

Nutrition for Adventure Racing

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Abstract

Adventure racing requires competitors to perform various disciplines ranging from, but not limited to, mountain biking, running, kayaking, climbing, mountaineering, flat- and white-water boating and orienteering over a rugged, often remote and wilderness terrain. Races can vary from 6 hours to expedition-length events that can last up to 10-consecutive days or more. The purpose of this article is to provide evidence-based nutritional recommendations for adventure racing competitors. Energy expenditures of 365–750 kcal/hour have been reported with total energy expenditures of 18 000–80 000 kcal required to complete adventure races, and large negative energy balances during competitions have been reported. Nutrition, therefore, plays a major role in the successful completion of such ultra-endurance events. Conducting research in these events is challenging and the limited studies investigating dietary surveys and nutritional status of adventure racers indicate that competitors do not meet nutrition recommendations for ultra-endurance exercise. Carbohydrate intakes of 7–12 g/kg are needed during periods of prolonged training to meet requirements and replenish glycogen stores. Protein intakes of 1.4–1.7 g/kg are recommended to build and repair tissue. Adequate

replacement of fluid and electrolytes are crucial, particularly during extreme temperatures; however, sweat rates can vary greatly between competitors. There is considerable evidence to support the use of sports drinks, gels and bars, as they are a convenient and portable source of carbohydrate that can be consumed during exercise, in training and in competition. Similarly, protein and amino acid supplements can be useful to help meet periods of increased protein requirements. Caffeine can be used as an ergogenic aid to help competitors stay awake during prolonged periods, enhance glycogen re-synthesis and enhance endurance performance.

1. Adventure Racing

Adventure racing is an unusual wilderness, multi-sport ultra-endurance event raced over challenging topography and often during extreme environmental conditions.^[1] Adventure races usually involve continuous, multiday multisport events and competition duration can vary from 2 hours to several uninterrupted days.^[2] Participants compete either individually or in teams of mixed gender consisting of three to five members.^[3] To successfully complete an adventure race, competitors must use a range of specific athletic abilities including, but not limited to, trekking, mountain biking, paddling, climbing, swimming and orienteering.^[2] Although some adventure races can be rather complex, the overall aim is to cross the finish line after navigating through specific checkpoints designated by the organizers without incurring any penalties.^[4] The team must stay together at all times and the first team across the finish line is the winner.

Although humans have been involved in adventure for a long time, the modern era of adventure racing can be traced back to the early 1980s when New Zealand hosted the Coast-to-Coast event^[5] and the Wilderness Classic race started in Alaska in 1983.^[4,6] Over the past decade, adventure racing has become very popular with an increasing number of participants and events each year.^[5] Adventure races are categorized by duration into sprint races (<6 hours), intermediate races (6–12 hours), long races (12–26 hours) and expedition-length races (>36 hours).^[4,5,7] Table I summarizes the various adventure race distances and events.

It should be acknowledged that conducting research in adventure racing presents numerous difficulties, as competitors face competing in challenging environments over several consecutive days in typically remote locations. Although some research has been conducted in challenging race conditions,^[8] or during training,^[3] gathering physiological and nutritional data during adventure races can be complex. Consequently,

Table I. Characteristics of adventure races

Race type	Event example (location)	Typical distance (km)	Disciplines	Typical race completion time for winning team (h)
Sprint	Action Asia Challenge (Hong Kong)	51.5	Rappelling, zip lines, Tyrolean crossing, ocean kayaking, trail running, hiking, rock river scrambling, map reading, orienteering	4
Intermediate	Swazi extreme (Kingdom of Swaziland)	121	Hiking, running, mountain biking, white-water rafting, canoeing, tubing, fixed ropes, canyoning, swimming, caving and navigation	20
Long	Arctic Team Challenge (East Greenland)	257.5	Ice fjord paddling, glacier- and off-track trekking, climbing, mountain biking	30
Expedition	Subaru Primal Quest (various locations in the US)	724	Caving, mountain biking, flat-water paddling, white-water paddling, hiking, orienteering, rappelling, ascending, Tyrolean transverse	120

some researchers have attempted to simulate races in the laboratory.^[2,8] There are inherent problems with both laboratory- and field-based studies. Adventure race simulations in the laboratory lack ecological validity and extraneous variables are difficult to control in studies conducted during actual races. Due to the lack of research and the complexities in conducting research in adventure racing, we are dependent on scientific findings from other similar ultra-endurance sports. The purpose of this article is to provide evidence-based nutritional recommendations for adventure racing competitors.

2. Methods

2.1 Literature Search

The articles retrieved for this review were searched using MEDLINE (1966–2012), SPORTDiscus™ (1966–2012), Scopus (1960–2012), and Google Scholar (1980–2012) using the following keywords: 'nutrition', 'diet', 'food', 'supplements' that were combined with 'adventure race', 'ultra-endurance', 'extreme' and 'expedition'.

2.2 Criteria for Inclusion and Exclusion

Of the 37 abstracts retrieved, the following inclusion/exclusion criteria was applied: (i) the article explored nutrition/diet variables in adventure racing; (ii) the article explored physiology variables in adventure racing; and (iii) the article was available in English. Four articles met the inclusion criteria and the reference lists were hand searched by the author to identify any articles that may have been missed. Relevant references cited in the retrieved articles were also considered in this review. The last search was performed on 28 March 2012.

3. Dietary Practices of Adventure Racers

Data on dietary practices of adventure racing athletes are limited, as few studies have examined nutritional status and dietary intakes of adventure racers. Zalcman and colleagues^[3] collected detailed 3-day food records during a typical training phase from 24 adventure race athletes

(18 male and 6 female) who had been practicing the sport for a minimum of 3 years, and had competed in both national and international races. Furthermore, these athletes placed within the first five positions of the Brazilian ranking system, indicating that they were participating at a competitive level. Food records were evaluated using nutrition software.^[3] Mean energy intakes for men and women were 45 kcal/kg/day and 48 kcal/kg/day, respectively. Mean protein, carbohydrate and fat intakes for men were 1.9 g/kg/day, 5.7 g/kg/day and 1.5 g/kg/day, respectively, and for women were 2.0 g/kg/day, 6.9 g/kg/day and 1.5 g/kg/day, respectively.^[3] These data indicate that carbohydrate intakes in men were below recommended values for ultra-endurance athletes^[9,10] and carbohydrate intake for women were on the bottom end of range of recommendations.^[11] These findings are somewhat lower than those of Zimberg et al.^[2] who described the food intake of ten male adventure racers during a competition simulated in the laboratory race simulation that lasted 67 hours where total distance covered was 477.3 km. Average energy intake was 79.6 kcal/kg/day and mean protein carbohydrate and fat intake was 2.3 g/kg/day, 11.7 g/kg/day and 2.6 g/kg/day, respectively. It should be noted that Zimberg et al.^[2] had greater control in collecting energy intakes during the race simulation in the laboratory as the researchers had overseen food consumed by the participants. In contrast, Zalcman et al.^[3] required athletes to keep their own 3-day food log during the usual training phase where energy intake could have been under reported. An additional explanation for the differences in reported energy intakes could be attributed to the fact that energy expenditures during the training phase can vary greatly among athletes and are usually less demanding than a race, even considering that the simulated race was held in a controlled environment. Moreover, replicating dietary intakes that would occur in an actual race are difficult to simulate in the laboratory.

Limited data exists regarding micronutrient intakes of adventure racing athletes. Zalcman et al.^[3] reported that intakes of most vitamins and minerals was adequate in 24 athletes (18 men and

6 women), with the exception of magnesium, zinc and potassium in men and women, and vitamin E and calcium in women, which were below the recommended amounts.^[9,10] The findings of Zalcmán et al.^[3] should be interpreted with caution, as dietary intakes were assessed during training using 3-day food records and nutrition software. Assessing macro- and micronutrient intake using short-term (<5 days) food records and nutrition software may not be accurate due to issues such as under reporting, duration of survey and validity. It should be noted that although food diaries and records are useful to gain an insight into dietary habits and intakes, these techniques are associated with several limitations as they require accurate recall from memory and cooperation from the participant. Furthermore, it is not uncommon for athletes to under report food intake either intentionally or unintentionally.^[12]

4. Energy Expenditures of Adventure Racers

Adventure racing typically requires athletes to be completely self-sufficient for the duration of the race.^[13] Carrying equipment, food and water supplies can further increase energy expenditures in addition to the energy demands required to complete the race. Zimberg et al.^[2] assessed energy expenditures in ten male athletes with international experience in adventure races. The athletes were required to complete a competition simulation of the Ecomotion-Pro 2003 race in the laboratory. Energy expenditure during the laboratory race simulation was estimated using heart rate monitors. More specifically, oxygen consumption was estimated using heart rate data and Weir's equation^[14] was then used to determine energy expenditure. The race simulation lasted 67 hours and total distance covered was 477.3 km. Athletes' mean energy expenditure was 365 kcal/hour although it should be noted that three athletes did not finish the race due to muscle injury and psychological stress. The expenditures found in this study were lower than those reported in other ultra-endurance studies.^[15-17] The lower expenditures in the study of Zimberg et al.^[2] could be due to greater laboratory control, lack of competition and the absence of challenging

terrain that athletes typically have to overcome in actual races. In addition, climate conditions were controlled to temperatures of 22–24°C and relative humidity was set at 58–62%, conditions less extreme than those faced by competitors in actual races. More recently, Enqvist et al.^[8] assessed energy turnover in two separate events of mixed ultra-endurance exercise. In the first event, energy expenditure was measured in the laboratory in nine male international-standard ultra-endurance athletes over a 24-hour period. Athletes performed 12 blocks of kayaking, running and cycling (4 blocks of each discipline) and each block consisted of 110 minutes of exercise. All participants completed this simulation and mean energy expenditure was 750 kcal/hour. Data in the second event was collected 9 months after the laboratory simulation and involved nine male participants competing in an 800 km adventure race. The event involved running, mountain biking, kayaking, in-line skating, climbing, caving and canyoneering. The average racing time for the athletes was 149 hours 33 minutes and mean energy expenditure per hour was 500 kcal/hour. Energy expenditure in the first event was higher than the second event because the simulation required athletes to complete the exercises at a fixed intensity in the laboratory with short rest periods between exercise modes, whereas the second event was self-paced as it was performed under race conditions.^[8] Collectively, these findings indicate that adventure races produce high-energy expenditures due to their long duration and reduced rest periods. More research is needed to accurately measure energy expenditures during actual adventure races using elite athletes including the faster finishers. Although heart rate data can be useful for indirectly estimating energy expenditure during competitions, future research should use more accurate stable isotope techniques, such as doubly labelled water, as it enables total daily energy expenditure to be measured accurately on free-living conditions.^[18]

5. Physiological Characteristics of Adventure Racers

Adventure racing is an ultra-endurance sport that requires competitors to cover a set distance,

typically over challenging terrain using various modes of exercise in the fastest time possible. As the energy demands and modes of exercise are similar to long-distance running and cycling, issues such as power-to-weight ratio, low body mass and low body fat levels are crucial factors for successful performance. Table II summarizes the available physiological and anthropometrical data from the few studies that have been conducted on adventure racing athletes. Data on adventure racers are lacking and future research should investigate the physiological and anthropometrical characteristics of elite-level athletes before any sound conclusions regarding their physiological characteristics can be inferred.

6. Nutritional Issues and Challenges

6.1 Meeting Energy Demands

It is important for adventure racing athletes to consume sufficient energy during periods of prolonged training or multiple-day training to ensure body mass is maintained and adequate energy is available to complete weekly training volumes. Moreover, it has been established that optimum athletic performance is supported by adequate energy intake.^[9] It is recognized that meeting very high energy expenditures (354–750 kcal/hour) over prolonged periods (>6 hours) during adventure races may not be possible; however, the ultra-endurance athlete should ensure energy demands for training are met to maximize training effects. The obvious exceptions to this are when the goal is to reduce body fat levels. High energy demands can be met by using appropriate portion sizes, number of meals consumed, feeding during training and the use of nutrient-dense foods. Furthermore, the use of high-energy supplements such as high-calorie carbohydrate/protein supplements can provide convenient sources for athletes to supplement their diet to ensure energy expenditures are matched during training.^[10]

6.2 Carbohydrate Requirements

Adventure racing athletes need to consume sufficient amounts of carbohydrate during single bouts of prolonged training or multiple daily

Table II. Physical and physiological characteristics of adventure racers^a

Study	No. of participants	Age (y) [mean ± SD]	Stature (cm) [mean ± SD]	Body mass (kg) [mean ± SD]	Body fat (%) [mean ± SD]	VO _{2peak} (L/min) [mean ± SD]
Enqvist et al. ^[8]	15 M	27 ± 3	182.0 ± 4	80.4 ± 7.4	NR	Run: 5.01 ± 0.43 Cycle: 4.96 ± 0.42
Zimberg et al. ^[2]	10 M	31 ± 5.6	175.0 ± 5.7	75.4 ± 6.1	13.5 ± 3.4	Run: 4.13 ± 0.33 Cycling: 4.12 ± 0.36 Arm crank: 2.77 ± 0.58
Levada-Pires et al. ^[19]	11 M	30.8 ± 6.2	173.0 ± 6	69.0 ± 7.2	13.4 ± 3.5	Run: 3.92 ± 0.37
Zalcman et al. ^[3]	18 M	30.9 ± 5.8	176.0 ± 5.6	75.5 ± 5.1	12.5 ± 3.5	Run: 4.42 ± 0.50
	6 F	30.3 ± 7.8	168.0 ± 5.3	63.7 ± 4.0	20.2 ± 5.7	Run: 3.36 ± 3.5
Lucas et al. ^[20]	7 M	40.9 ± 10.2	180.3 ± 7.1	82.8 ± 10.2	NR	Cycling: 4.63 ± 0.37
	5 F	28.0 ± 5.0	168.0 ± 9.3	68.2 ± 6.8	NR	Cycling: 3.38 ± 0.24
	61 M	31.5 ± 6.2	177.3 ± 5.68	76.6 ± 7.2	13.1 ± 3.5	Cycling: 4.57 ± 0.38 Run: 4.37 ± 0.41
	11 F	29.1 ± 6.4	168.0 ± 7.3	69.9 ± 5.4	20.2 ± 5.7	Cycling: 3.38 ± 0.24 Run: 3.36 ± 3.5

^a Data in bold represent the mean values from all studies combined. F = female; M = male; NR = not reported; SD = standard deviation; VO_{2peak} = peak oxygen uptake.

sessions to maximize training effects and promote quicker recovery. Carbohydrates maintain blood glucose levels during training, provide fuel to muscles and the central nervous system and replace muscle glycogen.^[9,21] Current carbohydrate recommendations for ultra-endurance athletes range from 7–12 g/day.^[9–12] In addition, it is recommended that most of the dietary carbohydrate should be derived from complex carbohydrates with a low to moderate glycaemic index such as whole grains, vegetables and fruit; however, during periods of intense training, concentrated carbohydrate juices, drinks and supplements may be used to meet the high carbohydrate needs.^[10] It should be acknowledged that Burke et al.^[11,12] have suggested that these recommendations may be unrealistic for female athletes who may be more concerned with low body mass and body fat percentage, and therefore may restrict carbohydrate intake. However, it has been suggested that nutrition could be periodized to ensure that body composition and competition goals are prioritized accordingly.^[11]

A joint position statement by the American College of Sports Medicine (ACSM) and the American Dietetic Association (ADA)^[9] recommend carbohydrate intakes of 30–60 g/hour during prolonged exercise. Several studies have demonstrated consistent positive performance benefits related to carbohydrate ingestion at these rates in highly trained endurance runners,^[22] cyclists^[23,24] and triathletes.^[15,25] More recently, however, Pfeiffer and colleagues^[26] found that carbohydrate intakes greater than the recommended 30–60 g/hour by the ACSM and ADA^[9] were associated in faster finishing times in ironman races. 221 male and female endurance athletes competing in ironman races, marathons and 100–150 km cycle races completed a standardized post-race questionnaire that quantified nutrient intake and assessed 12 gastrointestinal symptoms. Carbohydrate ingestion rates varied greatly between competitors (6–136 g/hour) and the authors concluded that high carbohydrate intake during exercise was associated with better performances during ironman triathlons; however, scores for nausea and flatulence were also higher.^[26]

6.3 Protein Requirements

Ultra-endurance exercise increases protein requirements due to an increased protein oxidation during endurance exercise.^[27] Studies investigating protein requirements in endurance athletes have suggested that dietary protein intakes of 1.4–1.7 g/kg/day are required to support nitrogen balance and enhance protein accretion.^[28–31] It is important for ultra-endurance athletes to consume adequate protein because protein may be oxidized during periods of high-energy expenditure^[32] and recovery after continuous exercise over consecutive days may be compromised. Consuming adequate protein from food sources during multiday adventure racing may provide some challenges. For instance, carrying complete protein sources from food such as meat, dairy and fish may not be practical because of the difficulties associated with preparation, cooking and transporting these perishable items.

6.4 Lipid Requirements

Lipids have several important functions in the body such as energy storage and utilization, providing essential elements of cell membranes, hormone production and are required for storage of fat-soluble vitamins.^[27] Several studies have investigated the effects of whether a high-fat diet (approximately 65% of energy intake) can be beneficial to endurance athletes.^[33–35] Although there is some evidence that following a high-fat diet over a period of as little as 5 days does enhance fat oxidation during submaximal exercise, there is no evidence that this increased fat oxidation enhances performance.^[36] Moreover, high-fat diets have been associated with gut upset and gastrointestinal distress.^[11] As there is little evidence to support the use of high-fat diets, it is recommended that adventure racing athletes should consume fats between 20–35% of their total energy intake.^[9]

6.5 Nutrient Timing

It is recognized that the timing of ingesting macronutrients may significantly affect the adaptive response to exercise.^[37] Moreover, prolonged

exercise will deplete glycogen stores, therefore, recovery nutrition and nutrient timing are crucial factors for ultra-endurance athletes as they often train for prolonged periods over consecutive days. Several studies have demonstrated that maximal endogenous glycogen stores are best promoted by following a high-glycaemic, high-carbohydrate diet (7–12 g/kg/day).^[38–40] Amounts of carbohydrate demonstrated to improve exercise performance have ranged from approximately 200 g to 300 g of carbohydrate for meals eaten 3–4 hours before exercise.^[9] Therefore, adventure racers should ensure that their pre-exercise meal is high in carbohydrate; however, there is considerable variation between individual tolerance and athletes should ensure that they know what strategy works best for themselves.^[9,10] Carbohydrate loading typically involves increasing carbohydrate intakes to 10–12 g/kg/day several days prior to the competition, with the goal of increasing muscle glycogen stores, and various studies have found positive performance benefits.^[41–43] The reader is referred to Burke^[41] for further details regarding various carbohydrate loading protocols for endurance athletes. Overall, there is strong evidence to suggest that carbohydrate loading can improve performance over long distances (>20 km),^[42,43] therefore, this ergogenic strategy may be useful for adventure racers competing in prolonged exercise over consecutive days.

For prolonged exercise, exogenous carbohydrate sources are crucial to maintain blood glucose and muscle glycogen stores. Convincing evidence suggests that for prolonged endurance events such as adventure racing, consuming 0.7 g/kg of carbohydrates (approximately 30–60 g/hour) can extend endurance performance.^[40,41,44] More recently, studies have investigated whether co-ingestion of protein and carbohydrate in a ratio of 4:1 during endurance exercise can improve performance and recovery. Several studies have found that adding between 6.5–19.4 g of protein to carbohydrate drinks during exercise improved time to exhaustion.^[45,46] However, these findings should be interpreted with caution because the drinks investigated (carbohydrate vs carbohydrate+protein) were not isocaloric, and this highlights a key limitation of these studies. More-

over, a further limitation of the carbohydrate+protein research^[45,46] is that the time-to-exhaustion protocols that were used have been shown to have a poor test-retest reliability, and Currell and Jeukendrup^[47] have suggested that time trials may be a more reliable method. Despite the conflicting evidence, it should be noted that adding protein to carbohydrate drinks during exercise may offer some benefits to adventure racers, as protein ingested during exercise could contribute to the overall energy and protein intake, particularly when exercising for prolonged periods over consecutive days. However, the importance of adequate amounts of carbohydrate ingestion during exercise is emphasized and should not be compromised for the sake of protein ingestion. Some competitors may prefer ingesting solid foods containing protein during exercise and it has been reported that adventure racers prefer food to supplements because of its palatability.^[2] This preference has also been attributed to the fact that consuming large volumes of sweet carbohydrate supplements can cause taste fatigue,^[48] which in turn could result in competitors not ingesting sufficient energy.

There is strong evidence to suggest that the post-exercise meal should be consumed within 30 minutes^[37] and it should contain high amounts of carbohydrate (1–1.2 g/kg/day) to stimulate glycogen resynthesis.^[40,49] In addition, adding 0.2–0.5 g/kg/day of protein to carbohydrate has been shown to stimulate glycogen resynthesis to a greater extent than consuming carbohydrate alone.^[50]

6.6 Fluid and Electrolyte Balance

It is well known that fluid and electrolyte balance are important factors for optimal endurance exercise, particularly in extreme temperatures and environments.^[51] Very few studies have investigated fluid and electrolyte balance of multiday sporting events, and the few studies published have been based on case studies and investigations involving small numbers of participants. Moreover, it should be acknowledged that calculating fluid loss as a result of exercise is not simple, and most studies do not correct for the

metabolism of endogenous substrates and subsequent loss of CO₂ over O₂ gained when investigating fluid balance.^[51] White et al.^[16] collected fluid balance data of a cyclist competing in a 24-hour ultra-endurance event. The male cyclist lost 1.19 kg of body mass despite consuming 5.48 kg of fluids, 3.97 kg of semi-solids and 1.64 kg of solid food. The authors calculated that the rate of fluid intake throughout the event was 417 mL/hour; however, electrolyte losses were not reported. Rehrer et al.^[52] investigated the physiological changes in 91 participants (86 men and 5 women) competing in the Swiss Alpine Marathon (67 km). Mean fluid intake for the duration of the race was (mean $\pm$ standard deviation) 3300 $\pm$ 100 mL in men and 2700 $\pm$ 300 mL in women resulting in fluid ingestion rates of 398 mL/hour for men and 302 mL/hour for women.^[52] Kreider^[53] measured a range of physiological data of six professional cyclists simulating stage races in the laboratory. Cyclists consumed fluids at a rate of 1200 $\pm$ 300 mL/hour and slightly higher losses of 1500 mL/hour were measured. It should be noted that although adventure racing is characterized by similar energy demands of these studies, competitors are also required to race across challenging and often extreme terrain and weather conditions. In addition, competitors typically have to be self-sufficient; therefore, carrying large amounts of fluid may not be feasible. It seems sensible that race organizers could provide access to fluids at the end of stages or during check points during the race, particularly during extreme hot weather conditions.

There is evidence that a drink containing multiple transportable carbohydrates (i.e. glucose and fructose) can enhance gastric emptying rates and therefore improve the delivery of fluid compared with a single carbohydrate drink.^[54]

Moreover, it is recommended that a drink should also contain sodium (10–30 mmol/L) for optimal fluid absorption and prevention of hyponatraemia.^[55] Although hyponatraemia has not been reported in adventure racing, there is some evidence that slower competitors in triathlons and ultramarathon races^[56] are at greater risk, particularly if high sodium losses occur alongside very high intakes of water or other low sodium drinks.^[57]

Further research is needed to establish fluid intake and assess fluid losses in adventure racers. Taking current recommendations into consideration,^[9,10] adventure racers should ensure they consume adequate fluid but should also recognize that fluid losses may not be adequately met. In addition, sodium in drinks (10–30 mmol/L) consumed in conjunction with multiple transportable carbohydrates can aid fluid uptake and prevent hyponatraemia therefore athletes should consider using drinks containing these ingredients for optimal hydration, particularly in extreme hot and humid environments.

6.7 Carrying Food Supplies

Adventure races typically involve participants carrying their own food and water supply for the duration of stages within expedition length races or the entire race for sprint (<6 hours) and intermediate distance races (6–12 hours). Therefore, it is important that the foods chosen provide adequate amounts of energy, macro- and micro-nutrients but do not burden the athlete with excess weight. Carbohydrate sports drinks, gels and bars are convenient supplements to carry for consuming during exercise and meal replacement products, protein and amino acid supplements can be used when food is of short supply. Although sports foods and dietary supplements can be convenient for competitors to carry, it has been reported that international-standard male adventure racing athletes prefer whole foods to supplements due to their palatability.^[2] These findings suggest that athletes have individual preferences that should be taken into consideration alongside cultural differences. Competitors should practice individualized feeding strategies using a combination of whole foods and dietary supplements in training to establish if they are well tolerated in races.

7. Nutritional Supplements and Sports Foods

7.1 Supplement Use by Adventure Racing Athletes

The use of supplements in international-standard adventure races is common^[2,3] and Zalcman

et al.^[3] have reported that the most frequent use of supplements in 24 national and international Brazilian adventure racers during training were sports drinks (37%), carbohydrate in gel and powder forms (33%), protein supplements (29%), vitamin C (20%), multivitamins (20%), isolated amino acids (16%), glutamine (12%), meal replacement (12%), vitamin E (8%) and ferrous sulphate (4%). However, the authors did not specify the difference in supplement use between the male and female competitors. In a separate study that simulated a 3-day adventure race in the laboratory, Zimberg et al.^[2] reported that 14% of the total energy consumed during the race simulation came from supplements. The supplements consumed included isotonic 6–8% carbohydrate drinks, carbohydrate gels, sports bars and protein bars.

7.2 Supplements That May Promote Optimum Performance

There are numerous sports foods and supplements aimed at ultra-endurance athletes and, subsequently, the use of supplements which have the greatest efficacy include sport drinks, gels and bars because of their convenience, and because they are a portable source of carbohydrate that can be consumed during exercise.

The carbohydrate content in these products are typically derived from glucose and dextrose and numerous studies have found that sports drinks, gels and bars can prolong endurance performance.^[58–61] More recently, however, there have been developments regarding the type of carbohydrate and its effects on endurance performance. Currell and Jeukendrup^[62] found that sports drinks containing glucose and fructose in a ratio of 2 : 1 led to an 8% improvement in cycling time-trial performance compared with ingestion of glucose alone. These findings have since been replicated and furthered in several other studies,^[54,63,64] which have demonstrated that sports drinks and gels containing multiple transportable carbohydrates (i.e. glucose and fructose) when ingested at high rates (>60 g/hour), can be beneficial during endurance sports in which the duration of exercise is 3 hours or more.^[61] Taking these findings into consideration, it is recom-

mended that the sports drinks, gels and bars used by adventure racing athletes should contain multiple transportable carbohydrates in the form of glucose and fructose. Supplements that provide 60–90 g/hour of multiple transportable carbohydrates should be consumed during adventure races. There are now several commercially available powders, energy gels and ready-to-drink beverages that contain multiple transportable carbohydrates; therefore, it is recommended that athletes choose these products over single carbohydrate ones. In addition, competitors should practice feeding strategies during training to ensure these carbohydrate doses are well tolerated and minimize the likelihood of gastrointestinal distress. Due to individual preferences, certain competitors may prefer taking carbohydrate supplements in the form of a gel or bar as opposed to a drink.

It has been suggested that athletes can train the carbohydrate absorptive capacity of the gut,^[48] and Cox and colleagues^[65] have reported higher rates of exogenous carbohydrate oxidation after consuming a high-carbohydrate diet; therefore, if adventure racers are going to ingest multiple transportable carbohydrates at a rate of 90 g/hour, they should train the gut to tolerate these amounts.

The prevalence of gastrointestinal complaints has not been investigated in adventure racing. Prevalence rates between 10% and 95% have been reported amongst long-distance runners, triathletes and athletes involved in other types of strenuous prolonged endurance exercise.^[52] More recently, Pfeiffer and colleagues^[26] reported gastrointestinal prevalence rates of up to 4% in cycling and running and 32% in triathletes competing in ironman races. It has been suggested that the likelihood of experiencing gastrointestinal problems increase with the ingestion of fibre, fat, protein and, more commonly, concentrated carbohydrate solutions, in particular in drinks with a very high osmolality.^[48] In addition, athletes that have experienced gastrointestinal distress in the past are more likely to experience future problems.^[48] It is therefore recommended that competitors have individual feeding strategies that are practiced during training. Drinks with a very high osmolality (i.e.

hypertonic drinks) and foods containing large amounts of fat and protein should also be avoided during exercise to minimize or prevent the incidence of gastrointestinal problems.

Caffeine has been studied extensively over the past two decades, and numerous studies have demonstrated the ergogenic effects of caffeine on endurance performance.^[66-69] It should be noted that although no studies have investigated the ergogenic effects of caffeine in adventure racing, the improvements demonstrated in endurance performance from caffeine intake can be applied to adventure racing. For instance, the use of caffeine for performance has several benefits including the mobilization of fatty acids to enhance fuel use, changes to muscle contractility, stimulation of the central nervous system, stimulation of the release and activity of adrenaline^[12] and enhancing glycogen resynthesis.^[70]

As adventure racing is characterized by its very long distances, athletes often choose to go without sleep for a period of greater than 24 hours while competing in races.^[71] In these instances, caffeine can be used by competitors to help them stay awake and enhance performance. When taken in low to moderate doses (3–6 mg/kg) caffeine is effective for enhancing endurance performance^[68,69] and it has been demonstrated that caffeine can enhance vigilance during bouts of extended exhaustive exercise, as well as periods of sustained sleep deprivation.^[72-75]

There is emerging evidence that large amounts of caffeine taken with carbohydrate can enhance glycogen resynthesis post-exercise.^[70,76] Pederson and colleagues^[70] found that co-ingestion of carbohydrate and caffeine (4 g/kg and 8 mg/kg, respectively) resulted in greater glycogen resynthesis compared to 4 g/kg of carbohydrate only. Muscle biopsy data showed that although no differences were observed in glycogen resynthesis after 1-hour post-exercise (133 ± 37.8 vs 149 ± 48 mmol/kg dry weight; $p > 0.05$, for carbohydrate and caffeine, respectively), after 4 hours of recovery the caffeine condition resulted in a 66% higher glycogen accumulation (313 ± 69 vs 234 ± 50 mmol/kg dry weight; $p < 0.001$). Similarly, Taylor et al.^[76] found that co-ingestion of carbohydrate and caffeine (1.2 g/kg and 8 mg/kg,

respectively) resulted in an increased time to exhaustion on the Loughborough Intermittent Shuttle Test compared with the carbohydrate only and water condition. Although Taylor et al.^[76] did not take any muscle biopsy data to measure glycogen resynthesis, the authors concluded that adding 8 mg/kg of caffeine to a post-exercise carbohydrate drink improved subsequent high-intensity interval-running capacity, a finding that may be related to higher rates of post-exercise muscle glycogen resynthesis.

Whilst the findings of Pedersen et al.^[70] and Taylor et al.^[76] may be useful for recovery, as they suggest that adding large doses of caffeine to carbohydrate post-exercise can enhance glycogen resynthesis, this strategy may not always be practical, particularly when ingesting a recovery meal a few hours before competitors are due to sleep. Nonetheless, this strategy could be employed in races where competitors are required to complete two or more stages in a day over consecutive days.

It should be noted that the scientific literature does not support the theory of caffeine-induced diuresis during exercise or detrimental effects on fluid balance that would negatively affect performance;^[77] therefore, caffeine use should be considered by adventure racing athletes.

Ultra-endurance exercise increases protein requirements due to an increase in protein oxidation during endurance exercise.^[27] As adventure racing athletes typically exercise in continuous activity for several hours over consecutive days and most races require participants to be self-sufficient, protein and amino acid supplements in the form of powders and bars can be useful to help meet these increased protein requirements. As carrying complete protein sources from food such as meat, dairy and fish may not be practical because of the difficulties associated with preparation, cooking and transporting these perishable items, protein supplements can provide a convenient and lighter option to carry compared with protein-based foods.

8. Conclusion

Adventure racing is an ultra-endurance sport and racing times can vary from 6 hours to

Table III. Summary of nutrition guidelines

- Energy demands of competing in adventure races can vary from 365–750 kcal/h and total energy expenditures of 18 000–80 000 kcal have been reported to complete adventure races therefore it is important that competitors consider how they will meet these high-energy demands. Nutrient-dense foods and dietary supplements can help athletes meet high-energy requirements
- Carbohydrate intakes of 7–12 g/kg are required during periods of prolonged training/racing to meet requirements and replenish glycogen stores
- Protein intakes of 1.4–1.7 g/kg are recommended for adequate recovery
- Fluid and electrolyte requirements vary greatly depending on individual sweat rates and the environment. Adding sodium in drinks (10–30 mmol/L) consumed in conjunction with multiple transportable carbohydrates can aid fluid uptake, particularly in extreme hot and humid environments
- Carbohydrate drinks, gels and bars can help provide energy during training and recent developments suggest that carbohydrate supplements should contain multiple transportable carbohydrates
- Caffeine can be used as an ergogenic aid to both improve endurance performance and help competitors stay awake during prolonged periods of exercise when sleep deprived. Large caffeine doses of 8 mg/kg consumed with carbohydrate can enhance glycogen resynthesis
- As adventure racers typically have to carry their food supplies during the race, nutrient-dense foods and the use of dietary supplements providing carbohydrates, proteins/amino acids and caffeine should be considered whilst keeping excess weight to a minimum

10-consecutive days for expedition-length races. Competitors often race in extreme conditions therefore energy demands could be as high as 750 kcal/hour. An inadequate diet and poor fueling strategies could impair performance, particularly when competing over consecutive days, and could increase the risk of injury and illness during a race. It is well known that fluid and electrolyte balance are important factors for optimal ultra-endurance performance, particularly in extreme temperatures and environments;^[51] therefore, competitors should ensure appropriate fluid is ingested and electrolyte supplements are considered. Drinks should contain multiple transportable carbohydrates to enhance fluid delivery and adequate sodium to replace salt losses in sweat. As competitors are often required to carry their own supplies, portable foods high in carbohydrates, moderate in protein and fat and dietary supplements and sports foods such as carbohydrate bars, gels and drinks can offer a considerable advantage. Similarly, protein and amino acid supplements can help ensure adequate recovery between and after stages. Strategic caffeine use can be useful to enhance performance, keep competitors awake during longer races and enhance glycogen resynthesis after exercise. A summary of the key nutrition guidelines for adventure racers is presented in table III. Further research on the physiological and anthropometrical characteristics and energy expenditures of high-performance adventure racers is warranted.

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