Fatigue in prolonged exercise is normally the result of depletion of the body's carbohydrate stores or of the related problems of dehydration and hyperthermia. The recovery process after such exercise therefore requires replacement of the liver and muscle glycogen stores and restoration of sweat losses. Much attention has been paid to glycogen resynthesis, and the need for dietary carbohydrate intake as soon as possible after exercise (in amounts of about 50-100g and in the form of carbohydrates with a high glycaemic index) has been clearly established.

Restoration of water and electrolyte balance is also an essential part of the recovery process after exercise that results in sweat loss, and is a major concern for all athletes training and competing in hot and humid environments. However, in spite of the extensive investigations into fluid replacement during prolonged exercise, little attention has been paid to the optimum conditions for recovery after exercise. This paper reviews recent work relating to the formulation of fluid replacement drinks following sweat loss induced by exercising in the heat.

Early studies in this area established that ingestion of plain water after exercise-induced dehydration resulted in a rapid fall in the plasma sodium concentration and in plasma osmolality: this has the twin effects of reducing the drive to drink and of stimulating output of a dilute urine (Nose et al, 1988). Both these factors will prevent effective rehydration. We have recently investigated the effects of drink composition and of the volume consumed on the effectiveness of the restoration of fluid homeostasis after exercise in the heat. We have also examined the effects of consuming solid food with a drink and of the addition of alcohol to ingested fluids on rehydration effectiveness. Restoration of fluid balance at different stages of the menstrual cycle has also been examined in healthy young women with regular cycles. In all of these studies, a prescribed volume of fluid has been ingested after a fixed loss of body mass induced by intermittent exercise in the heat. In a further study, we have allowed ad libitum intake of fluids of varying composition and palatability. The effectiveness of rehydration in these studies has been assessed primarily by measurement of net fluid balance during the recovery period after exercise, and of changes in blood volume and electrolyte concentration.

Addition of sodium and potassium to rehydration fluids decreased urine output in the 6 h after rehydration, but when a volume of fluid equal to the sweat loss was ingested, there was no additive effect when both electrolytes were added (Maughan et al, 1994). Because of ongoing urine output, subjects were in net negative fluid balance throughout the recovery period. When the sodium concentration of the ingested fluid was varied (0, 25, 50 or 100 mmol/1) and fluid was ingested in a volume equal to 1.5 times the sweat loss, urine output was inversely proportional to the sodium concentration of the ingested fluid (Maughan and Leiper, 1995). Ingestion of large volumes of fluid (up to twice the volume of sweat lost) was not effective in maintaining positive fluid balance for more than a few hours when the sodium concentration of the drinks was low (20 mmol/1), but positive fluid balance was maintained with a drink containing 60 mmol/1 sodium when the volume ingested was greater than the volume of sweat lost (Shirreffs et al, 1996). In this study, the higher sodium concentration was effective in maintaining
a larger plasma volume.

Ingestion of solid food together with plain water was more effective in maintaining fluid balance than ingesting the same total amount of water in the form of a sports drink: The electrolyte (sodium plus potassium) content of the meal consumed was greater than that of the sports drink, emphasising the importance of restoration of electrolyte losses for the retention of the ingested water (Maughan et al, 1996a). Addition of alcohol to ingested fluids had little effect in concentrations of 1 or 2%, but there was a tendency for a diuretic effect that became significant at an alcohol concentration of 4% (Shirreffs and Maughan, 1997). There was no variation in responses at different stages of the menstrual cycle (Maughan et al, 1996b). When ad libitum intake of different drinks was allowed, the volume ingested in the time allowed was strongly influenced by the perceived palatability: urine output was determined by the volume consumed and by the electrolyte content of the drinks.

For effective rehydration, drinks should replace electrolytes lost in sweat as well as the volume loss: this means that they should contain moderately high (perhaps 50-60 mmol/l) levels of sodium, and possibly also some potassium. To surmount ongoing obligatory urine losses, the volume consumed should be greater (by at least 50%) than the volume of sweat lost. Palatability of drinks is important in stimulating intake. Where there is an opportunity for eating in the recovery period, the electrolytes required may be ingested as solid food consumed with a drink, but it is recognised that there are situations where consumption of solid food is not possible and all intake will be in liquid form. There are no special concerns for females related to changes in hormone levels associated with the menstrual cycle. The effects on performance of an uncorrected fluid deficit should persuade all athletes to attempt to remain fully hydrated at all times, and the aim should be to commence each bout of exercise in a fluid replete state. This will only be achieved if a volume of fluid in excess of the sweat loss is ingested together with sufficient electrolytes. Further studies to investigate the effects of different rehydration procedures on subsequent exercise performance remain to be carried out.

REFERENCES