

Review Article

Nutritional Requirements of Athletes Exercising in a Hot Environment

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ABSTRACT

Competition in a hot environment is not conducive for optimal sports performance as both dehydration and hyperthermia adversely affect mental and physical performance. In addition, the ability to train in heat is also impaired if the nutritional needs are inadequate. During prolonged bouts of exercise in a hot environment, an excess of 1 liter of body fluid per hour can be lost. Fluid intake strategies should be undertaken and should be of paramount concern to the athlete if the athlete has to perform more than one training or competition sessions in a single day. Fluid strategies, including hydration well prior to the exercise bout, drinking as much as is comfortable and practical during the exercise session, and rehydrating aggressively afterwards in preparation for the subsequent exercise bouts, are needed to ensure an adequate water intake to prevent chronic dehydration during competition in hot conditions as the body does not adapt to dehydration. Rapid recovery of fluid losses after an exercise bout is assisted by the replacement of some of the electrolytes losses. Carbohydrate is the main fuel used by the muscle during hard training and competition and its requirement for exercise in hot conditions is further increased due to the shift in substrate utilisation towards carbohydrate oxidation. Daily food intake should focus on replacing glycogen stores after exercise. Competition diet strategies such as enhancing carbohydrate availability (carbohydrate loading) prior to endurance competition, pre-event carbohydrate intake, intake of sports drinks in events lasting longer than 45 minutes should be undertaken in hot conditions and practised during training. Carbohydrate ingestion may not enhance performance for all events undertaken in hot environment, however, there is no disadvantage of consuming sports beverages containing the appropriate carbohydrates and electrolytes during competition and training. There is also no good evidence to suggest that specific supplementation is necessary or will improve performance in sports activities undertaken in a hot environment. In conclusion, the primary aim of athletes training in a hot environment must be to ingest a source of energy, usually carbohydrate and fluid for replacement of water lost as sweat.

INTRODUCTION

Major sporting events in Malaysia and other tropical countries are commonly staged in hot environments where the average daytime temperature is generally between 29-31°C with the average relative humidity ranging from 70-90%. Although these conditions are not conducive for optimal sports performance, particularly for events involving prolonged aerobic activity or activity involving intermittent high-intensity exercise, nutritional strategies can play an important role in assisting the athlete to perform to the best of their ability. This paper will highlight the major issues in nutrition for sports performance in the heat and the strategies needed for long periods of training in the heat, as well as acute strategies for optimising competitive performance.

EFFECTS OF TEMPERATURE AND DEHYDRATION DURING EXERCISE IN THE HEAT

The most notable effect of exercise in a hot environment is the increased loss of body fluids. In the hot environment, the main method of dissipating body heat produced by the exercising muscles or absorbed from the environment is through the evaporation of sweat. In such hot conditions, sweat losses during prolonged submaximal exercise may be as high as 2-3 l/h. A loss of body water corresponding to as little as 2% of body weight can result in some impairment of exercise tolerance (Maughan & Shirreffs, 1998; Walsh *et al.*, 1994) and losses in excess of 5% of body weight can decrease the capacity for work by about 30%. The reduction of plasma volume may be of particular significance and could have a significant impact on performance.

During exercise, the heat generated from energy metabolism can easily increase 10-fold in active healthy persons,

and up to 20-fold in well-trained athletes, which will increase the core temperature and bring about premature onset of fatigue or reduced performance. The physical work capacity for aerobic exercise of progressive intensity is decreased when a person is dehydrated (Sawka, Montain & Latzka, 1996). Physical work capacity has been shown to decrease even with marginal (1-2% body weight loss) water deficits and the reduction is larger with increasing water deficits. Dehydration results in much larger decrements of physical work capacity in hot than in temperate climates (Webster, Rutt & Weltman, 1990). In a temperate environment, loss of less than 3% body weight appears not to alter the maximal aerobic power. Maximal aerobic power decreased when dehydration equalled or exceeded 3% body weight. In a hot environment, it is known that small (2% body weight) to moderate (4% body weight) water deficits result in large reduction of maximal aerobic power. It is believed that the thermoregulatory system, via increased body temperature plays an important role in the reduced exercise performance mediated by a body water deficit.

Exercise in the hot environment is also associated with a shift in substrate utilisation towards a greater reliance on body carbohydrate stores. This is associated with increased respiratory ratio, muscle glycogenolysis and lactate accumulation (Febbraio, 1999).

FLUID STRATEGIES FOR EXERCISE IN THE HEAT

The maintenance of fluid balance is the key issue for performance of the athletes. In a hot environment, significant dehydration is inevitable during exercise activities and poses a challenge to both the health and performance of the athlete. The hypohydration state occurs when sweat rates are extremely high and when there is

little opportunity to drink during the event or when both these factors are combined. Therefore, to sustain high work output in the heat, replacement of fluid losses are required to prevent dehydration. Strategies to minimise the degree of hypohydration during activity in the heat should be undertaken pre-, during and in the post-exercise period.

Hyperhydration

Hyperhydration or "fluid overloading" has been practised by some athletes in the hours prior to a competition, in the hope of reducing the total fluid deficit that was incurred during the competition. This has been shown to increase total body water, expand plasma volume and enhance performance in the subsequent exercise bout. However, there are some potential disadvantages with the simple hyperhydration technique. Immediately after hyperhydration, much of the fluid is excreted via urination and this may even have a detrimental effect on performance when the urge to urinate occurs immediately prior to the event or in the early stages of the event. Gastric discomfort associated with ingesting large amounts of fluid has also been shown to impair performance of moderate-high intensity (Robinson *et al.*, 1995). In some susceptible individuals, excessive fluid intake may lead to hyponatremia or "water intoxication" (Noakes, 1992).

Hydration during exercise

Numerous studies have shown that water intake during prolonged exercise is effective in improving performance and in delaying the onset of fatigue (Below *et al.*, 1995; Montain & Coyle, 1992; Sawka, 1992) that occurs during exercise in the heat. However, ad libitum fluid intake during exercise does not fully prevent a fluid deficit. Studies have shown that voluntary intake of fluids across a range of sports

show that athletes typically replace only 30-70% of the sweat losses incurred during exercise (Broad *et al.*, 1996).

Fluid intake during exercise is governed by a number of factors, such as thirst, availability of drinks, opportunity to drink, gastrointestinal comfort and palatability of the drink. Although athletes will naturally increase their fluid intake during exercise in the heat, it is likely that the net fluid deficit will be increased compared to exercise in a cooler environment.

One of the nutritional strategies for athletes undertaking training or competition in a hot environment is to increase fluid intake during the training sessions and competition. Although it may be uncomfortable or impractical to consume fluid equal to the rate of sweat losses, it is possible for most athletes to be able to increase their fluid intake. Since the effect of hypohydration increases in relation to the fluid deficit (Montain & Coyle, 1992), any increase in fluid intake will attenuate the problems associated with exercise in the heat. Although the initial guidelines by the American College of Sports Medicine (1996) of drinking 100-200 ml of fluid every 2-3 km during a prolonged race is ambiguous and unable to address individual requirements or for different sports, the more recent guidelines have taken a more practical approach. They recommend that athletes recognise individual rates of sweat loss and use the opportunities within their sport to maximise or at least improve their hydration practices (American College of Sports Medicine, 1996; O'Connor, 1996; Burke & Hawley, 1997). Other strategies include the provision of cool and palatable beverages, use of creative tactics to make fluids accessible and easy to consume, and use of pre- and post-exercise weighing to monitor fluid deficits (O'Connor, 1996). Athletes are reminded to practise these strategies during training sessions as well as competitive events. This will reduce chronic hypohydration problems as well as allow the

athlete to fine-tune a suitable fluid intake plan for competition.

Post-exercise rehydration

Replacement of water and electrolyte losses in the post-exercise period may be of great importance for maintenance of exercise capacity when repeated bouts of exercise have to be performed. The need for replacement will obviously depend on the extent of losses incurred during exercise, on non exercise losses and also on the time and nature of subsequent exercise bouts. Athletes living in a hot environment will experience substantially increased fluid losses even when not exercising.

After exercise, athletes may fail to drink sufficient amounts of fluid to restore fluid balance, even when drinks are made freely available. Many studies (Gonzalez-Alonso, Heaps & Coyle, 1992; Wong *et al.*, 1998; Greenleaf, 1992) have reported that incomplete rehydration or "involuntary dehydration" is often observed. One reason for this phenomenon is that normal dipsogenic response is not strong enough to fully replace fluid that is lost during the preceding exercise (Greenleaf, 1992; Gisolfi & Duchman, 1992). In addition, obligatory urine losses persist even in the dehydrated state, because of the need for elimination of metabolic waste products. Therefore the volume of fluid consumed after exercise-induced or thermal sweating must be greater than the volume of sweat lost if effective rehydration is to be achieved.

The other primary factors influencing post-exercise rehydration process are composition and volume of the fluid consumed. Plain water is not the ideal post-exercise rehydration beverage when rapid and complete restoration of fluid balance is necessary. Ingestion of plain water in the immediate post-exercise period results in a rapid fall in plasma sodium concentration and in plasma osmolality and a subsequent diuresis. These changes have the

effect of reducing the stimulus to drink (thirst) and of stimulating urine output, both of which will delay the rehydration process. However, when an electrolyte-containing solution is ingested, urine output is less and net water balance is closer to the pre-exercise level (Gonzalez-Alonso, Heaps & Coyle, 1992). Several studies have shown that the replacement of electrolytes, particularly sodium, in conjunction with fluid intake is important in maximising fluid retention and restoring fluid balance (Maughan & Leiper, 1995; Shirreffs *et al.*, 1996). It is therefore proposed that drinks used for post-exercise rehydration should have a sodium concentration similar to that of sweat or greater.

The requirement for sodium replacement stems from its role as the major ion in the extracellular fluid. It has been speculated that inclusion of potassium, the major cation in the intracellular space, would enhance the replacement of intracellular water after exercise and thus promote rehydration (Nadel, Mack & Nose, 1990). Maughan *et al.*, (1994) found that a smaller volume of urine was excreted after rehydration when sodium- or potassium-containing beverages were ingested compared with the electrolyte-free beverage. It appears that inclusion of potassium was as effective as sodium in retaining water ingested after exercise-induced dehydration. Using a natural fruit drink high in potassium and low in sodium, Singh and co-workers (2001) and Saat *et al.* (2002) found that blood and plasma volume restoration was similar with intake of coconut water and carbohydrate-electrolyte beverage during the 2 h rehydration period after exercise-induced dehydration indicating the role of potassium in enhancing rehydration by aiding intracellular rehydration. It is clear that an effective rehydration fluid must contain sufficient sodium and some potassium to maintain the thirst stimulus and to promote the retention of the ingested fluid.

CARBOHYDRATE REQUIREMENTS

The availability of carbohydrate as a substrate for muscle contraction is a critical factor in the performance of prolonged submaximal or intermittent high-intensity exercise (Hargreaves, 1999). The total carbohydrate stores in the body are limited and are often less than the fuel requirements of training and competition sessions undertaken by many athletes. This causes a greater concern when training and exercise are undertaken in a hot environment because the rates of muscle glycogen utilisation are increased in a hot environment (Febbraio, 1999).

Guidelines for sports nutrition suggest a variety of options for increasing carbohydrate availability for exercise, including consuming carbohydrate before, during and in the post-training period. When these carbohydrate strategies enhance or maintain carbohydrate status, they may delay the onset of fatigue and enhance exercise capacity. Although there is little research to document how well the performance benefits translate to exercise undertaken in the heat, where the dual issue of increased carbohydrate utilisation and increased thermoregulatory concerns co-exist, it is recommended that strategies to enhance carbohydrate status be practised. Athletes should choose eating patterns that provide daily carbohydrate intakes of 7-10 g/kg body weight to ensure restoration of muscle glycogen stores between training bouts. These refuelling strategies improve performance and contribute to the total daily carbohydrate intake. Athletes are encouraged to practise such strategies during training and fine-tune their competition intake plan.

Pre-competition carbohydrate strategies

Athletes should ensure that their liver and muscle glycogen stores are full and are able to support the anticipated fuel requirements of the event, prior to com-

peting in any event. For events less than 60 minutes in duration, muscle glycogen levels should be normalised to the resting levels of trained athletes and this should be adequate for the event. This can be achieved by consuming 7-10 g carbohydrate/kg body weight per day, in conjunction with reduced training volume and intensity.

Athletes who compete in events greater than 90 minutes may improve their performance by undertaking an exercise-diet programme known as carbohydrate loading during the three days prior to competition. This is achieved by tapering training with a daily carbohydrate intake of ~8-10 g carbohydrate/kg body weight over the 72 hours prior to competition. This can increase muscle glycogen levels by 25-100% (Hawley *et al.*, 1997). This pre-competition carbohydrate strategy can increase the time to fatigue by ~20%, decrease the time taken to complete a set task of prolonged duration by 2-3% or improve the performance of the movement patterns in a soccer-stimulated trial and indoor soccer game (Hawley *et al.*, 1997; Bangsbo, Norregaard & Thorsoe, 1992; Balsom *et al.*, 1999). However such carbohydrate strategies do not benefit short-duration high-intensity exercise or events lasting up to 1 hour (Hawley *et al.*, 1997). Although the effect of the exercise environment has not been systematically studied in relation to carbohydrate loading, it is likely that this strategy will be of greater benefit in hot conditions where rates of glycogen utilisation are increased.

Pre-exercise meal of >200 g carbohydrate has been shown to improve endurance (Wright, Sherman & Dernbach, 1991) and enhance the performance of a time trial undertaken at the end of a prolonged exercise session. Such meals should be eaten 1-4 hours before prolonged exercise and may enhance carbohydrate availability by increasing liver and muscle glycogen stores, or by providing a source of glucose in the gut for later

release. This pre-exercise meal strategy may be important where there has been inadequate time for recovery from previous training or competitive session.

Guidelines for pre-exercise meals need to take into account gastrointestinal comfort as well as the potential for enhancing body carbohydrate stores. Athletes must ensure that pre-exercise meals do not cause excessive stomach fullness, discomfort or upsets during exercise. The general rule of thumb regarding prevent meals is that a carbohydrate-rich meal or snack should be consumed 2-4 hours prior to the event.

Carbohydrate intake during exercise

There is strong evidence that the intake of carbohydrate during prolonged, moderate-intensity exercise or during intermittent high-intensity exercise can improve work capacity and performance (Hargreaves, 1999; Hargreaves *et al.*, 1996). The major effects of carbohydrate intake during prolonged exercise are to maintain plasma glucose concentration, sustain high rates of carbohydrate oxidation and spare liver glycogen (Bosch, Dennis & Noakes, 1993). Increasing the availability of carbohydrate also causes glycogen sparing in slow-twitch muscle fibres during running (Tsintzas *et al.*, 1996).

Through tracer-determined rates of oxidation of ingested carbohydrates, studies have shown that there are no physiologically important differences between moderate and high-glycaemic index carbohydrate sources ingested during prolonged moderate-intensity exercise (Hawley, Dennis & Noakes, 1992). However, fructose and galactose are slowly oxidised. It is recommended that 30-60 g per hour be taken during prolonged exercise (American College of Sports Medicine, 1996), although higher intakes may be needed to support oxidation rates of 1 g/min and that this carbohydrate intake should start well in advance of

fatigue and depletion of body carbohydrate stores (McConell, Klood & Hargreaves, 1996). Sports drinks which provide 4-8% carbohydrate, electrolytes and palatable flavours play an important role during exercise as these allow carbohydrate to be delivered in addition to meeting the need for fluid replacement in a hot environment (American College of Sports Medicine, 1996).

Post-exercise carbohydrate intake

Resynthesis of depleted glycogen stores is a key issue in post-exercise recovery and is a challenge for athletes who train or compete more than once a day. The amount and type of carbohydrate consumed are the dietary factors, which will influence glycogen synthesis during post-exercise period (Burke, Collier & Hargreaves, 1993). There is evidence that moderate and high-glycaemic index carbohydrate-rich foods and drinks are more favourable for glycogen storage than some low-glycaemic index foods (Burke, Collier & Hargreaves, 1993) and effective refuelling does not start until ~1 g/kg body weight of carbohydrate are consumed. Glycogen resynthesis occurs at a slightly faster rate during the first two hours after training (Ivy *et al.*, 1998) when the appropriate amount of carbohydrate is consumed. This strategy is important when there is less than 8 hours between exercise sessions (Parkin *et al.*, 1997) but when recovery time is longer, the athlete can choose the most practical or comfortable meal schedule in achieving total carbohydrate intake goals. Interestingly, hypohydration does not interfere with restoration of muscle glycogen stores (Neufer *et al.*, 1991).

As appetite can be suppressed by hot weather or by the effect of fatigue due to increased training stress, athletes may need practical guidance to organise their diet based on palatable and easily eaten foods. Fluid-rich or liquid-rich forms of

carbohydrate, such as sports drinks, liquid meal supplements, fruits, flavoured yoghurts, can be useful in enhancing the appetite of athletes as well as the ability in providing fluid and carbohydrate simultaneously.

OTHER NUTRITIONAL ISSUES

There is evidence that exercise in hot environment increases protein catabolism and cellular damage due to generation of free radicals (Davis *et al.*, 1982; Jenkins, 1988). This has led to many athletes increasing their protein intake and supplementing with anti-oxidant vitamins. An earlier study has indicated that co-ingestion of protein with carbohydrate feedings may enhance glycogen synthesis (Zawadzki, Yaspelkis & Ivy, 1992), however, this finding has been refuted in recent well-controlled studies (Roy & Tarnopolsky, 1998; Van Hall, Shirreffs & Calbert, 2000). Nevertheless, there may be other reasons for including carbohydrate-rich foods that are also good sources of proteins during the post-exercise meals or snacks so as to provide protein for other recovery processes, or to add to the total daily intake of protein when protein needs are increased. More research is needed to see if the increased protein oxidation and production of oxygen radicals during exercise in heat translates into additional requirements for protein, anti-oxidant vitamins and minerals or other micronutrients.

CONCLUSION

Carbohydrate requirements for exercise are increased in the heat, due to the increase of carbohydrate utilisation. Training diets should focus on replacing glycogen stores after exercise including strategies to enhance carbohydrate availability during exercise. Dehydration as

little as 2% of body weight significantly degrades exercise performance in the heat. In order to minimise the adverse consequences of dehydration on exercise performance, it is recommended that athletes training in a hot environment ingest a source of carbohydrate and fluids for replacement of water as sweat. Athletes are encouraged to drink more than their urge and equivalent to their weight loss. Although carbohydrate ingestion may not enhance the performance of all events in a hot environment, however, there is great advantage in consuming beverages containing 4-8% carbohydrate and electrolytes. After exercise, complete restoration of fluid balance and glycogen stores is an important part of the recovery process.

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