarathon performance.

Thermoregulation is an important physiological aspect of ultramarathon running, especially when events are conducted in hot (e.g., ≥30°C) and humid (e.g., ≥80% relative humidity (RH)) ambient conditions. The increased production of internal body heat during prolonged strenuous running, concomitant with external heat stress from the environment, can challenge thermoregulation mechanisms of ultramarathon runners. For example, it is well established that greater physiological and psychophysiological disturbances, prompted by thermoregulatory strain, are seen during running in ≥30°C (with ~20% RH) compared with temperate ambient conditions (Costa *et al*., 2014a; Snipe *et al*., 2018). Therefore, success in ultramarathon running events conducted in hot ambient conditions, irrespective of humidity, requires an ability to maintain homeostatic core body temperature *via* thermoregulatory and/or cooling strategies (e.g., heat acclimatization/acclimation, internal cold fluid intake and/or external body cooling), and/or maintaining euhydration (Brown & Connolly, 2015; Stevens *et al*., 2017). Nevertheless, given the lower exercise intensity of ultramarathon running, compared with shorter endurance running events, the risk of developing heat exhaustion is also lower (ACSM *et al*., 2007). However, ultramarathon runners are at greater risk of heat stroke (i.e., gastrointestinal and systemic immune response pathophysiology), with clinical or subclinical issues potentially determined by running duration and magnitude of ambient heat exposure (Epstein *et al*., 2015; Gill *et al*., 2015).

Sleep deprivation is another common element of ultramarathon events that may influence performance outcomes. Evening or night scheduled event start times, organized overnight single-stage events or overnight stages within multi-stage events, ultramarathon events lasting >24-h, and potentially rough sleeping arrangements may disturb sleep quantity and quality. Laboratory controlled trials have shown that sleep deprivation adversely impacts running performance, compared with a full night of restful sleep, albeit in a 30 min running distance test (Oliver *et al*., 2009). How these outcomes translate into the field setting within ultramarathon competitions is not clear, since there exists substantial intra- and inter-individual variation in sleep quantity and quality within and between events (Martin *et al*., 2018).

Unlike shorter endurance running events, it is clear that the physiological demands of both single-stage and multi-stage ultramarathon participation vary considerably. These demands constitute both internal (e.g., physiological capabilities) and external (e.g., course topography, environmental conditions and/or lifestyle management) factors, which can differ widely among ultramarathon events.

Nutritional demands and support strategies

Information on the metabolic needs of ultramarathon runners is largely from either extrapolations or indirect estimates using a variety of methods (e.g., equations, heart rate responses, and/or accelerometry), predominantly from either single-case or case-series research designs (Williamson, 2016). Nevertheless, total caloric expenditure rates, using validated accelerometry and/or breath-by-breath indirect calorimetry methodologies, appear to be positively associated with overall exertional stress (Vernillo *et al.,* 2017; Williamson, 2016). Data have shown 3831-4999 kcal·day^{-1} during a 225 km 5-day undulating multi-stage ultramarathon conducted in hot ambient conditions (Costa *et al.*, 2013a), 4764-5654 kcal·day^{-1} during a 305 km 8-day mountain based multi-stage ultramarathon conducted in cold to temperate ambient conditions (Britton *et al.*, 2011), 6000-8000 kcal·day^{-1} during a 250 km 5-day multi-stage ultramarathon laboratory simulation (Alcock *et al.*, 2018), and up to 18000 kcal·day^{-1} for a 24-h single-stage trail ultramarathon (coverage range: 122-208 km) event (Costa *et al.*, 2014b). These data suggest that single-stage ultramarathon events may result in a vast energy expenditure; however, at a relatively low continuous hourly rate (e.g., ~550 kcal·h^{-1} over a 24-h period), with the total energy cost dependent on the specific race distance/time (Costa *et al.*, 2014b; Williamson, 2016).

Considering the typically longer non-stop distance of single-stage ultramarathon events, compared to each individual stage of multi-stage ultramarathon events and subsequent non-exercising rest periods between stages, it is likely to be more difficult for ultramarathon runners to match energy expenditure with energy intake during single-stage ultramarathon competitions, resulting in a substantial acute energy deficit (Costa *et al.*, 2014b; Enqvist *et al.*, 2010, Martinez *et al.*, 2018). Multi-stage ultramarathon events may present longer total distance coverage, but the segmentation of distance covered per day allows the opportunity for nutrition management and the provision for full requirements even with pack-weight restrictions (e.g., ≤15 kg) (Alcock *et al.*, 2018). A closer match between energy expenditure and intake, especially carbohydrate provisions, is associated with better performance outcomes and less physiolgical disturbances (Alcock *et al.*, 2018; Costa *et al.*, 2013a; Costa *et al.*, 2014b; Eden & Abernethy, 1994). Moreover, with increased food and fluid volume, in order to reduce the energy deficit gap, there is a potential risk of developing exercise-associated gastrointestinal symptoms due to compromised gastrointestinal function (i.e., delayed gastric emptying, intestinal transit, digestion and intestinal absorption) consistently observed in response to exercise stress *per se* (Costa *et al*., 2017a; 2017b; Horner et al., 2015; Leiper, 2015). However, it appears that training status may influence food and fluid intake tolerance during running, since highly trained runners display lower gastrointestinal intolerance and symptoms during endurance running compared with recreational counterparts at the same relative running intensity, duration, and carbohydrate challenge dose (Costa *et al*., 2017a). It is suggested that these observations may be associated with practicing race nutrition during training at the elite level of competition. From a practical perspective, ultramarathon runners should experiment with different degrees of food and fluid quantities and qualities (i.e., liquid, semi-solid and solids) to ascertain individual upper limits of gastrointestinal tolerance and preferences.

Meeting energy demands, and subsequent macronutrient profile and micronutrient provisions, for general ultramarathon running training and multi-stage ultramarathon events appears to be manageable with appropriate planning, as per general endurance exercise consensus guidelines (Thomas *et al*., 2016). For consecutive days of prolonged endurance running, achieving energy balance is recommended, alongside the provision of sufficient carbohydrate to meet exercise load demands (i.e., up to 12 $g \cdot kg^{-1} \cdot day^{-1}$, total running load dependent), and consumption of sufficient protein to meet daily nitrogen balance (i.e., 1.2-2.0 $g \cdot kg^{-1} \cdot day^{-1}$), to support tissue recovery and adaptations (Phillips & van Loon, 2011; Tarnopolsky *et al*., 1988). Habitual dietary protein needs for elite endurance athletes are estimated to be 1.6-1.8 $g \cdot kg^{-1} \cdot day^{-1}$ (Tarnopolsky *et al*., 1988; Kato *et al*., 2016), and such a requirement is likely to be similar for ultramarathon runners, given similar training volumes. In contrast, consuming this amount of dietary protein during single-stage ultramarathon running events is unlikely to be possible for most runners, especially if unsupported (Kato *et al*., 2016). For example, elite 100-mile ultramarathon runners consume very little protein before or during competition

(Stellingwerff, 2016). However, 1.3-2.2 g·kg^{-1}·day^{-1} of protein has been observed in successful semi-supported and self-sufficient multi-stage ultramarathon finishers (Costa *et al.*, 2013a; McCubbin *et al.*, 2016). Although the co-ingestion of protein with carbohydrate during exercise does not appear to improve endurance exercise performance in activities $\leq$2 h in duration (Cermak *et al.,* 2009; Beelen *et al.,* 2011), there is an improvement in net protein balance with protein and carbohydrate versus carbohydrate alone in a 6-h ultra-endurance trial (Koopman *et al.,* 2004), and it would be of interest to see if this enhances ultramarathon running performance. Fat intake supports the provision of additional daily energy requirements, usually 20-35% of total daily energy intake/requirements. Further limiting fat intake has not proven beneficial for performance outcomes and risks overall nutritional inadequacy (e.g., fat soluble vitamins and essential fatty acids).

With regards to specific macronutrient intake and timing, 1-4 g·kg^{-1} of carbohydrate 1-4 h before endurance running is recommended (Thomas *et al.*, 2016). This is particularly beneficial when carbohydrate intake within the recovery period between running bouts fails to fully restore muscle glycogen storage, and in addition supports glucose availability during the initial phase of exercise. The choice of food and/or fluid to be consumed during the pre-exercise period should focus on avoiding potential gastrointestinal discomfort and/or intolerance (e.g., low in fat, protein, fibre, and fermentable oligo-di-mono- saccharides and polyol (FODMAP) content). Immediately after prolonged strenuous running, the consumption of 1.0-1.2 g·kg^{-1} of carbohydrate is recommended to assist muscle glycogen resynthesis, with some additional protein (up to 0.3-0.4 g·kg^{-1}) to aid tissue recovery (Beelen *et al.,* 2010).

Although the nutritional intake to meet the demands of shorter endurance running events seems feasible, evidence suggests that competitive ultramarathon runners find these nutritional recommendations hard to implement on an *ad libitum* basis, especially during the competition phase (Heaney *et al.*, 2011; Costa *et al.*, 2013a; Costa *et al.*, 2014). Excessive transient or long-term low-grade energy (and nutritional) deficits justify considering ultramarathon runners as a high risk population for the development of relative energy deficiency syndrome (RED-S, including the female triad), unexplained under-performance (overtraining) syndrome, exercise-induced gastrointestinal syndrome, soft tissue injuries and illnesses/infections, with associated acute and chronic health implications of clinical significance (Mountjoy *et al.*, 2018; Lewis *et al.*, 2015; Costa *et al.*, 2017b; Soligard et al., 2016; Schwellnus et al., 2016).

Considering nutritional recommendations for general endurance exercise are predominately derived from controlled laboratory settings, generally amongst highly trained individuals, differing modalities (e.g., endurance cycling), and distances shorter than in typical ultramarathon running; it is plausible that these current recommendations may need adjusting to cater for the specific population demographics, real-life practical barriers, and specific race characteristics. Further research is warranted in this area, including the comprehensive and accurate assessment and analysis the nutrition protocols of successful ultramarathon runners and comparison against recommendations for endurance exercise, and the role of prescriptive energy and nutrient intake templates on markers of fuel kinetics, physiological and psychophysiological disturbance markers, symptomology and performance outcomes.

Fat adaptation protocols

In recent years, anecdotal evidence from sport nutrition professionals suggests a growing number of elite and amateur ultramarathon runners are purposely attempting, with or without professional guidance, adhering to LCHF or ketogenic diets, aiming to enhance maximal and relative fat oxidation capacity during moderate to vigorous running speeds, and subsequently enhance ultramarathon running performance. This growing dietary trend amongst ultramarathon runners occurs despite scarce research supporting performance improvement with these dietary interventions (Pinckaers *et al*., 2017).

Fat is a favourable fuel substrate during low and moderate intensity running, and/or when endogenous muscle glycogen stores become depleted. It is well established that fat oxidation, at a given running intensity, can be upregulated by appropriate training, or in response to dietary carbohydrate and fat manipulations (Burke, 2015; Impey *et al*., 2016; Pinckaers *et al*., 2017). Theoretically, ultramarathon runners with high fat oxidation rate adaptations (e.g., $\geq$1.2 g·min^{-1}) could sustain ~700 kcal·h^{-1} of energy from fat oxidation alone, which may be beneficial if running duration is prolonged (e.g., $\geq$10 h), and of low (i.e., walking pace at 5-6 km·h^{-1} ; equivalent to ~45% $\dot{V}O_{2max}$) to moderate (i.e., 8-12 km·h^{-1} ; equivalent to 55-70% $\dot{V}O_{2max}$) intensity (Alcock *et al.,* 2018; Costa *et al.,* 2013a; 2014a; 2014b; 2017a; Rauch *et al.,* 2018; Snipe *et al.,* 2018). From an ultramarathon perspective, higher exercise intensities (i.e., >70% $\dot{V}O_{2max}$) could intermittently occur with undulating or extreme course topographies, and/or while managing course obstacles (Balducci et al., 2017; Degache *et al*., 2016; Fornasiero *et al*., 2018; Kerhervé *et al*., 2015; Vernillo *et al*., 2017), which may not be sufficiently fueled for by utilization of fat energy substrate alone.

There is considerable debate about whether an ultramarathon runner might have a performance benefit from dietary carbohydrate or fat manipulations, ketogenic adaptation, or simply training in a glycogen depleted state to enhance fat oxidation (Burke, 2015; Impey *et al.*, 2016; Pinckaers *et al.*, 2017). Indeed, such dietary behavior has consistently shown increased peak fat oxidation rates at exercise intensities between 60-80% $\dot{V}O_{2max}$ (1.5-1.8 g·min^{-1}) (Burke *et al.*, 2017; Volek *et al.*, 2016). However, high fat oxidation rates also appear to be inherent in ultramarathon runners regardless of background macronutrient dietary modifications. A recent study (n= 15 men) found a wide range of maximal fat oxidation rates (mean: 68% (95% CI: 61-74%) $\dot{V}O_{2max}$) and steady-state fat oxidation rates (0.8-1.7 g·min^{-1}) over 3 h of running at 60% $\dot{V}O_{2max}$ (mean ± SD: 10.0 ± 1.2 km·h^{-1}), while adhering to a macronutrient balanced diet (20% protein, 52% carbohydrate, 28% fat) and consumpting carbohydrates during exercise (90 g·h^{-1}, 2:1 glucose-fructose 10% *wv*) (Rauch *et al.*, 2018).

Determining whole body fuel utilization during ultramarathon events presents challenges and complexities, which will impact on the magnitude of exercise stress, and subsequently dictate fuel kinetics (Howe *et al.*, 2018). Although a comprehensive evaluation of dietary manipulation in ultramarathon runners has not yet been completed, positive correlations of pre-exercise dietary carbohydrate manipulations and during running carbohydrate intake with performance outcomes are consistently observed in endurance models that may be applicable to ultramarathon runners (Smith *et al.*, 2013; Stellingwerff & Cox, 2014). Further research is needed, however, to investigating the potential role of dietary carbohydrate and fat manipulations specific to ultramarathon running performance.

Race nutrition

Logistics

Due to the wide variation in ultramarathon events, the logistics of race nutrition management varies dramatically. In some events, few supplies are needed and can be accommodated by a hand-held water bottle, soft flask or small pack with water bladder, with minimal nutritional items carried in pack, clothing pockets and/or waist band. In contrast, other events require a larger pack to carry mandatory gear, multiple days of food, equipment and other necessities; and ability to carry sufficient water for consecutive hours of running and/or a means of water purification. However, some general factors appropriate for all events can be considered.

Energy intake ranging from 36-63% of energy expenditure have been reported in continuous single-stage ultramarathon events lasting from 24-30 h (Costa *et al.*, 2014b; Stuempfle *et al.*, 2011). Whereas, energy deficits of >1000 kcal·day^{-1} have been seen in semi-supported and self-sufficient multi-stage ultramarathon competitions (Costa *et al.*, 2013a; McCubbin *et al.*, 2016). With this in mind, ultramarathon runners are unlikley to fully replace energy expenditure acutely, and need not plan carrying full energy requirements. Alternatively, they should strive to logistically organize and consume what is feasibly tolerable (Table 1).

[Insert Table 1 near here]

Avoiding an excessive energy deficit is best accomplished with nutrient dense foods and fluids, which have been practiced in training that mimicks race conditions, and is adequately tolerated. To avoid carrying excessive amounts of nutritional items during the event, and therefore unneccessary pack weight, ultramarathon runners should determine in advance which nutritional items will be available during the event and assess such items in training. Furthermore, it is important to determine whether certain foods are available in the race country, since local choices can vary widely. Regardless, appetite dysfunction, taste fatigue, and gastrointestinal symptoms are common during ultramarathon events (Costa *et al.*, 2016; Hoffman & Fogard, 2011), so runners should be flexible to the nutritional items consumed by conceding to cravings or what appears most tolerable. Finally, if nutrients are being largely or exclusively consumed in liquid form, caution should be taken to avoid hyperhydration and associated health complications (e.g., hyponatremia).

Feeding during running

It is well established that carbohydrate consumption during exercise enhances endurance performance (Smith *et al.*, 2013; Stellingwerff & Cox, 2014). Research that has formed the basis for feeding during endurance exercise consensus guidelines and recommendations (Thomas *et al.*, 2016), predominantly used experimental designs less than the marathon distance/time and/or other modalities (e.g., cycling) (Smith *et al.*, 2013; Stellingwerff & Cox, 2014). Nevertheless, for ultramarathon running, whereby duration is typically >4 h, it is generally recommended to consume 90 $g \cdot h^{-1}$ of a multiple-transportable carbohydrate blend (e.g., 2:1 glucose-fructose ratio) (Thomas *et al.*, 2016). Gastric emptying, intestinal transit and nutrient absorption in response to exertional-stress, together with blood glucose availability, glucose muscle uptake and oxidation capacity, are influential factors in an individual's ability to tolerate and utilise exogenous carbohydrates during exercise (Costa *et al.*, 2017a; Cox *et al.*, 2010; Horner *et al.*, 2015; Leiper, 2015). It appears that such high levels of carbohydrate intake during running are not achievable by the majority of both elite and amateur ultramarathon runners (Costa *et al.*, 2016). For example, *ad libitum* carbohydrate intake rates during running in single-stage and multi-stage ultramarathon events are consistently reported between 20-40 $g \cdot h^{-1}$, despite reports of runners carrying >60 $g \cdot h^{-1}$ (Costa *et al.*, 2013a; Costa *et al.*, 2014; Kruseman *et al.*, 2005; Martinez *et al.*, 2018; Stuempfle *et al.*, 2011). Moreover, >50% of participants during various distances of the

'*Ultra Mallorca Serra de Tramuntana*' and a 44-km mountain ultramarathon failed to consume >30 g·h^{-1} of carbohydrate (Kruseman *et al.*, 2005; Martinez *et al.*, 2018).

Given that general aerobic fuel oxidation rates for ultramarathon running have not yet been fully explored, applying the guidelines and recommendations for shorter endurance exercise could be erroneous. Therefore, individual specific assessment for carbohydrate gastric emptying and intestinal transit, digestibility and absorbability, and oxidation rates during exercise stress is recommended. Using, for example, ^{13}C labelled food or fluid ingestion or lactulose challenge followed by breath sampling and analysis with or without electrogastrography to assess gastrointesintal transit functional responses; specific (i.e., quantity and quality) food or fluid challenge with breath sampling and analysis to quantify H_2 and CH_4 concentration to assess feeding tolerance and magnitude of malabsorption; breath-by-breath indirect calorimetry to assess total carbohydrate oxidation rates at the point of stressed muscle glycogen stores (e.g., ≥3 h running at 55-70% $\dot{V}O_{2max}$); and in adjunct with a validated and reliable gastrointestinal symptoms assessment tool (Costa *et al.*, 2017a; Costa *et al.*, 2017b; Gill *et al.*, 2015; Snipe *et al.*, 2018). Such outcomes could be integrated into competition nutrition plans (Table 2). However, the proposed high rates of 90 g·h^{-1} of a multiple-transportable carbohydrate blend for endurance exercise ≥3 h likely requires scaling down for ultramarathon activities, due to the lower absolute exercise intensity (Jeukendrup, 2014).

[Insert Table 2 near here]

Gastrointestinal disturbance and symptoms

Gastrointestinal symptoms are a common feature of ultramarathon running, with a 60-96% prevalence of severe symptoms reported after ultramarathon competition (Costa *et al.*, 2017b). Gastrointestinal symptoms have been reported as a major factor limiting nutritional intake during and after ultramarathon events, withdrawal from competition, and are linked to severe clinical episodes of acute colitis with accompanying fecal blood loss (Costa *et al.*, 2016; Costa *et al.*, 2017b). The causes of adverse gastrointestinal symptoms during and after ultramarathon running appear to be multi-factorial in nature, but are likely related to splanchnic hypoperfusion and increased sympathetic drive, which results in clinically significant secondary outcomes such as: epithelial injury and permeability, impaired gastrointestinal function, and systemic responses (i.e., endotoxaemia and cytokinaemia), termed '*exercise-induced gastrointestinal syndrome*' (Costa *et al.*, 2017b). The management of extrinsic (e.g., magnitude of exercise stress and coping with environmental conditions) and intrinsic (e.g., feeding tolerance and underlying gastrointestinal conditions) exacerbating factors appears to be the first line action against exercise-induced gastrointestinal syndrome and associated symptoms. Certain dietary strategies before and/or during exercise may be beneficial, favourable, neutral, or damaging in supporting gastrointestinal integrity and function during exercise stress models (Figure 2). However, an individualized approach, after gastrointestinal assessment and tolerance measurements during running, is essential for the efficacious prevention and/or management of exercise-induced gastrointestinal syndrome in ultramarathon runners.

[Insert Figure 2 near here]

Hydration

Proper management of hydration is critical for both performance and overall health in ultramarathon running. However, it is apparent that there are many challenges facing ultramarathon runners in managing hydration, as evident from observations at a 161-km ultramarathon, in which 10% of participants gained body mass and 7% were hyponatremic at the finish (Hoffman & Stuempfle, 2015). Similar hydration mismanagement has been observed during multi-stage and 24-h ultramarathon events (Costa *et al*., 2013b; Costa *et al*., 2014). The present review will focus on aspects of hydration unique to ultramarathon participation (Table 3), which may vary in comparison to hydration needs of shorter endurance running events (see Casa *et al.,* 2018).

[Insert Table 3 near here]

During the hours or days of running while participating in ultramarathon events, proper hydration involves maintaining adequate fluid intake to avoid performance limiting hypohydration, while also avoiding excessive fluid intake with potential for developing exercise-associated hyponatremia (EAH) (Hew-Butler *et al*., 2015). Endurance exercise performance has been reported to be impaired with 1-2% total body water loss in controlled laboratory studies (Sawka *et al*., 2001). Though it has been suggested that such conditions do not necessarily translate into field based scenarios (Wall *et al*., 2015), and must be interpreted with recognition that changes in body water and body mass are not equivalent (Hoffman *et al.,* 2018a; Maughan *et al.,* 2007). On the other hand, hyperhydration is the primary risk for the development of EAH, from which a number of fatalities have been reported during various activties (Hew-Butler *et al*., 2015). Fortunately, to date we are unaware of any EAH related deaths in ultramarathon events. Hyperhydration can also decrease performance indirectly by increasing body mass and unnecessary fluid carrying, time delay for drinking and filling fluid containers, and pauses required for urination. Additionally, excess fluid intake may result in an overwhelming gastric load (i.e., increase intragastric pressure) and contribute to upper-gastrointestinal symptoms (Costa *et al.*, 2017a; Leiper, 2015). Thus, avoiding hyperhydration or hypohydration is recommended for both health and performance in ultramarathon running.

Proper hydration during ultramarathon running requires the understanding that all fluid losses need not be replaced, as body mass loss from endogenous substrate oxidation is expected (Hoffman *et al.*, 2018a; Maughan *et al.*, 2007). It is also recognized that water is produced during fuel oxidation, and some water linked with glycogen may be released in response to oxidation of endogenous glycogen stores. However, the extent of availability of these water sources to support the intravascular water pool remains controversial, so the proper proportion of body mass loss during endurance running is not completely clear. Nonetheless, if the running bout is long enough, the desired body mass loss will be beyond the typical guidelines suggesting that losses should be limited to no more than 2% of body mass (McDermott *et al.*, 2017).

Drinking to thirst (also referred to as *ad libitum* drinking) is now considered by many authorities to be the optimal strategy to assure proper hydration during endurance running (Hew-Butler *et al.*, 2015; Hoffman *et al.*, 2016; Hoffman *et al.*, 2018b). On the contrary, others consider thirst to be an inadequate stimulus to maintain proper hydration (Armstrong *et al.*, 2016), though past recommendations emphasizing this were largely intended for situations in which dehydration might develop rapidly from high sweat rates associated with high exercise intensities (Hew-Butler *et al.*, 2015), which is not applicable to moderate intensity competitive ultramarathon running and large sections of walking (i.e., low intensity exercise) in recreational ultramarathon participants. Indeed, considerable evidence has demonstrated that drinking to thirst during ultramarathons, even under hot ambient conditions (e.g., ≥30°C), supports adequate hydration (Costa *et al.*, 2013b; Hoffman *et al.*, 2018b; Hoffman & Stuempfle, 2014; Hoffman & Stuempfle, 2016; Tam *et al.*, 2011). Thus, adequate fluid intake during ultramarathon running can generally be achieved by simply drinking fluids *ad libitum*, as long as there is adequate access to fluids when desired. When fluid access is limited, it is essential for runners to estimate the fluid volume required to carry between sources to support thirst (i.e., balance availability with avoiding the need to carry unnecessary fluids). This is best done through experience, while recognizing variability in the appropriate fluid intake with exercise intensity and ambient conditions.

In conjunction with hydration strategies, sodium supplementation, before and during running, is a common practice among ultramarathon runners, owing to beliefs that sodium will prevent dehydration, muscle cramping, nausea and EAH, and subsequently enhance performance (McCubbin & Costa, 2018; McCubbin *et al.,* 2018). It has, however, been demonstrated that supplemental sodium is not necessary to maintain euhydration during ultramarathon competition, even under hot ambient conditions (Hoffman *et al*., 2015). Moreover, sodium intake during exercise will also not prevent EAH in the presence of hyperhydration (Hew-Butler *et al.,* 2015). Thus, best practice suggests avoiding attempts to replace all sodium lost in sweat through the intake of sodium supplementation during ultramarathon running, recognizing that considerable sodium is present in the typical race diet (e.g., electrolye beverages, sports bars and gels, savory sandwiches, crisps, pretzels, and soups).

Conclusions

In comparision with shorter endurance running events, it is evident that the physiological demands, and subsequently the total nutritional and hydration demands, of ultramarathon running are far greater, and dependent on the event distance or time, course topography, environmental conditions, and degree of support and/or self-sufficiency. While considering nutrition and hydration guidelines and recommendations for general endurance exercise may provide some guidance and support for shorter running events and ultramarathon training, caution is warranted in using those guidelines for ultramarathon competition due to the large diversity of participant demographics and event characteristics. It is clear that individual assessment to determine daily and event nutrition and hydration requirements, based on the runner's specificities (e.g., physiology, tolerance, and preference) and event characteristics, is essential to inform appropriate customized nutritional action plans. It is unlikley that full energy and nutritional provisions can be met during single- and multi-stage ultramarathons; however developing training and race nutritional strategies to amelorate the potentially extreme deficit will support training and event performance, and also contribute to the prevention or attenuation of any associated health complications of sub-clinical or clinical significance.

Take home messages:

- Aerobic capacity and lactate responses, running economy and skill, pacing strategies, exogenous and endogenous energy substrate availability and utilization kinetics, thermoregulation, gastrointestinal integrity and functional responses, lifestyle management, mental attitude and cognitive function are important physiological and psychophysiological characteristics for performance success in ultramarathon competition.
- The physiological demands and subsequently nutritional requirements of ultramarathon running are greater than shorter track and road endurance running events.

- Consuming sufficient foods and/or fluids, within tolerance level, in the attempt to meeting energy (and macronutrient) demands provides an efficacious base for optimal ultramarathon training and competition.
- The consumption of 1.6-1.8 $g \cdot kg^{-1} \cdot day^{-1}$ of protein is likely to be sufficient for ultramarathon training. However, it is unclear what the amino acid or protein needs are during ultramarathon competition to optimize performance.
- Race nutrition management varies widely due to differences in ultramarathon events, but individual gastrointestinal tolerance, food-fluid availability and preference will dictate the magnitude of an energy deficit during ultramarathon competition.
- Gastrointestinal assessment and tolerance measurements during running is essential for the application of appropriate feeding plans during running and management of exercise-induced gastrointestinal syndrome.
- Proper hydration during ultramarathon participation can generally be maintained by drinking to thirst.

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Conflicts of interest

All authors declare no conflicts of interest.

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Figures legends

Figure1. Schematic description of the complex multi-factorial characteristics, challenges and demands of ultramarathon running, and how it may impact on nutritional provisions during a period of increased requirements. ^{1} injury, illness, signs and symptoms, $^{+}$ positive, $^{-}$ negative.

Figure 2. Schematic description of updated evidence for dietary modification and nutritional supplement interventions for the prevention and management of exercise-induced gastrointestinal syndrome. Adapted from Costa *et al.*, (2017b) with permission. $^{++}$ Evidence of substantial beneficial effect; $^{+}$ evidence of beneficial effect, but modest in nature; $^{\leftrightarrow}$ none or insufficient evidence of beneficial effect; $^{?}$ inconclusive, unknown, and (or) conflicting efficacy. [a] splanchnic hypoperfusion, and subsequent intestinal ischemia and injury (including mucosal erosion) results in direct (e.g., enteric nervous system and/or enteroendocrine cell) or indirect (e.g., nutrient malabsorption) alterations to gastrointestinal motility. [b] Amino acids glutamine, L-arginine, and L-citrulline. [c] Gastrointestinal symptoms include: upper- (gastro-esophageal and gastro-duodenal originated: regurgitation, urge to regurgitate, gastric bloating, belching, stomach pain and heartburn/gastric acidosis) and lower- (intestinal originated: flatulence including lower-abdominal bloating, urge to defecate, abdominal pain, abnormal defecation including loose water stools, diarrhoea and blood in stools) gastrointestinal symptoms, and/or other related symptoms (e.g., nausea, dizziness and acute transient abdominal pain).

Figure 1.

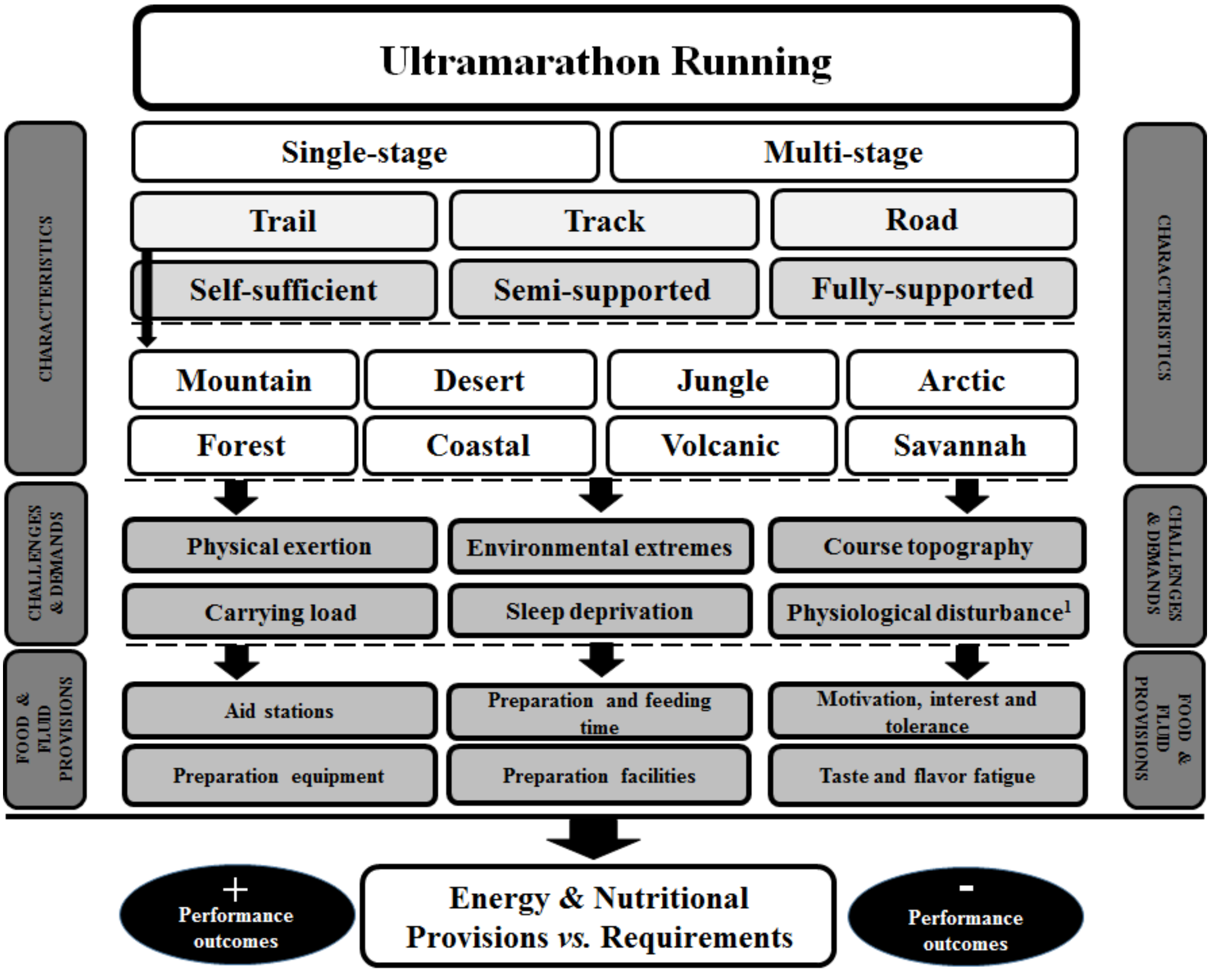

Ultramarathon Running
Single-stage
Multi-stage
Trail
Track
Road
Self-sufficient
Semi-supported
Fully-supported
Mountain
Desert
Jungle
Arctic
Forest
Coastal
Volcanic
Savannah
Physical exertion
Environmental extremes
Course topography
Carrying load
Sleep deprivation
Physiological disturbance¹
Aid stations
Preparation and feeding time
Motivation, interest and tolerance
Preparation equipment
Preparation facilities
Taste and flavor fatigue
CHARACTERISTICS
CHALLENGES & DEMANDS
FOOD & FLUID PROVISIONS
+ Performance outcomes
Energy & Nutritional Provisions vs. Requirements
- Performance outcomes

Figure 2.

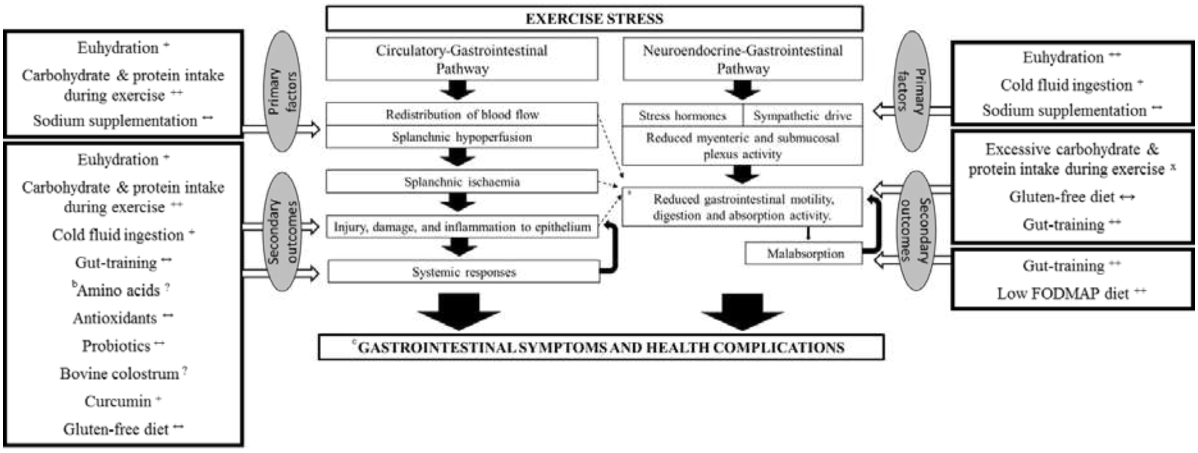
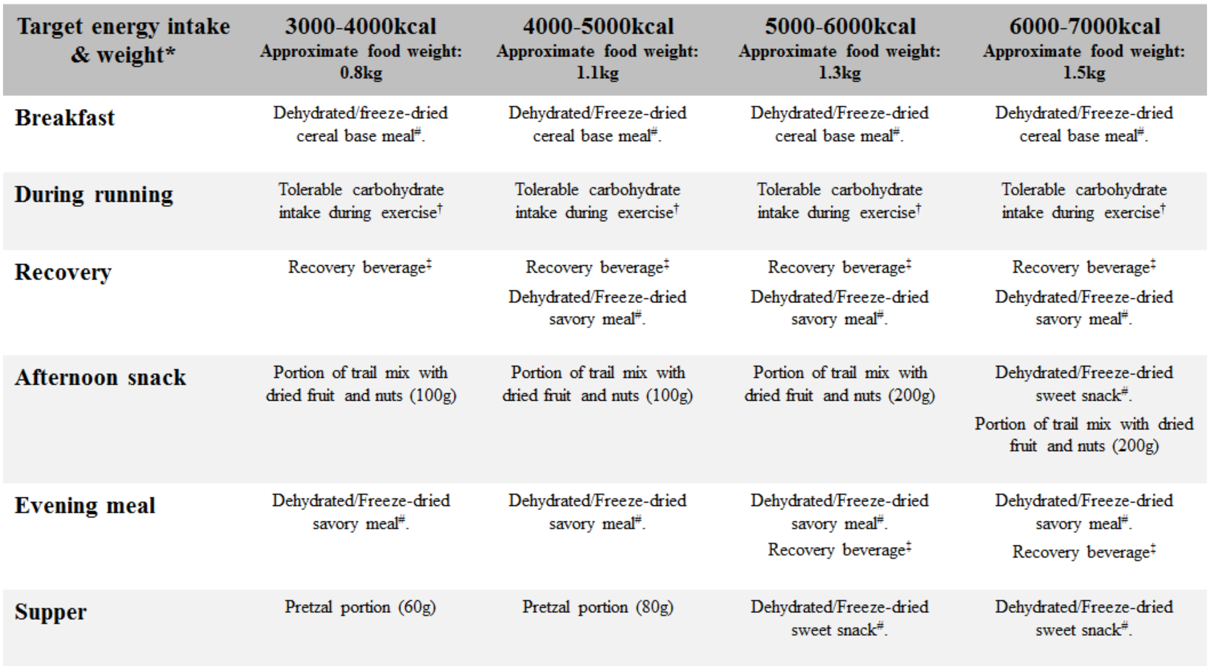

EXERCISE STRESS
Circulatory-Gastrointestinal Pathway
Neuroendocrine-Gastrointestinal Pathway
Euhydration +
Carbohydrate & protein intake during exercise ↔
Sodium supplementation ↔
Primary factors
Redistribution of blood flow
Splanchnic hypoperfusion
Stress hormones
Sympathetic drive
Reduced myenteric and submucosal plexus activity
Primary factors
Euhydration ↔
Cold fluid ingestion +
Sodium supplementation ↔
Euhydration +
Carbohydrate & protein intake during exercise ↔
Cold fluid ingestion +
Gut-training ↔
bAmino acids ?
Antioxidants ↔
Probiotics ↔
Bovine colostrum ?
Curcumin +
Gluten-free diet ↔
Secondary outcomes
Splanchnic ischaemia
Injury, damage, and inflammation to epithelium
Systemic responses
a Reduced gastrointestinal motility, digestion and absorption activity.
Malabsorption
Secondary outcomes
Excessive carbohydrate & protein intake during exercise x
Gluten-free diet ↔
Gut-training ↔
Gut-training ↔
Low FODMAP diet ↔
cGASTROINTESTINAL SYMPTOMS AND HEALTH COMPLICATIONS

Table 1. Example dietary plan for semi-supported and self-sufficient multi-stage ultramarathon competition.



Target energy intake & weight*	**3000-4000kcal** **Approximate food weight: 0.8kg**	**4000-5000kcal** **Approximate food weight: 1.1kg**	**5000-6000kcal** **Approximate food weight: 1.3kg**	**6000-7000kcal** **Approximate food weight: 1.5kg**
Breakfast	Dehydrated/freeze-dried cereal base meal[#].	Dehydrated/Freeze-dried cereal base meal[#].	Dehydrated/Freeze-dried cereal base meal[#].	Dehydrated/Freeze-dried cereal base meal[#].
During running	Tolerable carbohydrate intake during exercise[†]	Tolerable carbohydrate intake during exercise[†]	Tolerable carbohydrate intake during exercise[†]	Tolerable carbohydrate intake during exercise[†]
Recovery	Recovery beverage[‡]	Recovery beverage[‡] Dehydrated/Freeze-dried savory meal[#].	Recovery beverage[‡] Dehydrated/Freeze-dried savory meal[#].	Recovery beverage[‡] Dehydrated/Freeze-dried savory meal[#].
Afternoon snack	Portion of trail mix with dried fruit and nuts (100g)	Portion of trail mix with dried fruit and nuts (100g)	Portion of trail mix with dried fruit and nuts (200g)	Dehydrated/Freeze-dried sweet snack[#]. Portion of trail mix with dried fruit and nuts (200g)
Evening meal	Dehydrated/Freeze-dried savory meal[#].	Dehydrated/Freeze-dried savory meal[#].	Dehydrated/Freeze-dried savory meal[#]. Recovery beverage[‡]	Dehydrated/Freeze-dried savory meal[#]. Recovery beverage[‡]
Supper	Pretzal portion (60g)	Pretzal portion (80g)	Dehydrated/Freeze-dried sweet snack[#].	Dehydrated/Freeze-dried sweet snack[#].

[*] Estimations based on 10-15% protein, 70-75% carbohydrate, and 10-20% fat energy contribution. Does not include water (i.e., hydration needs). [#] Nutritional value based on standard dehydrated/freeze-dried meal averages. [†] Approximately 0.8-1.0 g·kg^{-1}·h^{-1} carbohydrate, in a 6-10% *wv* solution (Costa *et al.*, 2017a). [‡] 1.2 g·kg^{-1} carbohydrate and 0.4 g·kg^{-1} protein, in a 10% carbohydrate *wv* solution (Beelen *et al.*, 2010).

Table 2. Practical nutrition recommendations to support individualized strategies during participation in ultramarathon running events.

Nutrition- Practical Recommendations
• Trial and practice race nutrition in training sessions, including specific food and fluid quality and quantity.
• Experiment with different fluid volumes, and carbohydrate intake rates and concentrations, and find the optimal individualized tolerance levels. Increasing fluid volume first, then try increasing carbohydrate concentration.
• Experiment with different carbohydrate types (e.g., blends such as glucose-fructose) and forms (e.g., fluids, gels, bars, puree, fruits, and other carbohydrate rich foods).
• Undertake a gastrointestinal assessment during running in a competition mirrored simulation to establish individual tolerance to carbohydrate types, forms, and concentrations.
• Alter the acute rate of intake (e.g., small and frequent intake), and experiment with higher intake rates early into running, since gastrointestinal symptoms are generally lower during the first 2 h of running and then start to develop thereafter.
• Practice race nutrition strategies in less important ultramarathon running events to try and identify 'outside' contributing factors (e.g., travel effects, competition stress, changes in habitual food availability, weather conditions, and pacing).
• Identify the food and fluid provisions (including the bottled water) of each ultramarathon event participation, and experiment with these both chronically (throughout the day) and during exercise. This is especially important to consider when racing away from home-base (e.g., nationally or internationally).
• In longer races (≥8 h) experiment with various easily digestible and carbohydrate rich solid food sources. Avoid foods excessively rich in protein, fat, fibre and FODMAPs.
• In longer races (≥8 h), in cases where tolerance to carbohydrate intake and gastrointestinal symptoms are an issue, mouth rinsing with a carbohydrate beverage may support the maintaining of workload through the oral-cortex sensory network.

Table 3. Practical hydration recommendations to support individualized strategies during participation in ultramarathon running events.

Hydration- Practical Recommendations
• Initiate exercise in an euhydrated state and avoid pre-exercise hyperhydration.
• During running '*drink to thirst*' using '*ad libitum*' drinking strategies, provided fluids are available.
• Avoid excessive volumes of fluid intake, know fluid tolerance limits. Small and frequent- limit gastric overload during a period of compromised gastrointestinal function.
• Avoid excessive sodium supplementation during running. Consume sodium based on food cravings. Do not use highly visible salt losses as a signal for increasing sodium intake.
• When fluid access is limited and must be carried by the runner between sources, estimating fluid needs is best done through experience, or through training or laboratory conditions to assess the range of potential requirements, while recognizing that the appropriate fluid intake will vary with course topography, ambient conditions, and pacing.
• Determining hydration status is best achieved through history of fluid intake and monitoring body mass, recognizing that some body mass should be lost during prolonged exercise as a result of oxidation of endogenous fuel stores, water generation with fuel oxidation, and the release of water bound to glycogen during glycogenolysis.
• If training and/or competing in hot ambient conditions (both dry and humid), prior heat acclimatization/acclimation is valuable as it results in plasma volume expansion.
• Oliguria (limited urine output) is not necessarily a signal of dehydration. Avoid using urine measures of hydration (e.g., urine colour, urine specific gravity, and urine osmolality) as a method of monitoring hydration status during ultramarathon running activities.