

Fluid Replacement

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Many factors will affect the sportsman's need for fluid replacement during training and competition. The composition of the fluid, as well as the volume and frequency of drinks, which will confer the greatest benefit during exercise will depend very much on individual circumstances. As with most physiological variables, there is a large inter-individual variability in the rates of fluid loss during exercise under standardised conditions and also in the rates of gastric emptying and intestinal absorption of any ingested beverage. Marathon runners competing under the same conditions and finishing in the same time may lose as little as 1% or as much as 5% of bodyweight, even though their fluid intake during the race is the same (Maughan 1985). Under more controlled conditions, Greenhaff and Clough (1989) found that sweat rate during 1 hour of exercise at a workload of 70% VO_2 max and an ambient temperature of 23°C ranged from 426 to 1665 g/h: the sweat rate in this situation is largely determined by the metabolic rate, and is related to fitness and bodyweight. It would seem logical that the need for fluid (water) replacement is greater in the individual who sweats profusely, and any guidelines as to the rate of fluid ingestion and the composition of fluids to be taken, must be viewed with caution when applied to the individual athlete. Sweat rate during activities such as running can be predicted from estimates of the energy cost of running, as used by Barr and Costill (1989), but these do not explain the variation which is observed between individuals. A more reliable method might be for the individual to measure bodyweight before and after training or simulated competition and to estimate sweat loss from the change in bodyweight.

Many individuals and organisations have issued recommendations as to the most appropriate fluid replacement regimens (e.g., American College of Sports Medicine 1975, 1984; Olsson & Saltin 1971). Olsson and Saltin (1971) recommended 100 to 300 ml of a 5 to 10% sugar solution every 10 to 15 minutes during exercise; they also suggested that the temperature of ingested fluids should be 25°C. At the extreme ends of this range, this would give an intake each hour of 400 to 1800 ml of liquid and 20 to 180 g of sugar. In 1975 the American College of Sports Medicine published a Position Statement on the prevention of heat injuries during distance running, in which an intake of 400 to 500 ml of fluid 10 to 15 minutes before exercise was recommended. Although no figures were given, it was also suggested that runners ingest fluids frequently during competition and that the sugar and electrolyte content of drinks should be low (2.5% glucose and 10 mmol/L sodium, respectively) so as not to delay gastric emptying. A revised version of these guidelines (American College of Sports Medicine 1984) continued to recommend hyperhydration prior to exercise by the ingestion of 400 to 600 ml of cold water 15 to 20 minutes before the event. The recommendations as to intake during a race were more specific than previously: cool water was stated to be the optimum fluid, and an intake of 100 to 200 ml every 2 to 3 km was suggested, giving a total intake of 1400 to 4200 ml at the extremes. Again, taking these extreme values, it is unlikely that the elite runners could tolerate a rate of intake of about 2 L/h, and equally unlikely that an intake of 300 ml/h would be adequate for the slowest competitors except when the ambient temperature was low.

Exercise Intensity and Duration

The rate of metabolic heat production during exercise is dependent on the exercise intensity and the body mass; in activities such as running or cycling this is a direct function of speed. The rate of rise of body temperature in the early stages of exercise and the steady state level which is eventually reached are both proportional to the metabolic rate. The rate of sweat production is therefore also closely related to the absolute workload. In many sports, including most ball games, short bursts of high intensity activity are separated by variable periods of rest or low intensity exercise.

The time for which high intensity exercise can be sustained is necessarily rather short: the factors limiting exercise performance where the duration is in the range of about 10 to 60 minutes are not clear, but it does seem that substrate availability is not normally a limiting factor and that performance will not be improved by the ingestion of carbohydrate-containing beverages during exercise. Also, even though the sweat rate may be high, the total amount of water lost by sweating is likely to be rather small. Accordingly there is generally no need for fluid replacement during very high intensity exercise, although it is difficult to define a precise cut-off point. In a recent study, however, the effects of an intravenous infusion of saline during cycle ergometer exercise to exhaustion at an exercise intensity equivalent to 84% of VO_2 max were investigated (Deschamps et al., 1989). In the control trial a negligible amount of saline was infused, whereas an infusion rate of about 70 ml/min was used in the other trial. The saline infusion was effective in reducing the decrease in plasma volume which occurred in the initial stages of exercise, although it did not completely abolish this response, and the core temperature and heart rate at the point of exhaustion were both lower in the infusion trial. There was no effect on endurance time which was the same in both trials. The endurance times were, however, short (20.8 and 22.0 minutes for the infusion and control trials, respectively), although the range was large (from about 9 to 43 minutes), and these results support the idea that fluid provision will not benefit exercise performance when the exercise duration is short.

There are also likely to be real problems associated with any attempt to replace fluids orally during very intense exercise. The rate of gastric emptying, which is probably the most important factor in determining the fate of ingested fluid, is impaired when the exercise intensity is high, as described above. Even at rest, the maximum rates of gastric emptying which have been reported are only about half the saline infusion rate (70 ml/min) used in the study of Deschamps et al., (1989) and are commonly much less than this. To achieve a high rate of fluid delivery from the stomach, it is necessary to ingest large volumes, and any attempt to do so when the exercise intensity exceeds about 80% of VO_2 max would almost certainly result in nausea and vomiting.

At lower intensities of exercise, the duration of exercise is inversely related to the intensity. In an activity such as running, this holds true for populations as much as for individuals. As the distance of a race increases, so the pace that an individual can sustain decreases (Davies & Thompson 1979); equally, in an event such as a marathon race where all runners complete the same distance, the slower runners are generally exercising at a lower relative (as a percentage of VO_2 max) and absolute work intensity (Maughan & Leiper 1983). Because the faster runners are exercising at a higher workload, in absolute as well as in relative terms, their sweat

rate is higher, although this effect is offset to some extent by the fact that they generally have a lower bodyweight: because the faster runners are active for a shorter period of time, however, the total sweat loss during a marathon race is unrelated to finishing time (Maughan 1985). The need for fluid replacement is therefore much the same, irrespective of running speed, in terms of the total volume required but there is a need for a higher rate of replacement in the faster runners. Among the fastest marathon runners, sweat rates of about 30 to 35 ml/min can be sustained for a period of about 2 hours 15 minutes by some runners. The highest sustained rates of gastric emptying reported in the literature are greater than this, at about 40 ml/min (Costill & Saltin 1974; Duchman et al., 1990). These gastric emptying measurements were made on resting subjects, and it is possible that there may be some inhibition of gastric emptying at the exercise intensity (about 75% of VO_2 max) at which these elite athletes are running (Costill & Saltin 1974). In the slower runners, the exercise intensity does not exceed 60% of VO_2 max, and gastrointestinal function is unlikely to be impaired relative to rest (Mitchell et al., 1989; Rehrer et al., 1989b). In these runners, sweat rates will also be relatively low (Maughan 1985).

Although in theory, therefore, it should be possible to meet the fluid loss by oral intake, gastric emptying rates of fluids are commonly much lower than the maximum figures quoted above, and it is inevitable that most individuals exercising hard, particularly in the heat, will incur a fluid deficit. It is surprising, and remains unexplained, that the majority of recreational long distance runners appear to incur a relatively small fluid deficit in spite of their low rates of fluid intake (Maughan 1985; Noakes et al., 1988).

Composition of Drinks

In spite of the definitive statement by the American College of Sports Medicine in their 1984 Position Statement on the prevention of thermal injuries in distance running that cool water is the optimum fluid for ingestion during endurance exercise, some of the evidence presented above indicates that there may be good reasons for taking drinks containing added substrate and electrolytes. In prolonged exercise, performance is improved by the addition of an energy source in the form of carbohydrate; the type of carbohydrate does not appear to be critical, and glucose, sucrose and oligosaccharides have all been shown to be effective in improving endurance capacity. Recent studies have suggested that long chain glucose polymer solutions are more readily used by the muscles during exercise than are glucose or fructose solutions (Noakes 1990), but others have found no difference in the oxidation rates of ingested glucose or glucose polymer (Massicote et al., 1989; Rehrer 1990). Massicote et al., (1989) also found that ingested fructose was less readily oxidised than glucose or glucose polymers. Fructose in high concentrations is best avoided on account of the risk of gastrointestinal upset. The argument advanced in favour of the ingestion of fructose during exercise, namely that it provides a readily available energy source but does not stimulate insulin release and consequent inhibition of fatty acid mobilisation, is in any case not well founded: insulin secretion is suppressed during exercise.

The optimum concentration of sugar to be added to drinks will depend on individual circumstances. High carbohydrate concentrations will delay gastric emptying, thus reducing the amount of fluid that is available for absorption: very high concentrations will result in secretion of water into the intestine and thus actually increase the danger of dehydration. High sugar concentrations (>10%)

may also result in gastrointestinal disturbances. Where there is a need to supply an energy source during exercise, however, increasing the carbohydrate content of drinks will increase the delivery of carbohydrate to the site of absorption in the small intestine: although the volume emptied from the stomach is reduced as the carbohydrate concentration increases, the amount of carbohydrate emptied is increased, and so is the rate of carbohydrate oxidation by the muscles.

There is no good evidence to support the addition of electrolytes other than sodium to drinks to be consumed during exercise. Sodium will stimulate carbohydrate and water uptake in the small intestine and will help to maintain extracellular fluid volume. Most soft drinks of the cola or lemonade variety contain virtually no sodium (1 to 2 mmol/L; sports drinks commonly contain 10 to 25 mmol/L; oral rehydration solutions intended for use in the treatment of potentially fatal diarrhoea-induced dehydration have higher sodium concentrations, in the range 30 to 90 mmol/L). A high sodium content tends to make drinks unpalatable, and it is important that drinks intended for ingestion during or after exercise should have a pleasant taste in order to stimulate consumption. Specialist sports drinks are generally formulated to strike a balance between the twin aims of efficacy and palatability, although it must be admitted that not all achieve either of these aims.

When the exercise duration is likely to exceed 3 to 4 hours, there may be advantages in adding sodium to drinks to avoid the danger of hyponatraemia, which has been reported to occur when excessively large volumes of low sodium drinks are taken (Noakes et al., 1985). Sodium is also necessary for post event rehydration, which may be particularly important when the exercise has to be repeated within a few hours: if drinks containing little or no sodium are taken, urine production will be stimulated and most of the ingested fluid will not be retained. When a longer time interval between exercise sessions is possible, replacement of sodium and other electrolytes will normally be achieved from the diet.

It is often stated that there is an advantage to taking chilled (4°C) drinks as this accelerates gastric emptying and thus improves the availability of ingested fluids. The most recent evidence, however, suggests that the gastric emptying rate of hot and cold beverages is not different. In spite of this, there may be advantages in taking cold drinks, as the palatability of most carbohydrate-electrolyte drinks is improved at low temperatures.

Environmental Conditions

The ambient temperature and wind speed will have a major influence on the physical exchange of heat between the body and the environment. When ambient temperature exceeds skin temperature, heat is gained from the environment by physical transfer, leaving evaporative loss as the only mechanism available to prevent or limit a rise in body temperature. The increased sweating rate in the heat will result in an increased requirement for fluid replacement. Other precautions such as limiting the extent of the warm-up prior to competition and reducing the amount of clothing worn will help to reduce the sweat loss and hence reduce the need for replacement. For endurance events at high ambient temperatures, there may also be a need to reduce the exercise intensity if the event is to be successfully completed.

When the humidity is high, and especially in the absence of wind, evaporative heat loss will also be severely limited. In this situation, exercise tolerance is likely to be limited by dehydration and hyperthermia rather than by the limited availability of metabolic fuel. Suzuki (1980) reported that exercise time at a workload of 66% VO_2 max was reduced from 91 minutes when the ambient temperature was 0°C to 19 minutes when the same exercise was performed in the heat (40°C). In an unpublished study in which 6 subjects exercised to exhaustion at 70% VO_2 max on a cycle ergometer, we found that exercise time was reduced from 73 minutes at an ambient temperature of 2°C to 35 minutes at a temperature of 33°C: exercise time in the cold was increased by ingestion of a dilute glucose-electrolyte solution, but in the heat, the exercise duration was too short for fluid intake to have any effect on performance. Although fatigue at these work intensities is generally considered to result from depletion of the muscle glycogen stores, this is clearly not the case when the ambient temperature is high, as this would require the rate of muscle glycogen utilisation to be increased two-fold in the heat and this did not occur.

Supply of water should take precedence over the provision of substrate during exercise in the heat. There may therefore be some advantage in reducing the sugar content of drinks, to perhaps 2 to 5%, and in increasing the sodium content, to something in the range 30 to 50 mmol/L. Conversely, when exercise is undertaken in the cold, fluid loss is less of a problem, and the energy content of drinks might usefully be increased. Carbohydrate concentrations of up to about 15% are generally well tolerated if given as glucose polymers and some individuals can tolerate concentrations in excess of 20%. If given as free glucose, such solutions usually result in diarrhoea.

State of Training and Acclimation

It is well recognised that both training and acclimation will confer some protection against the development of heat illness during exercise in the heat. Although this adaptation is most marked in response to training carried out in the heat (Senay 1979), endurance training at moderate environmental conditions will also confer some benefit. Among the benefits of training is an expansion of the plasma volume (Hallberg & Magnusson 1984). Although this condition is recognised as a chronic state in the endurance-trained individual, an acute expansion of plasma volume occurs in response to a single bout of strenuous exercise: this effect is apparent within a few hours of completion of exercise and may persist for several days (Davidson et al., 1987; Robertson et al., 1988). Circulating electrolyte and total protein concentrations are normal in the endurance-trained individual in spite of the enlarged vascular and extracellular spaces, indicating an increased total circulating content (Convertino et al., 1980).

The increased resting plasma volume in the trained state allows the endurance trained individual to maintain a higher total blood volume during exercise (Convertino et al., 1983), allowing for better maintenance of cardiac output. In addition, the increased total extracellular water provides for an increased sweating rate which limits the rise in body temperature (Mitchell et al., 1976). These adaptive responses appear to occur within a few days of exposure to exercise in the heat. In a series of papers reporting the same study, Mitchell et al., (1976), Wyndham et al., (1976) and Senay et al., (1976) followed the time course of changes in men exposed to exercise (40 to 50% VO_2 max for 4 hours) in the heat (45°C) for 10 days. Although there were marked differences between individuals in their responses, resting plasma volume increased progressively over the first 6

days, reaching a value about 23% greater than the control, with little change thereafter. The main adaptation in terms of an increased sweating rate and an improved thermoregulatory response occurred slightly later than the cardiovascular adaptations, with little change in the first 4 days.

Although there is clear evidence that acclimation by exercise in the heat over a period of several days will improve the thermoregulatory response during exercise, this does not affect the need to replace fluids during the exercise period. Better maintenance of body temperature is achieved at the expense of an increased water (sweat) loss. Although this allows for a greater evaporative heat loss, the proportion of the sweat which is unevaporated and which therefore drips wastefully from the skin is also increased (Mitchell et al., 1976). The athlete who trains in a moderate climate for a competition to be held in the heat will, however, be at a disadvantage on account of his inability to sustain a high sweat rate.