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Effects of different carbohydrate-electrolyte beverages on the appearance of ingested deuterium in body fluids during moderate exercise by humans in the heat

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Abstract To determine whether different forms of glucose (free and polymer) associated with sodium chloride influence the rate of water absorption during exercise in the heat, six men took part in five trials. Each trial included a passive heating session which resulted in a 2% loss of body mass, followed by 1h of treadmill exercise (at 50% of maximal oxygen uptake) in warm conditions (dry bulb temperature 35°C, relative humidity 20%–30%). Immediately before exercise, the subjects were given either no fluid or a volume equal to 50% of the fluid previously lost (about 650 ml), chosen from among four D_2O-labelled beverages : mineral water, a 6% glucose-electrolyte solution (GS), a 6% maltodextrin solution and a 6% maltodextrin-electrolyte solution. No significant differences were observed among these various beverages so far as temporal accumulation of deuterium in plasma, sweat and urine was concerned. During GS, the plasma volume was completely restored and the drifts of heart rate and rectal temperature were less marked than during other trials. These results would suggest that rehydration with GS was more efficient, probably because of an internal redistribution of water. The proportion of ingested water was twice as high in sweat as it was in urine. These findings may reflect the essential part played by circulatory adjustments in the transfer of plasma water into sweat and urine.

Key words Rehydration · Deuterium · Body fluids · Cardiovascular responses · Body temperatures

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Introduction

During prolonged exercise in the heat, a considerable amount of body water is lost in sweat to dissipate the heat. It has been reported however that sweating-induced dehydration impairs physical performance, especially endurance capacity, in relation to the level of fluid loss (Melin et al. 1988). It has been shown that because it reduces skin blood flow and/or sweat rate (Fortney et al. 1984), the risk of hyperthermia is increased and that fluid replacement is therefore necessary to prevent the fall in plasma volume (PV) and the increase in plasma osmolality (Osm_{pl}), both implicated in maintaining internal body temperature and cardiocirculatory stability (Pitts et al. 1944; Costill et al. 1970; Nadel et al. 1980). It has been found that oral rehydration solutions can also provide the salt and carbohydrate that are necessary to prevent hyponatraemia (Noakes et al. 1985), hypoglycaemia (Coyle et al. 1986) and to improve exercise performance (Mitchell et al. 1988).

There is, however, still much debate over the composition of the beverage that should be used for prolonged exercise in warm conditions. Indeed, rehydration effectiveness depends on the rate of gastric emptying which conditions intestinal absorption. High free glucose osmolality solutions have been found to delay gastric emptying (Costill and Saltin 1974), while it has been shown that 5%–7% glucose polymer solutions can be emptied at rates similar to plain water (Seiple et al. 1983). Davis et al. (1987) have shown that a 6% glucose-electrolyte solution promoted water absorption into the vascular bed as a result of the coupled transport of glucose and sodium across the small intestine epithelium (Gisolfi et al. 1990). Our hypothesis was therefore that a 6% glucose polymer-electrolyte solution would better increase the transfer of water to the vascular system than a 6% free glucose-electrolyte solution because of its lower osmolality. This transfer would also be faster with a 6% glucose polymer-electrolyte solution than with the same solution without electrolytes, or than with pure

water, because of the beneficial effect of the coupled glucose and sodium transport.

The aim of this study was to test that hypothesis. We recorded temporal accumulation of plasma deuterium (D) as a tracer of water absorption from deuterium oxide (D_2O)-labelled beverages as did Davis et al. (1987, 1988). This isotope method allowed us to study the overall rate of gastro-intestinal transit and to follow the tracer elimination both in urine and sweat, which has been poorly described to date (Armstrong et al. 1987).

Methods

Subjects

Six active male volunteers gave their informed consent to the experimental conditions after the details of the protocol had been explained to them. This study was approved by an Ethics Committee (Comité Consultatif pour la Protection des Personnes dans le Recherche Biomédicale Grenoble 2). The selection of subjects was based on a normal clinical investigation that comprised a detailed medical history, a physical examination and general blood screening. All the subjects were French residents and were unaccustomed to heat; their mean anthropomorphic characteristics were: age 27 (SEM 2) years, body mass 70 (SEM 2) kg, height 1.79 (SEM 0.03) m. Their physical fitness was estimated from the maximal oxygen uptake ($\dot{V}O_{2max}$) measured during a progressive treadmill test, with an average of 58.8 (SEM 1.2) ml $\cdot$ min^{-1} $\cdot$ kg^{-1}. The experiments were made in late winter and early spring.

Experiment protocol

Each subject performed five trials each separated by 3 weeks. Experiments were conducted in a randomized crossover design. Each trial comprised a passive heating session performed to obtain a 2% body mass dehydration, and 1 h of physical exercise at 50% $\dot{V}O_{2max}$ in a warm environment (dry bulb, T_{db}, and wall temperatures 35°C, relative humidity, rh, 20%–30%, wind speed 0.8 m$\cdot$s^{-1}). We compared the control experiment without rehydration (Dh) with the other experiments in which a 50% replacement of water loss (about 650 ml) was made just prior to the exercising period. The drink had an optimal volume to encourage gastric emptying (Costill and Saltin 1974). An earlier study had also demonstrated that 50% rehydration given as a single drink was beneficial to performance because of its rapid correction of body fluid imbalance (Melin et al. 1994).

Four solutions were tested:

1. Mineral water (W)
2. A 6% glucose and 1.2 g $\cdot$ l^{-1} NaCl solution (GS)
3. A 6% maltodextrin solution (M)
4. A 6% maltodextrin and 1.2 g $\cdot$ l^{-1} NaCl solution (MS)

The osmolalities of the solutions were 15, 400, 70 and 110 mosmol$\cdot$kg$^{-1}H_2O$ for W, GS, M and MS, respectively. Beverages which contained 3.3% of D_2O (99.8% of D, group CEA, CE Saclay, Gif-sur-Yvette, France) had the same flavour and were ingested at 25°C.

The subjects arrived at the laboratory at 8.30 a.m. after a standard breakfast. They emptied their bladders, put on shorts and probes were attached to them. The passive heating session was conducted in a climatic chamber so that the subjects might lose 2% of their initial body mass. This method was derived from the passive controlled hyperthermia technique described by Henane and Valatx (1973). The subjects were asked to lie down on a balance (TESTUT 9009, France) to measure the sweat loss (sensitivity ±3 g). A copper-constantan (Cu-Ct) thermocouple was inserted and insulated in the auditory canal. Climatic parameters were then adjusted (successively T_{db} 45°C, rh 70% and T_{db} 50°C, rh 30%) to clamp the auditory canal temperature at 38°C. This passive heating session was immediately stopped when the subjects had lost 1.8% of body mass which generally took 2 h. Addition of urinary losses collected at the end of the climatic chamber session resulted in a total dehydration of 2% body mass. The subjects were then immediately removed to a thermoneutral environment for 1 h (T_{db} 25 ± 1°C), which was the time necessary to obtain basal thermal conditions. The physical exercise consisted of walking at 50% $\dot{V}O_{2max}$ (6–6.5 km$\cdot$h^{-1}, gradient 5%–7%) for 1 h in the climatic chamber on a calibrated motor-driven treadmill (Imbernon Jog-25, Lyon, France).

Physiological measurements

Every 20 min, the intensity of the exercise was checked by the measurement of oxygen consumption. The minute ventilation was measured during 5 min with a calibrated ultrasonic flowmeter (BRDL flowmetric FR 40, Birmingham University, UK). Expired air samples were analysed for O_2 and CO_2 with Taylor Servomex OA1600 and Cosma Rubis 6000 analysers.

Heart rate (HR) was monitored continuously from three chest electrodes connected to a heart rate monitor (Supermon 7210, Kontron Instruments, Watford, UK). Rectal temperature T_{re} and ten skin temperatures were recorded every minute with Cu-Ct thermocouples. Mean skin temperatures ($\overline{T}_{sk}$) was calculated using the equation of Colin et al. (1971).

Total body sweat loss was determined from the difference in nude body mass before and after the exercise (Sauter electronic scale EC 240, France, accuracy ± 1g by difference) adjusted for metabolic and water respiratory mass losses according to Mitchell et al. (1972), and for water intake. Urine was collected before and after the exercise.

Local sweat losses were collected from a 75 cm^2 sweat collector placed as described by Brisson et al. (1991) after shaving and cleaning the epigastric zone. Sweat samples were taken at 30 and 60 min for volume measurement and biochemical assays.

Biochemical assays

Blood samples were taken from a polyethylene catheter (angiocath F2818 Deseret) inserted in a antecubital vein at 8.30 a.m. The first blood sample was collected after 30 min spent in an upright position : it was used as a reference value for the calculation of PV changes. Thereafter, venous blood samples were drawn prior to exercise and rehydration (time 0) with subjects in an upright position for at least 30 min and at 5, 10, 20, 40 and 60 min of the exercise period.

Blood samples were immediately transferred into tubes containing lithium-heparin and analysed in quadruplicate for haemoglobin using the cyanmethaemoglobin method (Perkin-Elmer lambda 2UV/VIS Spectrophotometer, Uberlingen, Germany). Haematocrit was also determined in quadruplicate using microcentrifugation. Haemoglobin and haematocrit were used to calculate changes in PV according to the equation of Dill and Costill (1974). Plasma, urine and sweat osmolalities were measured by freezing point depression (Roebling osmometer, Berlin, Germany).

Plasma, sweat and urine samples were frozen and stored at −80°C in a nitrogen rich environment until they could be analysed for deuterium content. Isotope ratio (deuterium:hydrogen, D:H) was measured using nuclear magnetic resonance (NMR) spectroscopy in Eurofins Laboratories (Nantes, France). Samples were prepared weighing successively 3 ml of a reference solution (tetramethylurea), 0.75 ml of plasma (or sweat or urine) and 0.15 ml of trifluoroacetic acid. Once they were full, NMR tubes were introduced in a spectrometer (Bruker AM 500, Wissembourg, France) which gave five spectra for each sample. An average spectrum was calculated using the SNIF-NMR system 3.0 copyright Eurofins 1991, and the D:H ratio was determined. The

accuracy of this method was ± 0.2 ppm for a 0.5 h analysis, and the repeatability was 2%–3% (Guillou et al. 1988).

Calculations

Elimination of ingested water in sweat and urine was calculated as follows. When small quantities of D_2O were mixed with water, an equilibrium was reached: $H_2O + D_2O \rightarrow 2\,HOD$; 3.3% of D_2O then corresponded to 6.6% of HOD in labelled beverages. Furthermore, natural fluids have a ratio of deuterium to hydrogen (expressed as D:H ratio) background level of approximately 150 ppm. Therefore, total HOD concentration in all beverages was 3.66 mol · l^{-1}.

To calculate the accumulation of deuterium in body fluids due to water ingested we substracted the background value at time 0 from the D:H ratio measured at each sampling time. Variations in the D:H ratio in plasma, sweat and urine: $\Delta[D:H]_{pl}$, $\Delta[D:H]_S$ and $\Delta[D:H]_U$, respectively, were thus defined. Since no sweat sample was collected at time 0, the sweat background value was estimated as the mean of background values in plasma and urine, which were similar.

Since urine has been shown to contain 95% of water (Geigy 1972), the ingested water volume (x, in millitres) eliminated in urine was:

$$x = 2\Delta[D:H]_U \frac{1050}{19} \cdot \frac{U}{3.66 \cdot 0.95}$$

where *1050* is the density of HOD (grams per litre) estimated as mean of density of H_2O and D_2O at 25 °C (Geigy 1972), *19* is the molar mass of HOD (grams per mole), U (ml) is the volume of urine collected.

In sweat, the volume of ingested water eliminated was y (ml):

$$y = \left(2\Delta_1[D:H]_S \frac{1050}{19} V_1 + 2\Delta_2[D:H]_S \frac{1050}{19} V_2\right) \cdot \frac{S}{3.66(V_1 + V_2)}$$

where $\Delta_1[D:H]_S$ and $\Delta_2\,[D:H]_S$ are D accumulation in sweat collected at t_{30min} and t_{60min} (where t is time), respectively, V_1 and V_2 are the volumes (in millilitres) of sweat collected at t_{30min} and t_{60min}, respectively, and S is the total sweat volume of the whole body (in millilitres), as previously described.

Statistics

An ANOVA for repeated measures (fluid replacement condition by time) was conducted. When significant differences were found between experimental conditions, a Wilcoxon test for paired data was applied to examine the differences among means at several times during the exercise. A one-way analysis of variance and a Wilcoxon test for paired data were used to compare water losses and D accumulation in urine in the different experimental conditions. The null hypothesis was rejected when P was less than 0.05.

Results

Fluid losses

During the passive heating session, all the subjects lost 2% of body mass [1434 (SEM 58) ml in Dh, 1475 (SEM 44) ml in W, 1437 (SEM 39) ml in GS, 1512 (SEM 56) ml in M and 1409 (SEM 45) ml in MS]. During exercise, fluid losses through urine and respiration were similar in all trials (Table 1). Local sweat losses were higher ($P < 0.05$) during the second half of exercise but were similar in all experiments (Table 2).

PV and Osm_{pl}

Sweating-induced dehydration reduced PV (−5% to −9%) and increased Osm_{pl} (+1.5 to +3 mosmol·$kg^{-1}H_2O$; Fig. 1). During exercise, PV decreased ($P < 0.05$) and Osm_{pl} increased ($P < 0.05$) during Dh (−9.8% and 305 mosmol·$kg^{-1}H_2O$, respectively, at the end of the exercise). In the partially rehydrated subjects, PV increased ($P < 0.05$) and Osm_{pl} decreased ($P < 0.05$) after 40 min compared to Dh (Fig. 1). No significant differences were detected among rehydrating conditions, although PV appeared to be completely corrected during GS.

HR and thermal responses

The HR, T_{re} and $\overline{T}_{sk}$ did not differ significantly before exercise. In all experimental conditions, HR increased continuously during the exercise with lower values in partially rehydrated subjects (Fig. 2). After 30 min of exercise, a lower HR was observed only in GS compared to Dh ($P < 0.05$), whereas HR was lower for W, M and

Table 1 Fluid losses during 1 h of exercise. *Dh* without rehydration, *W* mineral water, *GS* glucose-electrolyte solution, *M* maltodextrin solution, *MS* maltodextrin-electrolyte solution

	Dh		W		GS		M		MS	
	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
Urine (ml)	27	4	30	6	25	6	29	9	27	4
Respiration (ml)	83	2	87	2	83	3	81	3	86	3
Sweat (ml)	883	61	874	38	833	30	881	26	868	20

Table 2 Local sweat losses. For definitions see Table 1

Local sweat losses	Dh		W		GS		M		MS	
	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
From 0 to 30 min (ml)	2.1	0.2	2.0	0.4	2.5	0.3	2.2	0.3	2.2	0.3
From 30 to 60 min (ml)	3.5	0.3*	3.4	0.4*	4.0	0.3*	3.4	0.3*	3.4	0.5*

* $P < 0.05$ Compared to the first half of exercise (0–30 min)

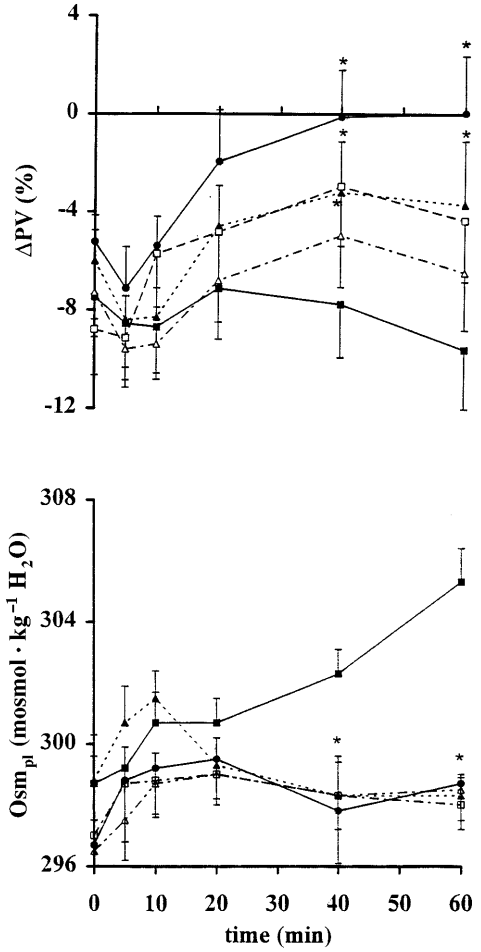

Fig. 1 Time course of changes in the subjects' calculated variation in plasma volume (*PV*) and plasma osmolality Osm_{pl} during exercise without rehydration (Dh ■), and rehydration with mineral water (W ▲), a 6% glucose-electrolytes solution (GS ●), a 6% maltodextrin solution (M □) or a 6% maltodextrin-electrolytes solution (MS Δ). Values are means and SEM ($n = 6$). $^{*}P < 0.05$ Compared to Dh

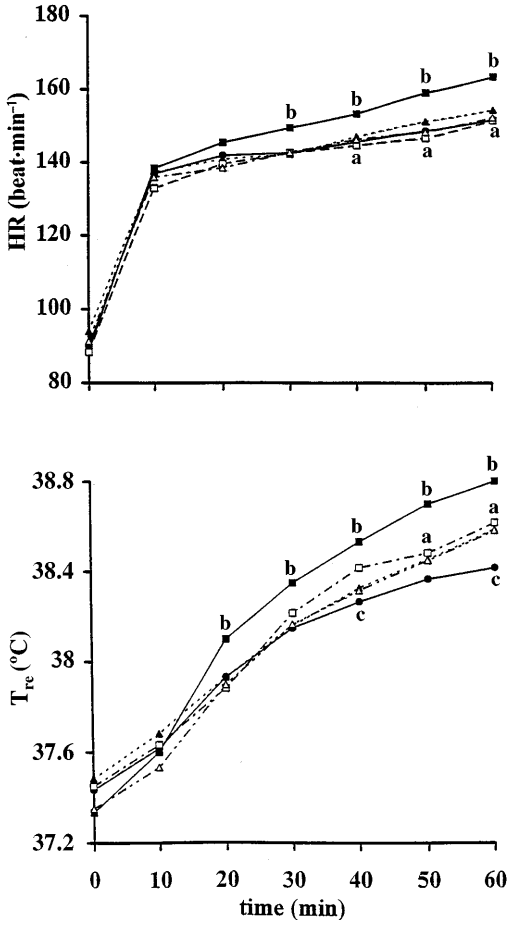

Fig. 2 Time course of changes in heart rate (*HR*) and rectal temperature (T_{re}) during exercise in Dh (■), W(▲), GS(●), M(□) and MS(Δ); for definitions see Fig. 1. Values are expressed as means ($n = 6$). $^{a}P < 0.05$ Compared to Dh, $^{b}P < 0.05$ compared to GS, $^{c}P < 0.05$ compared to M

MS after 50 min ($P < 0.05$). No significant differences in HR were detected among rehydrating conditions.

The T_{re} increase was also lower in partially rehydrated subjects (Fig. 2). Compared to Dh, T_{re} in GS was lower from $t_{20\ min}$ to the end of exercise ($P < 0.05$) and lower after 50 min only for all other rehydrating conditions ($P < 0.05$). Moreover, T_{re} in GS was lower compared to M at 40 and 60 min ($P < 0.05$).

No significant differences were detected in $\overline{T}_{sk}$ whatever the experimental conditions.

Appearance of ingested water in plasma, sweat and urine

As shown in Fig. 3, variations in plasma D:H ratio ($\Delta[D:H]_{pl}$) increased from $t_{5\ min}$ during GS, M and MS ($P < 0.05$) and from $t_{10\ min}$ during W ($P < 0.05$) to $t_{40\ min}$ during exercise. No significant differences were detected among the different rehydration conditions.

Variations in sweat D:H ratio ($\Delta[D:H]_S$) are given in Table 3. Compared to reference values, the D:H ratio increased in sweat at $t_{30\ min}$ of exercise ($P < 0.05$). Higher values were observed at $t_{60\ min}$ ($P < 0.05$) for all rehydrated conditions.

Variations in urine D:H ratio ($\Delta[D:H]_U$) increased in all rehydration conditions ($P < 0.05$) after exercise.

The ingested water volume eliminated was 0.09–0.16 ml in urine and 6.5–7.2 ml in sweat. These values corresponded to 4.8% in 1 ml of urine and 8.0% in 1 ml of sweat (Table 4). The eliminated proportion of water ingested was thus nearly twice as high in sweat as it was in urine ($P < 0.05$).

Discussion

The rate at which the water contained in an ingested beverage is absorbed into body fluids is important, particularly during prolonged exercise in a warm environment. To evaluate this rate, temporal profiles of plasma D:H ratio were recorded after ingestion of D_2O-labelled beverage. Even though it has been shown that this method does not accurately measure net fluid

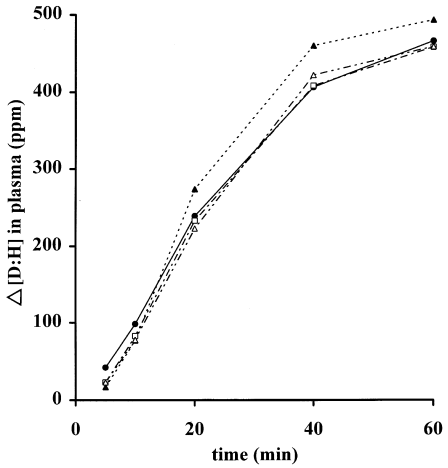

Fig. 3 Variations in plasma D:H ratio ($\Delta[D:H]_{pl}$) during exercise in W(▲), GS(●), M(□) and MS(Δ). Values are expressed as means ($n = 6$). For definitions see Fig. 1

movement from duodenum-jejunum into blood (Gisolfi et al. 1990), it allowed us to determine the overall rate of gastro-intestinal transit (Davis et al. 1987).

All rehydrating conditions were compared to the GS 6% carbohydrate-electrolyte beverage used by Davis et al. (1987). It was expected that with the hypotonic MS water absorption would be greater than with GS because of the influence of osmolality on gastric emptying (Costill and Saltin 1974), and that it would also be greater than with M (glucose polymer only) because of the stimulatory effect of glucose and sodium on water absorption through the small intestine (Gisolfi et al. 1990). However, present results failed to show any significant differences between the rates of appearance of D in plasma, which suggests that the beverage compositions tested did not influence water absorption. These data do not agree with the results given by Davis et al. (1987) who have observed an increased plasma D accumulation with GS for subjects at rest. Moreover, Gisolfi et al. (1991) have confirmed that during exercise, a greater fluid absorption rate was observed with a 6% carbohydrate-electrolyte solution compared to pure water or to an isotonic solution without carbohydrate. This discrepancy can be attributed to the differences in the method used to measure water absorption. In fact, Gisolfi et al. (1990, 1991) have not studied the overall rate of gastro-intestinal transit of various beverages but only intestinal absorption by the segmental perfusion technique.

In our study, the stimulatory effect of coupled glucose and sodium transport on intestinal absorption of water were probably counterbalanced by a delayed gastric emptying due to carbohydrate content (Costill and Saltin 1974) which could explain why we found no difference in plasma D accumulation between GS and pure water. Finally, our results agree with those of Davis et al. (1988) who have shown no significant differences between water and a 6% glucose-electrolyte beverage in the rates of plasma D appearance during prolonged intermittent exercise in the heat. The reason why we did not find any differences in plasma D accumulation between GS and MS was probably that energy density rather than osmolality is the major determinant of gastric emptying of dilute carbohydrate solutions as has been reported by Vist and Maughan (1995). Recently, Gisolfi et al. (1995) have shown that adding some Na^+ to a 6% carbohydrate solution does not enhance fluid absorption, which might explain why we did not find any differences in plasma D accumulation between M and MS.

Table 3 Changes in ratio of deuterium to hydrogen (Δ[D:H]) in sweat and urine. For definitions see Table 1

	W		GS		M		MS	
	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
Δ[D:H] in sweat (ppm)								
From 0 to 30 min (ml)	142	25	132	16	122	21	117	15
From 30 to 60 min (ml)	347	52*	340	29*	349	38*	363	27*
Δ[D:H] in urine (ppm)	153	15	150	19	141	27	144	20

*$P < 0.05$ Compared to the first half of exercise (0–30 min)

Table 4 Elimination of the water ingested in sweat and urine. For definitions see Table 1

	W		GS		M		MS	
	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
Volume in sweat (ml)	7.17	1.32	6.47	0.56	6.89	0.79	7.17	0.67
Fraction in 1-ml sweat	8.1	1.3 ($\cdot 10^{-3}$)*	7.8	0.7 ($\cdot 10^{-3}$)*	7.8	0.9 ($\cdot 10^{-3}$)*	8.2	0.7 ($\cdot 10^{-3}$)*
Volume in urine (ml)	0.09	0.03	0.12	0.05	0.16	0.09	0.11	0.04
Fraction in 1-ml urine	4.9	0.5 ($\cdot 10^{-3}$)*	4.8	0.6 ($\cdot 10^{-3}$)*	4.5	0.8 ($\cdot 10^{-3}$)*	4.6	0.6 ($\cdot 10^{-3}$)*

*$P < 0.05$ Compared to fraction in urine

All beverages tested in this study seemed to be similarly efficient in replacing fluid loss. However, the measurements of PV changes and of thermal and circulatory responses gave additional interesting information. As has been reported by Sawka et al. (1984), our study also showed that sweating-induced dehydration led to hyperosmotic hypovolaemia being partially restored during rehydration. A completely restored PV was even observed with GS although the volume of fluid intake represented only half of the initial dehydration. That unexpected result agreed with the data from Candas et al. (1986) who have shown that full PV restoration can be obtained with fluid intake, at least with an isotonic electrolyte-glucose solution.

These results also confirmed the suggestion that rehydration reduces HR and T_{re} drifts during exercise in dehydrated subjects (Pitts et al. 1944; Costill et al. 1970; Nadel et al. 1980; Fortney et al. 1984). Rehydration however would not appear to modify the time course of $\overline{T}_{sk}$ in so far as no significant changes in sweat rate were observed (see Candas et al. 1986). The earlier changes in HR and T_{re} observed during GS were probably due to the faster and larger restoration of circulating blood volume (see Melin et al. 1994) which occurred in that experimental condition. Since rates of D appearance in plasma from D_2O-labelled beverages were similar in all rehydration conditions, we hypothesize that PV modifications during GS could have been due to an internal redistribution of body fluids. Water might have shifted from the interstitial space to the intravascular bed according to the osmotic gradient caused by the slightly hyperosmotic GS drink. Observations of Osm_{pl} are in accordance with the above explanations, since Osm_{pl} was equally corrected whatever the drink. Further studies, including a complete analysis of body fluid compartments, would be necessary to demonstrate these body fluid shifts.

An original aspect of this study concerned the excretion in sweat and urine of the water ingested. Compared to the reference value, the plasma D:H ratio had increased as little as 5–10 min after the ingestion of the D_2O-labelled drink which could have represented the delay required to incorporate the fluids ingested into the plasma. We also observed that D:H ratio increased in the sweat sampled after 30 min of exercise. Our results agree with those by Armstrong et al. (1987) who have found delays of 8 and 18 min for the appearance of $H_2{}^{18}O$ in plasma and sweat respectively, during exercise in the heat. Although Schoeller et al. (1986) have demonstrated that D was not isotopically fractionated in urine and sweat, they have shown that transcutaneous water loss was fractionated, and that it could affect the D concentration of the mixed sweat and transcutaneous water collected during the exercise. However, the calculation of the transcutaneous water amount as described by Kuno (1956) has shown that only 1% of the water collected in the sweat collector derives from transcutaneous water. The potential error that could have been made by not taking isotope fractionation into account thus remains insignificant considering the precision of the D:H ratio measurement. We calculated the volume of ingested water that is excreted in sweat even if local sweat composition did not represent the mean value of overall sweat (see Brouns et al. 1992). This volume was much higher in sweat than in urine (0.10 ml) and varied from 6.5 to 7.2 ml. These differences between sweat and urine were primarily due to the high volume of sweat loss (800–900 $ml \cdot h^{-1}$) compared to the low rate of urine excretion (30 $ml \cdot h^{-1}$) even when the subjects were rehydrated (Table 1). The proportion of the water ingested which appeared in sweat was nearly twice the size of that in urine. That result confirmed the suggestion that the elimination of water ingested in sweat and urine might be dependent on local circulatory adjustments during exercise in the heat. Indeed, renal blood flow is reduced by half compared to the value at rest whereas skin blood flow can reach 3 $l \cdot min^{-1}$ which has been described as five times as large as renal blood flow (Rowell 1974).

In conclusion, absorption of water ingested into blood does not depend on the beverage composition during exposure to heat and exercise. However, beverage composition can influence other physiological responses such as HR and thermal drifts as a result of a better PV compensation. The GS with 6% free glucose and 1.2 $g \cdot l^{-1}$ sodium chloride would therefore seem to be the most efficient beverage for quick rehydration. Our results further showed that the elimination of water ingested in sweat and urine does not depend on the beverage composition. The proportion of water ingested was nearly twice as high in sweat as it was in urine which demonstrated the important role of circulatory adjustments in the transfer of plasma water into sweat and urine.

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