REHYDRATION AFTER EXERCISE WITH FRESH YOUNG COCONUT WATER, CARBOHYDRATE-ELECTROLYTE BEVERAGE AND WATER

By

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ABSTRACT

REHYDRATION AFTER EXERCISE WITH FRESH YOUNG COCONUT WATER, CARBOHYDRATE-ELECTROLYTE BEVERAGE AND WATER

This is cross-over randomized study that assessed the effectiveness of fresh young coconut water (CW), carbohydrate-electrolyte beverage (CEB) and plain water (PW) for whole body rehydration and blood volume (BV) restoration during a 2 h rehydration period following exercise-induced dehydration. Eight healthy male volunteers between the ages of 20 to 30 years (22.4±3 years), with an average VO_{2max} of 45.79±1.52 mL. kg.$^{-1}$.min.$^{-1}$ exercised at 60% of VO_{2max} at an environmental temperature of 31.1±0.03°C and relative humidity (rh) of 51.4±0.1% for 90 minutes until 2.78±0.06% (1.56±0.05 kg) of their body weight (BW) was lost. After exercise, the subjects sat for 2 h in a thermoneutral environment (22.5±0.1°C; 67.0±1.0% rh) and drank a volume of either CW, CEB or PW representing 120% of the fluid lost. Fluids were consumed in three boluses, representing 50% (781±47 mL), 40% (625±33 mL) and 30% (469±28 mL) of the fluid lost, at 0, 30 and 60 min respectively of the 2 h rehydration period. Subjects remained fasted throughout the rehydration period. The drinks given were randomized and the exercise-induced dehydration were done at one-week intervals. The percent of body weight loss that was regained (used as index of percent rehydration) during CW, PW, and CEB trials was 75±5%, 73±5%, and 80±4 % respectively, but was not statistically different between trials. At the end of all the trials the subjects were somewhat hypohydrated (range 0.08-0.20 kg BW below euhydrated BW; $p > 0.05$) after the 2 h rehydration period since additional water and BW were lost as a result of urine formation, respiration, sweat and metabolism. The rehydration index, which provided an indication of how much of what was ingested actually was used for body weight restoration, was again not different statistically between trials (1.56±0.14, 1.36±0.13 and 1.71±0.21 for CW, CEB and PW respectively). Although BV restoration was better with CW, it was not statistically different from CEB and PW. Cumulative urine output was similar in all trials: CW (394±75 mL), PW (351±47 mL) and CEB (325±69 mL). There were no differences at any time between the three trials in hemoglobin concentration, serum Na^+ and Cl^-, serum osmolality, urine output and net fluid balance. Urine osmolality decreased after 1 h during the rehydration period and it was lowest in PW trial. Plasma glucose concentrations were significantly higher when CW and CEB were ingested when compared with PW ingestion during the rehydration period. In conclusion, ingestion of fresh young coconut water, a natural refreshing beverage, could be used for whole body rehydration after exercise.

ABSTRAK

REHIDRASI MENGGUNAKAN MINUMAN KELAPA MUDA SEGAR, KARBOHIDRAT BERELEKTROLIT DAN AIR SETELAH MELAKUKAN SENAMAN KETAHAP DEHIDRASI

Kajian ini dilakukan secara bersilang dan rawak bertujuan untuk membandingkan keberkesanan rehidrasi keseluruhan badan dan pengembalian semula isipadu darah (BV) dengan menggunakan minuman air kelapa muda segar (CW), karbohidrat berelektrolit (CEB) dan air kosong (PW) dalam jangkamasa 2 jam rehidrasi setelah melakukan senaman sehingga ketahap dehidrasi. Seramai lapan orang subjek lelaki berumur antara 20–30 (min=22.4±3) tahun, dengan purata pengambilan oksigen maksimal (VO_{2max}) iaitu 45.79±1.52mL.kg.$^{-1}$.min.$^{-1}$ melakukan senaman pada tahap kelajuan 60% VO_{2max} selama 90 minit pada suhu 31.1±0.03°C dan berkelembapan relatif (rh) 51.4±0.1%, sehingga ketahap dehidrasi 2.78±0.06% ataupun (1.56±0.05 kg) kehilangan berat badan. Selepas senaman subjek diarah duduk berehat di dalam bilik bersuhu 22.5± 0.1^{0}C dan 67.0±1.0% (rh) sambil minum sama ada CW, CEB atau PW dengan jumlah 120% daripada kehilangan berat badan. Minuman diberi dalam tiga bolus 50% (781±47 mL), 40% (625±33 mL) dan 30% (469±28 mL) pada masa 0 min, 30 min, dan 60 minit dalam jangkamasa 2 jam rehidrasi. Subjek tidak dibenarkan mengambil apa-apa jenis makanan sepanjang kajian. Minuman diberi secara rawak manakala setiap ujian dilakukan selangmasa sekurangnya satu minggu. Peratus pengembalian semula berat badan (peratus rehidrasi) bagi CW, PW dan CEB adalah 75±5%, 73±5% dan 80±4% mengikut urutan, tetapi tiada menunjukkan signifikan pada ketiga-tiga ujian. Pada akhir kajian keputusan menunjukkan subjek mengalami kesan kekurangan berat badan hipohidrit (julat 0.08–0.20 kg dibawah paras euhidrasi; p>0.05) selepas 2 jam rehidrasi bagi

ketiga-tiga jenis minuman. Walaupun air didiberi semasa rehidrasi, berat badan tidak kembali ke paras asal disebabkan oleh kesan daripada pembentukan urin, respirasi, peluh dan metabolik. Indeks rehidrasi digunakan sebagai petunjuk sebanyak mana minuman yang telah diambil dapat mengembalikan berat badan keparas asal, keputusan menunjukkan tiada perbezaan secara statistik bagi setiap ujian CW (1.56±0.14), CEB (1.36±0.13) dan PW (1.71±0.21). Walaupun pengembalian semula isipadu darah lebih baik bagi CW, tetapi perbezaan tidak signifikan bila dibandingkan dengan CEB dan PW. Pengumpulan keluaran urin adalah sama bagi semua ujian, CW (394+75 mL), PW (351+47 mL) dan CEB (325+69 mL). Bagi kepekatan serum hemoglobin, osmolaliti, Na^+ dan Cl^- serta keluaran urin dan imbangan cecair bersih menunjukkan tiada perbezaan yang signifikan disepanjang masa rehidrasi dalam ketiga-tiga ujian. Kepekatan Osmolaliti urin menurun paling rendah bagi PW selepas 1 jam jangkamasa rehidrasi. Kepekatan plasma glukosa meningkat secara signifikan bagi CW dan CEB berbanding dengan PW sepanjang jangkamasa rehidrasi. Dengan ini dapatlah disimpulkan bahawa pengambilan air kelapa muda segar lagi asli boleh digunakan sebagai minuman rehidrasi seluruh badan selepas senaman.

CHAPTER 1

INTRODUCTION

Body water and electrolyte balance are essential to optimize physiological function and health. During exercise, or at high environmental temperatures, a significant level of dehydration can develop, and the ratio of extracellular to intracellular fluid can change despite an ample supply of water (Greenleaf & Harrison, 1986). Physical and cognitive performances are impaired at 1-2% dehydration (Armstrong & Epstein, 1999), and the body can collapse when water loss approaches 7% (Greenleaf & Harrison, 1986).

Prolonged exercise, particularly when carried out in conditions of high ambient temperature and humidity, is associated with significant sweat losses, and daily water requirements for athletes living and training in heat may reach 10-15 $L.d^{-1}$ (Maughan & Leiper, 1995). Even a low level of dehydration (e.g., equivalent to a 2% loss of body weight) impairs cardiovascular and thermoregulatory responses and reduces the capacity for exercise (Murray, 1998). Prolonged exercise that results in a loss of fluid corresponding to 2.5% of body mass results in a 15% fall in the capacity to perform high intensity exercise lasting about 7 minutes (Maughan & Leiper, 1995). Exercise in the heat requires the body to cope simultaneously with competing demands for cardiovascular homeostasis, thermoregulatory control, and maintenance of muscle energetics. When dehydration is superimposed upon this scenario (as is often the case during most forms of exercise), the results can be catastrophic for both health and performance. Fluid replacement during exercise reduces the risk of heat illness and improves exercise performance by preventing or reducing dehydration and by providing a convenient means of ingesting carbohydrate. For these reasons, optimal performance is possible only when dehydration is minimized by ingesting ample volumes of fluid during exercise. Recent research has demonstrated that consuming fluid in direct proportion to sweat loss (or close to it) maintains important physiological functions and significantly improves exercise performance (Murray, 1998). Preventing dehydration enables the cardiovascular system to maintain blood pressure and cardiac output, thereby sustaining the increase in skin blood flow and sweating that are essential for optimal temperature regulation (Murray, 1998). Remaining well hydrated during exercise also preserves muscle function (Murray, 1998), reducing the reliance on muscle glycogen as a fuel source. Carbohydrate ingestion also improves exercise performance, an effect that is independent of and additive to preventing dehydration (Murray, 1998). The practical application of this knowledge requires that athletes follow a more-aggressive fluid-replacement regimen than is now usually the case. Success during competition in warm weather is more likely for those athletes who are highly fit and well acclimatized to training and competing in the heat, and who diligently avoid even low levels of dehydration. The competitive advantage will definitely shift in favor of those athletes who recognize the fundamental value of fitness, acclimatization and hydration, coupled with other strategies for keeping themselves cooled and fueled.

The restoration of body fluid balance following dehydration induced by exercise will occur through regulatory responses which stimulate ingestion of water and sodium. Heavy sweating during exercise can cause body fluid losses in excess of 1 liter per hour (Costill, 1977). The restoration of body fluid losses is necessary for optimal cardiovascular function and thermoregulation during subsequent exercise (Costill & Sparks, 1973; Morimoto *et al.,* 1981; Sproles *et al.,* 1976). The replacement of water and electrolytes during rehydration can be limited by gastric emptying and intestinal absorption as well as the body's ability to retain the ingested fluids i.e., to prevent diuresis (Gisolfi *et al.,* 1990; Mitchell & Voll, 1991).

One of the factors for achieving optimal post exercise rehydration is that drink volume consumed should be greater than the volume of fluid loss (Shirreffs *et al.,* 1996). Drink palatability is important as individuals will not drink sufficient quantities of a drink they do not like (Hubbard *et al.,* 1990). Plain water is not the most effective post-exercise rehydration drink. The addition of electrolytes, in particular sodium, will help maintain thirst to stimulate drinking (Maughan & Leiper, 1995; Nose *et al.,* 1988; Takamata *et al.,* 1994). Consumption of solid food is likely to provide the necessary electrolytes, and therefore in this instance plain water can be consumed and rehydration achieved (Maughan *et al.,* 1996).

Rehydration after exercise requires not only replacement of volume losses, but also replacement of electrolytes, primarily sodium, lost in the sweat. Drinks containing approximately 50 mmol.L^{-1} sodium are likely to be most effective for most people provided the required volume is consumed (Shirreffs, 2000). In contrast, the sodium content of most Sports drinks is in the range of 10–25 mmol. L^{-1}; in some cases it is even lower (Shirreffs, 2000). Most commonly consumed soft drinks contain virtually no sodium and therefore, these drinks are unsuitable when the need for rehydration is crucial. The problem with a high sodium concentration in drinks is that some people find the taste undesirable, resulting in reduced consumption (Shirreffs, 2000). Where sweat losses are high, rehydration with carbohydrate solutions has implications for energy balance and will improve palatability (Shirreffs, 2000).

Most studies have been carried out using either carbohydrate-electrolyte solution or water as rehydration fluid. To our knowledge there has been no study done on using natural "fruit drinks" such as coconut water which contains sodium, potassium, chloride and glucose (See Table 4.2), as a rehydration fluid. Coconut water however, has been used as an oral rehydration in patients with diarrhoea to replace fluid loss from gastrointestinal tract (Chavalittamrong *et al.,* 1982) and in an extreme situation ever as a short-term intravenous hydration fluid in a patient on Soloman Island (Campbell-Faick *et al.,* 2000).

1.1 Objectives of the study

The objective of this study is to compare the effectiveness of water from fresh young coconuts, a carbohydrate-electrolyte beverage and plain water as a rehydration fluids after exercise-induced dehydration.

1.2 Research hypotheses

H_O1 = There is no difference between fresh young coconut water and carbohydrate-electrolyte beverage in the rehydration after exercise-induced dehydration but better than water.

H_A1 = There is a difference between fresh young coconut water and carbohydrate-electrolyte beverage in the rehydration after exercise-induced dehydration but better than water.

H_O2 = There is no difference between fresh young coconut water, carbohydrate-electrolyte beverage and plain water in fluid balance during dehydration.

H_A2 = There is a difference between fresh young coconut water, carbohydrate-electrolyte beverage and plain water in fluid balance during dehydration.

1.3 Operational definitions

Fresh young coconut water:	Fluid containing minerals such as sodium, potassium, chloride and glucose. A natural drink which is obtained from Malayan Tall coconut variety and is a very popular drink for quenching thirst in Malaysia.
Carbohydrate-electrolyte beverage:	Beverage which is available commercially and meets the requirement as a sport drink. This study was done using isotonic drink, ISOMAX (Ace Canning Corp. Sdn. Bhd.).
Exercise induced dehydration:	Running on the treadmill at a speed of 60% VO_{2max} until dehydration to about 2.5–3.0% body weight loss.
Drink volume:	120% of the fluid given to replace the fluid loss during exercise in heat in three boluses. Drink volume of 50% of the fluid volume is given at the beginning of the 2 h period and after 30 min a volume of equivalent to 40% of the fluid lost was ingested and remaining 30% of the rehydration drink necessary to replace 120% of the fluid lost was ingested at 60 min.

1.4 Significance of the study.

The purpose of this study is to evaluate and compare the effectiveness as a rehydration fluid of water from fresh young coconuts, with a carbohydrate-electrolyte beverages and plain water, after exercise-induced dehydration. If there is a significant evidence that this drink can help the process of a rehydration and to replace body electrolyte loss, it will have a potential use as a rehydration fluid after exercise-induced dehydration.

CHAPTER 2

LITERATURE REVIEW

Introduction

Water is the key to life. It is the body's transport medium. For nutrients, gases, and waste products, and all biochemical reactions take place in an aqueous environment.

During exercise there is a net loss of fluids and electrolytes that is tolerated until the bout of exercise is completed. The loss of fluid occurs via sweating necessitated by the increase in body heat associated with the performance of exercise. Even with access to fluids, moderate exercise at about 70% of maximum heart rate or VO_{2max} will result in decrease in body weight of approximately 930 $g.h^{-1}$ (Castenfors, 1967; Takamata *et al.,* 1994; Wade *et al.,* 1985).

Most electrolytes present in sweat have a net loss in total body content. The net loss in the body levels is not reflected in the plasma, which shows an increase in concentrations of electrolytes as the loss of water exceeds that of solutes during exercise. Following exercise the plasma levels of sodium may increase from 140 to 145 $meq.L^{-1}$, while osmolality increases from 290 to over 300 $mOsm.kg^{-1}$ (Wade *et al.,* 1980).

2.1 Body fluid compartments and importance of water

Water is the primary constituent, by weight and volume, of the human body. An 80-kg man contains about 53 L of water comprising 66% of the body weight (Fig. 2.1). It is arbitrarily divided into cellular (30 L) and extra cellular (23 L) water. Water in striated muscle (80% H_20) the skeleton (32% H_20), and adipose tissue (50% H_20)

account for 60% of the body weight. Women contain less water than men of similar weight because women have a higher ratio of adipose tissue to lean body mass (Greenleaf, 1992).

The major cation of the extra cellular fluid (ECF) is Na^+ (140 $mmol.L^{-1}$) and its attendant anions are Cl^- (110 $mmol.L^{-1}$) and HCO_3^- (27 $mmol.L^{-1}$). Thus, the osmolality of the ECF can be approximated by doubling plasma Na^+ concentration. Although water is in osmotic equilibrium between body fluid compartments, water molecules move freely among the compartments in response to change in hydrostatic and osmotic pressure. Both exercise and heat exposure influence circulation and body fluid osmolality, which shift water between body fluid compartments and modify thirst and drinking (Greenleaf, 1990).

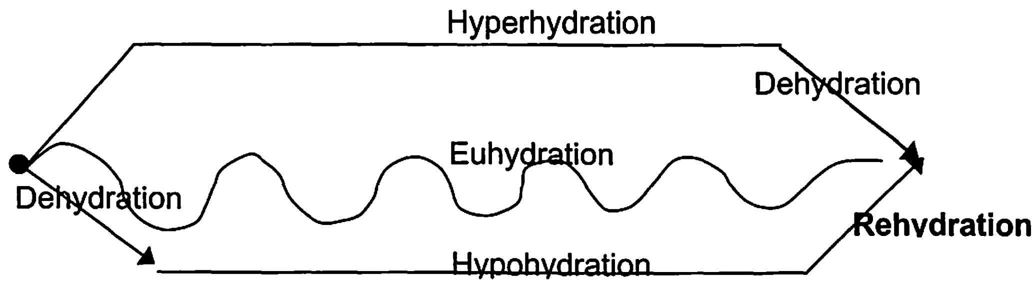
Water has many important functions in our body. All body fluids; including blood, urine, lymph, sweat and digestive juice are mostly water, moreover all chemical reactions in the body take place in water. Water dissolves nutrients during digestion, O_2 and CO_2 are also carried in this solution. As a transporter, water in the blood carries nutrients from the food we eat to the tissues. Waste products are transported by water to the lungs, kidney and skin to be discarded as CO_2, urine or sweat respectively. Blood plasma carries hormones to their specific target sites. Water also transports materials within cells. In temperature regulation, a lot of heat is lost through sweating. Sweating is part of a negative feedback mechanism that helps maintain thermal homeostasis (Carola *et al.,* 1990).

2.2 Body fluid states

Euhydration is represented by a sinusoidal wave indicating the normal, daily water content (Fig. 2.1). Hyperhydration and hypohydration define new steady-state conditions of increased and decreased respectively, of body water content.

Dehydration refers to the process of losing water that can occur from the hyperhydrated state to euhydration, and continuing downward to hypohydration. Rehydration is the process of gaining water from a hypohydrated state towards euhydration. Rehydration should not be used for the increase in body water from euhydration to hyperhydration.

In normal, healthy people euhydration body water is regulated daily to within ±0.22% (±165 mL) of body weight in normal temperate conditions (Adoplph, 1947), and to within ±0.48% (±382 mL) in heat and exercise conditions (Fig. 2.1) due in part to involuntary dehydration. Daily plasma volume variability is ±0.60% (±27 mL) of the blood volume (Fig. 2.1). There are many adverse effects of dehydration on humans including the beginning of impaired exercise thermoregulation at about 1% of body weight (water) loss, and leading to likely collapse at about 7% loss of body water (Fig. 2.2).



Plasma water	=	4 liters	(5% body wt.)
Interstitial water	=	19 liters	(24% body wt.)
Extracellular water	=	23 liters	(29% body wt.)
Cellular water	=	30 liters	(37% body wt.)
Total water	**=**	**53 liters**	**(66% body wt.)**

Daily euhydration variability of total body water
Temperate conditions = ±0.165 liters (±0.22% body wt.)
Heat and exercise conditions = ±0.382 liters (±0.48% body wt.)

Daily plasma volume variability = ±0.027 liters
(±0.6% blood volume)

Fig. 2.1 Body hydration terminology diagram and fluid compartment volumes and variability (Greenleaf, 1992).

Percent of Body Weight Loss	
0	
1	Thirst threshold, and threshold for impaired exercise thermoregulation leading to decrement in physical work capacity
2	Stronger thirst, vague discomfort and sense of oppression, loss of appetite
3	Dry mouth, increasing hemoconcentration, reduction in urinary output
4	Decrement of 20-30% in physical work capacity
5	Difficulty in concentrating, headache, impatience, sleepiness
6	Severe impairment in exercise temperature regulation, increased respiratory rate leading to tingling and numbness of extremities
7	Likely collapse if combined with heat and exercise

Fig. 2.2 Adverse effects of dehydration

Adapted from

Greenleaf, J.E and Harrison, M.H. Water and electrolytes. In: Nutrition and Aerobic Exercise, edited by Layman, D.K. Washington, D.C: American Chemical Society, 1986. p.107-24

2.3 Change in body fluid compartment volumes during exercise and heat stress

Physical exercise routinely increases total body metabolism by 5–15 times resting levels to support skeletal muscle contraction. Approximately 70 to 90% of this energy is released as heat and needs to be dissipated to achieve body heat balance. Depending on the climatic conditions, the relative contributions of evaporative and dry (radiative and conductive) heat exchange to the total heat loss will vary. The hotter the climate, the greater the dependence on evaporative heat loss, and thus on sweating. Therefore, a substantial volume of body water may be lost via sweating to enable evaporative cooling in hot climate (Sawka *et al.,* 1990).

Prolonged exercise, particularly when carried out in conditions of high ambient temperature and humidity is associated with significant sweat losses, and daily water requirements of athletes living and training in the heat may reach 10–15 $L.d^{-1}$ (Maughan *et al.,* 1994).

A person's sweating rate is dependent on climatic conditions, clothing worn, and exercise intensity. Soldiers in the desert often have sweating rates of 0.3 to 1.2 $L.h^{-1}$ while performing military activities (Adolph, 1947; Molnar *et al.*, 1946). Persons wearing protective clothing often have sweating rates of 1 to 2 $L.h^{-1}$ while performing light-intensity exercise (Levine *et al.,* 1990; Speckman *et al.,* 1988). During these situations, a principal problem is to match fluid consumption with sweat loss. Because thirst provides a poor index of body needs, people will dehydrate by 2 to 8% of their body weight during situations of prolonged high sweat loss (Greenleaf & Castel 1971).

Plasma volume decreases proportionately with exercise intensity (Convertino *et al.*, 1981; Wilkerson *et al.*, 1977). Because sweat is hypotonic when compared to plasma, sweating causes hyperosmolality of body fluid, which results in fluid shift between fluid compartments.

Fig. 2.3 shows the reduction of body fluid and distribution within body fluid compartments in 8 men after 2 h of exercise in heat and after 3 h of recovery with or without fluid replacements (Morimoto *et al.,* 1981; Morimoto & Nose, 1987). The subjects lost ~27 $mL.kg^{-1}$ body weight, and 23-26% of this loss (~7.0 $mL.kg^{-1}$) came from plasma with each treatment. There was further reduction of body weight during 3 h of recovery due to residual sweating and urine output. Reduction of plasma volume (hypovolemia) with dehydration recovered to 8% (2.7 $mL.kg^{-1}$) after 3 h of recovery even though no water was consumed, while loss of intracellular fluid volume increased from 20% to 44% (6.1 to 14.8 $mL.kg^{-1}$), indicating mobilization of intracellular fluid volume into the interstitial fluid and plasma compartments.

Rehydration with tap water or saline solution modifies the recovery of each fluid compartment in the body, showing higher recovery of plasma volume according to the degree of rehydration. Recovery of intracellular fluid varies considerably between the groups, while the difference in interstitial fluid was less. Hyperosmolality of the extracellular fluid from heat-induced sweating is the major cause of the intracellular fluid shift (Nose *et al.,* 1988). Reduction of intracellular fluid (cellular dehydration) stimulates osmoreceptors, and reduction of plasma volume (extracellular dehydration) stimulates volume receptors; both influence thirst and drinking behavior.

Free exchange of water among body fluid compartments ensures that the water content of sweat is derived from all compartments. The distribution is influenced by sweat rate, sweat composition and total water and electrolyte loss. In a study, Costill and co-worker (Costill *et al.,* 1976) dehydrated subjects to varying degrees by cycle exercise and heat exposure. At low levels of body water loss (3%), the water loss was derived largely from the extracellular space; as the extent of the water loss increased, a greater percentage of the loss came from the intracellular space. The longer time taken to achieve the higher levels of sweat loss resulted in some redistribution of body water. Sodium was the primary cation lost in sweat, with typical concentrations of about 40–60 mmol.L^{-1}, compared with about 4-8 mmol.L^{-1} for potassium (Maughan & Shirreffs, 1998). Given the higher sodium loss and the distribution of these cations between the body water compartments, the primary water loss is likely to be from the extracellular space.

2.4 Effects of body water deficit

Body water deficit as little as 1% of body mass can impair exercise performance (Walsh *et al.,* 1994) and a 35% fall in the capacity to perform high intensity exercise lasting about 7 minutes has been reported after a fluid loss of only 2.5% of body mass induced by sauna exposure (Maughan & Shirreffs, 1998). In another study, Armstrong *et al.*, (1985) had subjects take part in track races over 1500, 5000 and 10000 m after diuretic-induced dehydration of about 2% of body mass. The time to complete these races was increased by 0.16, 1.31, and 2.62 min (3.4, 7.2, and 6.7%) respectively, relative to their finishing time when euhydrated.

The plasma volume decrease that accompanies dehydration may be of particular importance in influencing work capacity. Blood flow to the muscles must be maintained at the higher level during exercise to supply oxygen and substrates, but a high blood flow to the skin is also necessary for convection of heat to the body surface where it can be dissipated. Hypohydration is associated with higher cardiovascular strain and impaired thermoregulation and with loss of the protection conferred by acclimatization. Loss of intracellular volume may be particularly important during recovery, however, in the light of the emerging evidence of role for cell volume in the regulation of metabolism. A reduced intracellular volume can reduce rates of glycogen and protein synthesis and a high cell volume can stimulate these processes (Shirreffs & Maughan, 2000).

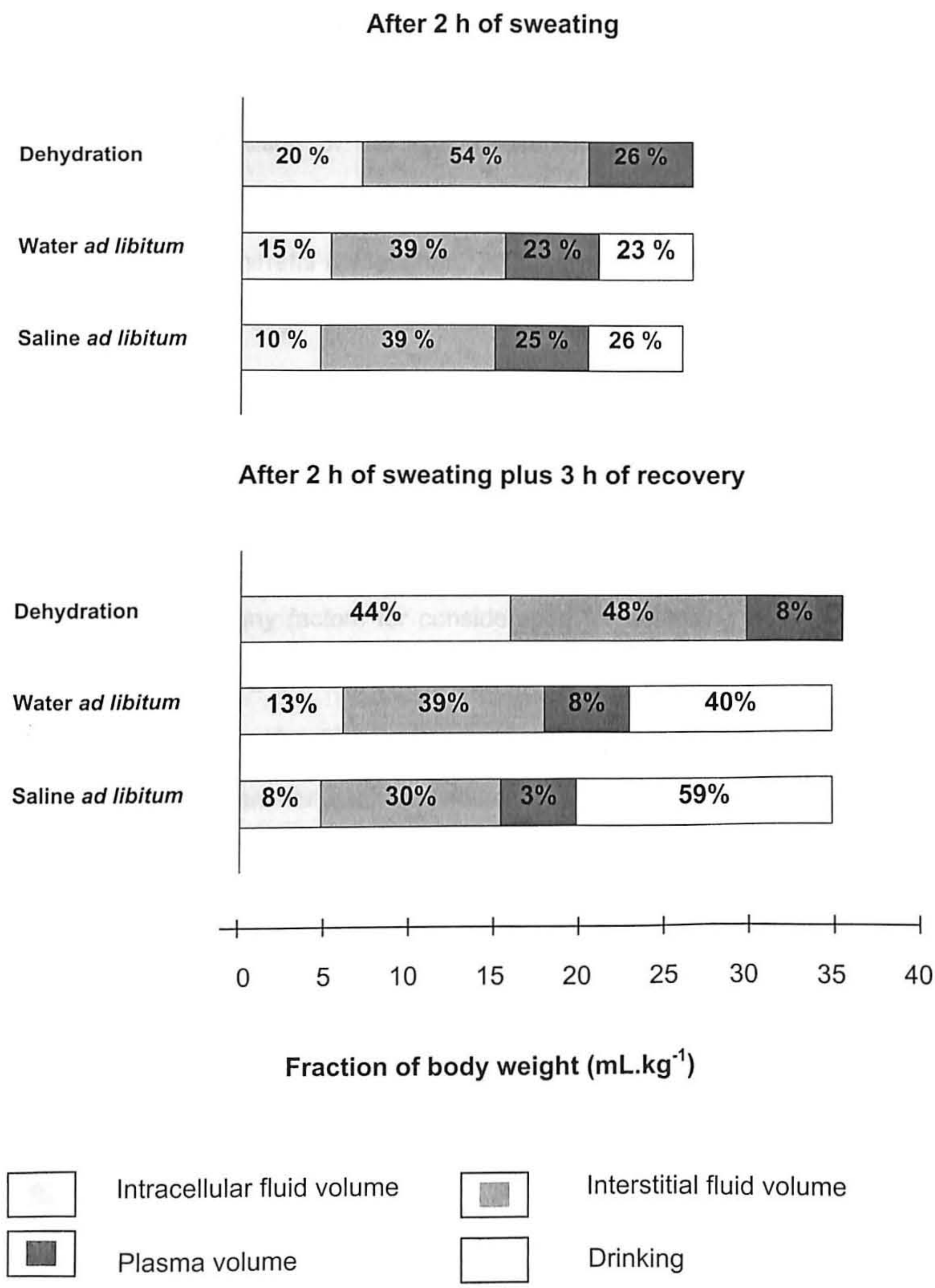


Fig. 2.3 Loss of body weight in 8 subjects due to sweating, reduction of body fluid compartments, and amount of fluid replacement. Values were obtained after 2 h of sweating (heat–exercise stress) and after 3 h of recovery with no drinking (dehydration), or with water or saline solution *ad libitum*. (Based on data from Morimoto *et al.*, 1981)

2.5 Post-exercise rehydration

The primary factors influencing post-exercise rehydration process are the volume and composition of the fluid consumed. The volume consumed will be influenced by many factors, including the palatability of the drink and its effects on the thirst mechanism (Shirreffs & Maughan, 2000). However, with conscious effort, some people can still drink large quantities of an unpalatable drink when they are not thirsty (Shirreffs, 2000). The ingestion of solid food, and the composition of that food, will also be important factors, but some people avoid solid food between exercise sessions or immediately after exercise (Shirreffs & Maughan, 2000).

There are many factors for consideration for achieving optimal post-exercise rehydration. According to Shirreffs *et al.*, (1996) a drink volume greater than the volume of sweat loss should be consumed. Hubbard *et al.*, (1990) found that drink palatability is important for each individual. Sufficient quantities of drink will not be consumed if they do not like it. However according to Nose *et al.*, 1988; Takamata *et al.*, 1994; Maughan & Leiper, 1995 plain water is not the most effective post-exercise rehydration drink. The addition of electrolytes, in particular sodium, will help maintain thirst to stimulate drinking. Maughan *et al.*, (1996) also found that consumption of solid food is likely to provide the necessary electrolytes, and therefore in this instance plain water can be consumed and rehydration achieved.

2.6 Beverage composition

Plain water is not the ideal post-exercise rehydration beverage when rapid and complete restoration of fluid balance is necessary and where all intake is in liquid form (Shirreffs, 2000). Costill & Sparks (1973) demonstrated that ingestion of plain water after exercise-induced dehydration of 4% of body mass caused a large fall in serum osmolality with a subsequent diuresis: the high urinary water loss resulted in failure to achieve positive fluid balance by the end of the 4-h study period. However, when an electrolyte-containing solution (106 g. L^{-1} carbohydrate, 22 mmol.L^{-1} Na^+, 2.6 mmol.L^{-1} K^+, 17.2 mmol.L^{-1} Cl^-) was ingested, urine output was less and net water balance was closer to the pre-exercise level. Nielsen *et al.,* (1986) showed differences in the rate and extent of changes in the plasma volume with recovery from exercise-induced dehydration when different carbohydrate-electrolyte solutions were consumed. In their study they found that the plasma volume increase was greater after drinks with sodium as the only added cation (at concentration of 43 and 128 mmol.L^{-1}) were consumed compared with drinks containing additional potassium (at concentration of 51 mmol.L^{-1}) or less electrolytes and more carbohydrate. None of these studies identified the mechanism of action, because the drinks used differed in a number of respects. They did establish, however, that the high urine flow that followed ingestion of large volumes of electrolyte-free drinks did not allow subjects to remain in positive fluid balance for more than a very short time. They also established that the plasma volume was better maintained when electrolytes were present in the fluid ingested, and this effect was attributed to presence of sodium in the drinks.

The first studies to investigate the mechanisms of post-exercise rehydration showed that the ingestion of large volumes of plain water after exercise-induced dehydration results in a rapid fall in plasma osmolality and sodium concentration (Nose *et al.,* 1988), leading to prompt and marked diuresis. In this study, subjects exercised at low intensity in the heat for 90–100 min, leading to a mean level of dehydration equivalent to 2.3% of the pre-exercise body mass, and then rested for 1 h before beginning to drink. Plasma volume was not restored until after 60 min when plain water was ingested together with placebo (sucrose) capsules. In contrast, when sodium chloride capsules were ingested with water to give a saline solution with an effective concentration of 0.4% (77 mmol.L^{-1}), restoration of plasma volume was complete within 20 minutes. In the NaCl trial, voluntary fluid intake was higher and urine output was less, 29% of the water intake being lost as urine within 3 h compared with 49% in the plain water trials. The delayed rehydration in the water trial was the result of a loss of water as urine caused by a rapid return to control levels of plasma renin activity and aldosterone levels (Nose *et al.,* 1988).

The addition of sodium to rehydration beverages can therefore be justified on two accounts. First, sodium stimulates glucose absorption in the small intestine: water absorption from the intestinal lumen is a purely passive process that is determined largely by local osmotic gradients. The active cotransport of glucose and sodium creates an osmotic gradient that acts to promote net water absorption, and the rate of rehydration is therefore greater when glucose-sodium chloride solutions are consumed than when plain water is ingested. Second, replacement of sweat losses with plain water will lead, if the volume ingested is sufficiently large, to hemodilution: the fall in plasma osmolality and sodium concentration that occurs in this situation will reduce the drive to drink and will stimulate urine output and has potentially more serious consequences, such as hyponatremia (Nose *et al.,* 1988). According to Maughan *et al.,* (1996) ingesting plain water may decrease plasma osmolality and plasma sodium concentration, causing circulating levels of vasopressin and aldosterone to be decreased. As a results, urine output increases.

It has been proposed that drinks used for post-exercise rehydration should have a sodium concentration similar to the sweat (Maughan & Shirreffs, 1998). However, the electrolyte content of sweat itself shows considerable variation among people and over time and its seems impossible to prescribe a single formulation for every person or every situation (Maughan & Shirreffs, 1998). In a systemic investigation of the relationship between whole-body sweat sodium losses and the effectiveness of beverages with different sodium concentrations in restoring fluid balance, Shirreffs & Maughan (1998b) showed that, provided that an adequate volume is consumed, euhydration is achieved when the sodium intake is greater than the sweat sodium loss.

Sodium is the major cation in the extracellular fluid but potassium is the major cation intracellular fluid. Potassium may therefore be important in achieving rehydration by aiding the retention of water in the intracellular space. Yawata, (1990) subjected rats to thermal dehydration of approximately 9% of body mass and then allowed them free access to either tap water, a 150 mmol.L^{-1} NaCl solution, or a 154 mmol.L^{-1} KCl solution. Despite ingestion of a smaller volume of the KCl solution compared to the NaCl solution, there was tendency for a greater restoration of the intracellular fluid space in the KCl group than in the NaCl group. Maughan *et al.,* (1994), dehydrated men by approximately 2% of body mass by exercise in the heat followed by ingestion of a glucose beverage (90 mmol.L^{-1}), a sodium-containing beverage (60 mmol.L^{-1} NaCl), a potassium-containing beverage (25 mmol.L^{-1} KCl), or a beverage containing all three components. All drinks were consumed in a volume equivalent to the mass loss, but a smaller volume of urine was excreted after rehydration when each of the electrolyte containing beverages were ingested (about 250-300 mL) compared with the electrolyte-free beverage (a mean volume of 577 mL). An estimated plasma volume decrease of 4.4% was observed with dehydration over all trials but the rate of recovery was slowest when the KCl beverage was consumed. There were differences in the total amount of electrolytes replaced and differences in the type of electrolytes present in the drinks. However, there was no difference in the fraction of ingested fluid retained 6 h after drinking the fluids that contained electrolytes. This was because the beverage volume consumed was equivalent to the volume of sweat lost. In addition, because of the ongoing urine losses, subjects were dehydrated throughout the entire study, even immediately after the drinking period. The volumes of urine excreted were close to basal levels and significant further reductions in output may not have been possible when both sodium and potassium is consumed, euhydration is achieved when the sodium intake is greater than the sweat sodium loss.

Sodium is the major cation in the extracellular fluid but potassium is the major cation intracellular fluid. Potassium may therefore be important in achieving rehydration by aiding the retention of water in the intracellular space. Yawata, (1990) subjected rats to thermal dehydration of approximately 9% of body mass and then allowed them free access to either tap water, a 150 mmol.L^{-1} NaCl solution, or a 154 mmol.L^{-1} KCl solution. Despite ingestion of a smaller volume of the KCl solution compared to the NaCl solution, there was tendency for a greater restoration of the intracellular fluid space in the KCl group than in the NaCl group. Maughan *et al.*, (1994), dehydrated men by approximately 2% of body mass by exercise in the heat followed by ingestion of a glucose beverage (90 mmol.L^{-1}), a sodium-containing beverage (60 mmol.L^{-1} NaCl), a potassium-containing beverage (25 mmol.L^{-1} KCl), or a beverage containing all three components. All drinks were consumed in a volume equivalent to the mass loss, but a smaller volume of urine was excreted after rehydration when each of the electrolyte containing beverages were ingested (about 250-300 mL) compared with the electrolyte-free beverage (a mean volume of 577 mL). An estimated plasma volume decrease of 4.4% was observed with dehydration over all trials but the rate of recovery was slowest when the KCl beverage was consumed. There were differences in the total amount of electrolytes replaced and differences in the type of electrolytes present in the drinks. However, there was no difference in the fraction of ingested fluid retained 6 h after drinking the fluids that contained electrolytes. This was because the beverage volume consumed was equivalent to the volume of sweat lost. In addition, because of the ongoing urine losses, subjects were dehydrated throughout the entire study, even immediately after the drinking period. The volumes of urine excreted were close to basal levels and significant further reductions in output may not have been possible when both sodium and potassium were ingested. Inference from the studies of Yawata (1990) and Maughan *et al.*, (1994), potassium may be important in enhancing rehydration by aiding intracellular rehydration, but further investigation is required to provide conclusive evidence (Shirreffs, 2000).

2.7 Drink volume

Obligatory urine losses persist even in the dehydrated states, because of the need for elimination of metabolic waste products. The volume of fluid consumed after exercise-induced or thermal sweating must therefore be greater than the volume of sweat lost if effective rehydration is to be achieved. This contradicts recommendations that athletes should match fluid intake exactly to the measured body mass loss (Shirreffs & Maughan, 2000). Shirreffs *et al.*, (1996) has investigated the influence of drink volume on rehydration effectiveness after exercise-induced dehydration equivalent to approximately 2% of body mass. Drink volumes equivalent to 50, 100, 150, and 200% of the sweat loss were consumed after exercise. To investigate the possible interaction between beverage volume and its sodium content, a drink with relatively low sodium (23 $mmol.L^{-1}$) and one with moderately high sodium (61 $mmol.L^{-1}$) were also compared.

With both beverages, the urine volume produced was related to the beverage volume consumed; the smallest volumes were produced when 50% of the loss was consumed and the greatest when 200% of the loss was consumed. Subjects could not return to euhydration when they consumed a volume equivalent to, or less than, their sweat loss, irrespective of the drink composition. When a drink volume equal to 150% of the sweat loss was consumed, subjects were slightly hypohydrated 6 h after drinking if the test drink had a low sodium concentration, and they were in a similar condition when they drank the same beverage in a volume of twice their sweat loss. With the high sodium drink, enough fluid was retained to keep the subjects in a state of hyperhydration 6 h after drink ingestion when they consumed either 150% or 200% of their sweat loss. The excess would eventually be lost by urine production of by further sweat loss if the person resumed exercise or moved to a warm environment. Calculated plasma volume changes indicated a decrease of approximately 5.3% with dehydration. At the end of the study period, the general pattern was for the increases in plasma volume to be a direct function of the volume of fluid consumed. The increase tended to be greater for those people who ingested the high-sodium drink (Shirreffs & Maughan, 2000).

2.8 Composition of commercially available sports drinks

A sports drink refers to a beverage that is formulated for quick replacement of fluids and electrolytes that are lost during exercise, and provides carbohydrate fuel to working muscles (Gisolfi, 1991). Sports drinks do have a distinct advantage over water in that they deliver both carbohydrates and electrolytes in addition to fluid replacement. This can be of substantial benefit during exercise to maintain blood glucose concentration, and reduce the rate of glycogen utilization by slow twitch muscle fibers. During recovery, sports drinks facilitate restoration of muscle and liver carbohydrate stores and the body's fluid balance (Wilmore *et al.*, 1998).

Gonzalez-Alonso *et al.*, (1992) found that a carbohydrate sports drink was more effective than either water or diet cola (Diet Coke) in rehydrating individuals after exercise. Rehydration was determined using body weight and relative blood volume (the extent of return to the normal, pre-exercise values) and urine production (amount of fluid not retained). The lack of sodium and carbohydrate in the water or diet cola, and the presence of caffeine (cola only) make these fluids less favourable for rehydration compared to the carbohydrate-electrolyte sports drink.

The production and sales of sports drink is a lucrative and competitive industry, as demonstrated by the rapidly growing variety of products being marketed, each with claims of benefits superior to rival beverages (Jeff & Hamilton, 2000). Sports drinks are typically formulated to (i) prevent dehydration; (ii) supply carbohydrates to augment available energy; (iii) provide electrolytes to replace losses due to perspiration; (iv) conform to requirements imposed by regulatory authorities; and, probably the most important, (v) be highly palatable (Jeff & Hamilton, 2000). Sports drinks can be classified as having a low carbohydrate concentration (<10%) or a high carbohydrate concentration (>10%). The higher carbohydrate content drinks are marketed for carbohydrate loading rather than for general consumption before or during the exercise. The more popular drinks are those that contain low carbohydrate concentrations (Jeff & Hamilton, 2000).

2.8.1 Carbohydrate content

The beverages contain between 6 and 8% carbohydrate, with considerable variation in the combination of carbohydrate sources used by manufacturers. The major carbohydrates used in sports drinks are the monomers glucose and fructose, the dimer sucrose, and the synthetic polymer maltodextrin, also known as glucose polymer. The use of glucose polymer in sports drinks has increased in recent years as they allow for provision of more carbohydrate without a resultant increase is osmolality. When designing the composition of sports drinks, a manufacturer balances the efficacy of the carbohydrate combination with palatability.

The rate at which carbohydrate/electrolyte drinks are emptied from the stomach is influenced primarily by the volume of fluid ingested and the carbohydrate content of the beverage (Coyle & Mountain, 1992; Elias *et al.,* 1968; Vist & Maughan, 1995). Fructose solutions have been shown to empty from the stomach at faster rates than equimolar glucose solution (Elias *et al.,* 1968). Shi *et al.,* (1995) found that the sucrose/glucose drink tended to promote the greatest water and sodium absorption, but stimulated only a moderate amount of carbohydrate absorption; conversely, the glucose/fructose solution induced the highest carbohydrate absorption and a moderate water absorption, but the lowest sodium absorption. A study by Gisolfi *et al.,* (1992) concluded that water absorption was independent of carbohydrate type in solutions containing up to 6% carbohydrate with the same osmolality and caloric concentration. However, increasing carbohydrate concentration up to 8% significantly reduced water absorption from isocaloric solutions of glucose and corn syrup solids, but not from 8% solutions of sucrose or maltodextrin. This is because the glucose polymer (sucrose or maltodextrin) allows provision of more carbohydrate without a resultant increase is osmolality.

2.8.2 Electrolyte content

Small amounts of electrolytes, generally sodium, potassium and chloride, are added to sports drinks to improve palatability and to, theoretically, help maintain fluid /electrolyte balance (Jeff & Hamilton, 2000). The goal of the manufacturer is to provide a sports drink that is isotonic with respect to the plasma. In the past, sports drinks were made hypertonic because of the over-use of simple sugars and electrolytes and were detrimental to performance. In the 1980s, many sports drink manufacturers began using maltodextrins in their drinks in addition to simple sugars. Maltodextrins allow for the carbohydrate content to be kept constant even with the addition of relatively high concentrations of electrolyte to improve palatability.

Given the knowledge that electrolyte losses decrease as the training level of an athlete increases, it is likely that differences in electrolyte composition play a significant role only for the untrained athlete or during particularly severe conditions of exercise and heat exposure (Powers *et al.,* 1997; Wyndham, 1973). However, it must also be mentioned that a dilute electrolyte solution can be consumed during exercise without