ON THE CHOICE OF FLUID FOR THE HYDRATION OF MIDDLE-AGED MARATHON RUNNERS

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ABSTRACT

Nine subjects (five well-trained post-coronary patients and four other middle-aged joggers) participated in a 42 km "Marathon" race. The course was covered in an average of 212 minutes under pleasantly warm conditions (Maximum 21.7°C, 69% relative humidity). Subjects were given initial hyperhydration and repeated subsequent doses of water, "Erg" (Na^+ 19mE/l K^+ 10.7mE/l, glucose 5.3g/100 ml) or a "Special Solution" (during the race Na^+ 21mE/1 glucose 4.1g/100 ml; after the race Na^+ 20 mE/l, K^+ 4.7mE/l., glucose 4.1 g/100 ml). Weight loss averaged 2.2 kg and sweat production 3.3l taking account of water liberated from the hydration of glycogen and the oxidation of food stuffs, it was estimated that most subjects suffered relatively little dehydration over the race (0.4 – 0.8l). This was confirmed by a sustained urine production of $>$ 100ml/hr. Nevertheless, rectal temperatures showed substantial elevation over the race (final readings 38.3 – 40.2°C). In terms of fluid balance and stability of plasma mineral composition, the runners drinking water performed slightly better than those receiving the other two solutions. Nevertheless, there may be merit in giving potassium solutions during recovery from vigorous effort.

INTRODUCTION

Dehydration of the marathon runner, well-recognized as a hazard for the young, top-level competitor (Wyndham & Strydom, Costill, 1972), can develop to an almost equal extent in a middle-aged post-coronary patient who covers the same distance at a much slower pace (Kavanagh & Shephard, 1974). However, a preliminary trial in the 1973 Hawaii Marathon (Kavanagh & Shephard, 1975) suggested that as in laboratory exercise with younger subjects (Kozlowski & Saltin, 1964), preliminary "super-hydration" and free access to fluids over the race were sufficient to sustain hydration throughout the 42 km event. Evidence supporting this view included (i) calculations of fluid balance, (ii) observation of continued urine secretion, and (iii) an increase of haematocrit relative to red cell count and haemoglobin levels (Costill et al, 1974).

Because of the distance from Toronto, only three of our post-coronary patients were able to participate in the Hawaii event, and the scope for scientific observations was also somewhat restricted. It was thus decided to organize a race over the marathon distance in the immediate environs of our laboratory. The objectives were to evaluate further the possibilities of sustaining body hydration in the middle-aged marathon runner, to study the evolution of the various physiological and biochemical variables, and to compare the merits of several possible replacement fluids.

METHODS

Subjects and experimental plan

Our subjects for the present experiment were five middle-aged patients seen 2-4 years after rehabilitation for myocardial infarction, and four healthy runners of similar age selected from the Metro Fitness Joggers Club. The physical characteristics of the two groups are summarized in Table I. There were no significant differences between the two groups, the five post-coronary patients being so completely rehabilitated that we were for practical purposes dealing with a homogenous and well-trained sample of middle-aged runners. Accordingly, data in subsequent tables is averaged without regard for clinical condition.

TABLE I

Physical characteristics of subjects (mean, S.D., range)

	"Normals"	"Post-Coronary" Patients	All Subjects
Age (yr)	45.4 ± 3.3	43.2 ± 8.2	44.3 ± 6.0
Height (cm)	172.8 ± 5.7	171.7 ± 5.5	172.3 ± 5.3
Weight (kg)	65.6 ± 3.3	67.0 ± 4.4	66.3 ± 3.8
Excess Weight (kg)	–0.5 ± 5.0	+0.0 ± 3.0	–0.2 ± 3.9
Aerobic power			
(l./min STPD)	3.41 ± 0.50	2.99 ± 0.41	3.18 ± 0.50
(ml./kg.min STPD)	52.0 ± 6.0	47.2 ± 5.8	49.3 ± 6.0

All subjects were given a full clinical and laboratory examination, including a sub-maximal bicycle ergometer prediction of maximum oxygen intake in the week preceding the race. The five "post-coronary" patients had also completed direct treadmill measurements of $\dot{V}O_2$ (max) previously, predictions made at that time agreeing well with the direct measurements. However, only two of the direct readings were obtained close to the timing of the laboratory race. The event was run for a four lap route of 42 Km, around roads in the vicinity of the Toronto Rehabilitation Centre. The runners set out at 8:30 a.m. on a pleasant June day; the air was almost still and a light haze reduced the radiant heat load. All competitors completed the race between 11:30 a.m. and 12:30 p.m. when the temperature had risen to 21.7°C with a relative humidity of 69%.

Subjects were allocated to three treatment groups. Three runners (a Metro Jogger & two post-coronary patients) were provided with the proprietary replacement fluid "Erg"*, four with our special fluids** (2 Joggers and 2 post-coronary patients), while the remaining 2 subjects were allowed only water.

On arrival, subjects were required to drink 200 ml of their allocated fluid, and to empty their bladders. Their clothing was weighed, and the subjects were then weighed wearing shorts, singlet, track shoes and socks. A further 200 ml of the allocated fluid was offered to the runners at 2.6 km intervals, and a careful record of actual intake was kept. Weighings were repeated eight times over the course of the race, and after completion of the event the clothing was weighed wet.

Blood samples were collected from the median antecubital vein immediately before the race, at the half-way point, and immediately on crossing the finishing tape. The four subjects drinking the special fluids contributed a further sample of venous blood one hour after completion of the run. Blood specimens were analyzed for sodium, potassium and chloride ions, glucose, blood urea nitrogen, creatine and bicarbonate, and muscle enzymes (lactate dehydrogenase, creatine phosphokinase) using standard automated biochemical procedures.

Blood pressures were measured immediately before and immediately after the event. Subjects were in the sitting position, and a standard clinical sphygmomanometer cuff was used. Rectal temperatures were measured by a clinical thermometer immediately after the race.

RESULTS

Performance

All subjects performed quite creditably, having regard to their age and medical history (Table II). The average running time for the 9 subjects was 212 min, corresponding approximately to a running speed of 12 km/hr. One of the Metro Joggers (L) showed some signs of vaso-vagal collapse after the event (pallor, sweating, retching), but none of the post-coronary patients felt any ill-effects.

The final examination showed a small decrement of both systolic and diastolic blood pressures in all subjects, but none were grossly hypotensive. The final core temperature ranged quite widely from 100.4°F to 104.4°F (38.0°C – 40.2°C), with little difference between the groups receiving "Erg", "special" fluid, and water.

If the oxygen cost of running had been as found in treadmill experiments on younger men (Shephard, 1969), our subjects would have sustained an average of 86.5% of their maximum oxygen intake over the course of the race, even higher than figures for the Boston Marathon (81% – Kavanagh & Shephard, 1974). However, running efficiencies were improved by the sustained jogging programme. Our data for the post-coronary patients showed an oxygen cost of treadmill running averaging only 87.2% of predictions from the Shephard nomogram. Dressendorfer & Scaff (1975) have also reported a road cost of 30 ml./kg.min. for well-trained cardiac patients running at a speed of 8.4 km/hr., 6% lower than predictions from the nomogram. Allowing for this greater efficiency, our runners were operating at 75.4% of their aerobic power, much as in younger marathon contestants.

Fluid Balance

All subjects lost weight progressively over the course of the race despite a steady intake of fluid (Fig. 1). As in the preliminary hyperhydration trial in Hawaii, the average loss of 2.2 Kg (Table III) was much smaller than in Boston (average loss 4.0 Kg), this reflecting in part the initial hyperhydration (0.20 l) and in part a much greater fluid intake during the race (an average of 1.59 l, as opposed to the very limited intake of 0.08 l to 0.18 l reported by six of the eight Boston runners). Despite more moderate environmental conditions, sweat loss (average 3.28 l) was only marginally less than in Boston (~ 3.5 l). Hydration of the subjects participating in the present experiment was such that 7 of the 9 subjects were able to produce some urine over the course of the race.

FOOTNOTES

* "Erg" is a proprietary hyperosmolar solution recommended by its makers for marathon runners; analysis by the authors showed the composition Na^+19 m Eq/l K^+ 10.7 m Eq/l, and glucose 5.3g/100 ml (294 mEq/l); total osmolarity is approximately 354 m Osmoles/l.

** The "special" fluid provided before and during the race was a glucose/chloride solution adjusted to be approximately isotonic with blood, containing Na^+ 21mEq/l., and glucose 4.1g/100 ml (228 mEq/l); total osmolarity was approximately 270 m Osmoles/l. After the race, the mixture was modified to Na^+ 20 mEq/l., K^+4.7m Eq/l, and glucose 4.1 g/100 ml; total osmolarity approx. 278 m Osmoles/l.

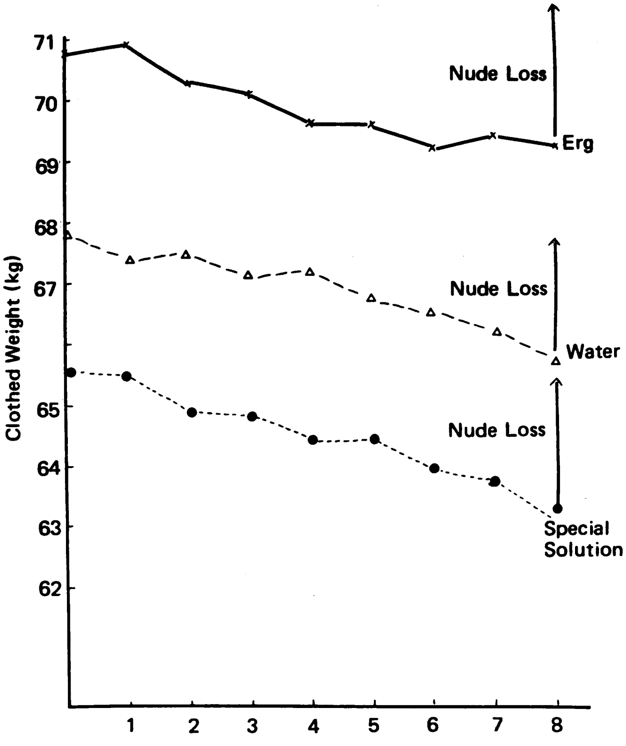

Fig. 1.
Cumulative Weight Loss over the Course of the Race.

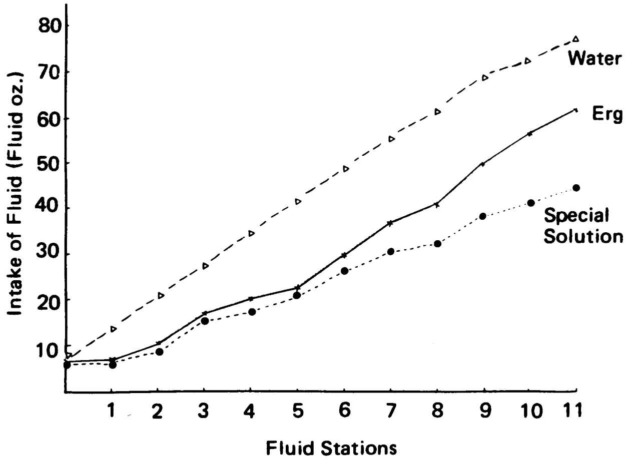

Fig. 2.
Cumulative Fluid Intake over the Course of the Race.

Comparison of the three fluids is complicated by inter-subject differences in the relative intensity of work and in the running speed. The subjects customarily drank "Erg", and the four allocated the "special" solutions found these rather bland in flavour. One of the two water drinkers (H.B.) complained that he felt much more exhausted in the final six miles than he had done in previous marathons where "Erg" was provided; however, his times were also better in the scientific marathon. In objective terms, the two water drinkers fared better than the other seven subjects, achieving the largest fluid intake (Fig. 2), the greatest urine formation, and the smallest weight loss (Table III). The highest rates of fluid intake (around 630 ml/hr) were realized by one of the water drinkers and one of the "Erg" drinkers.

Electrolyte Balance

Irrespective of the replacement fluid provided, there was a small increase of plasma sodium over the course of the race (Table IV). This occurred mainly in the second half of the run, and was greatest in the 7 subjects drinking fluids containing sodium ions. Potassium ion concentrations also rose, particularly in the first half of the race; the gain was no larger in subjects drinking the potassium fortified solution ("Erg") — indeed, the largest increments occurred in the two water drinkers. One hour after the race, blood potassium levels were depressed despite rehydration with the second special (potassium fortified) solutions.

Chloride ion concentrations increased slightly in the groups drinking "Erg" and the special solutions, but showed a slight drop in the two subjects who drank water.

Metabolites

Blood glucose readings increased over the first half of the race, and thereafter remained constant or showed a small decrease. Blood sugar readings were better sustained in the two runners who drank water than in the 7 who were given glucose-fortified solutions.

As in the Boston and Hawaii studies, blood urea rose over the race, with rather uniform increments in the two halves of the event. The largest increase was in the two subjects given the glucose-free solution; it is tempting to interpret this as indicating that these two subjects placed a greater reliance upon protein catabolism, but on the other hand, they showed a smaller increase of serum creatine than the other groups.

Blood lactates were not determined, but the occurrence of some anaerobic metabolism in all subjects may be inferred from the decrease of serum bicarbonate over the course of the race.

Serum Enzymes

All subjects showed a substantial increase of serum enzymes. This developed progressively over the course of the race (Table VI). The large change of lactate dehydrogenase in the two subjects receiving water may reflect an intense relative effort on their part.

TABLE II

Aerobic Power and Performance of Subjects in Marathon Event

Fluid Intake and Subject	**Aerobic Power (ml/kg.min)**	**Time for Marathon (min)**	**Speed km/hr**	**Rate of Working****		**Initial Blood Pressure (mm Hg)**	**Δ Over Race (mm Hg)**
				(ml/kg.min)	**% $\dot{V}O_2$ max)**		
Special Solution							
NC	59.2†	186	13.5	40.5	68.4	110/60	–10/–10
NL	47.1†	192	13.1	39.4	83.7	110/80	–30/–20
CR	55.0†	207	12.2	37.1	67.6	100/60	– 4/–10
CC	49.0†	225	12.1	37.0	75.3	128/80	–20/– 2
Mean	52.6	203	12.7	38.5	73.8	112/70	–14/–10
Erg							
NH	54.6†	182	13.8	41.2	75.3	110/70	–12/– 6
CS	38.9*	275	9.2	29.7	76.3	100/70	–20/–10
CV	46.6†	207	12.2	37.1	79.8	112/70	–20/– 2
Mean	46.7	221	11.7	36.0	77.2	107/70	–17/– 6
Water							
NH	47.0†	210	12.0	36.6	78.0	114/82	– 4/–10
HB	46.5*	226	11.2	34.7	74.6	110/80	0/– 6
Mean	46.8	218	11.6	35.7	76.1	112/81	– 2/– 8
Mean, all	49.3	212	12.1	37.1	75.4	110/72	–13.3/–8.4
Subjects	±6.0	±28	±1.4	±3.4	±5.1	±8/±9	±9.8/±5.5

† Predicted by Åstrand nomogram.

* Directly measured value.

** The estimate is based on the $\dot{V}O_2$ (max) as determined on a day of normal activity, assuming the oxygen cost of running to be 87.2% of that specified by Shephard (1969) – See text.

DISCUSSION

Hydration Although the body weight loss averaged 2.2 kg, it seems likely that there was little tissue dehydration. Indeed, the majority of subjects matched their normal daytime urine secretion of ~100 ml/hr, although much of this urine may have been formed in the early stages of the race, when the runners were still substantially hyperhydrated.

The method of estimating fluid balance has been discussed previously (Åstrand & Saltin, 1964; Kavanagh & Shephard, 1974). The total energy cost of the race is around 3700 Kcal; this is met by conversion of about 0.5 kg of foodstuffs into 0.3 kg of water and 0.73 kg of carbon dioxide. Much of the energy is derived initially from glycogen (400 g are stored within muscle fibres, 100 g within the liver); it is clear from the final blood sugar figures that not all of these reserves are exhausted over a race, but if 70% (350 g) were used by the water drinking runners, a substantial water of hydration (3g/g, 1.05 kg of water) would become available to the tissues. The true status of the water drinking subjects could thus be presented as follows:

(1)	Average weight loss	1.95 kg
(2)	Weight loss due to oxidation of food	0.20 kg
(3)	Weight loss due to sweat evaporation (1-2)	1.75 kg
(4)	Water gained from oxidation of food	0.30 kg
(5)	Water gained from breakdown of glycogen	1.05 kg
(6)	Net dehydration (3 – [4 + 5]) =	0.40 kg
(7)	Water intake	2.19 litres
(8)	Urine secretion	0.50 litres
(9)	Net fluid intake (7-8) =	1.69 litres
(10	Total sweat secretion (3 + 9) =	3.44 litres

Because of water liberated from glycogen molecules, it is likely that the water drinkers sustained a substantial weight loss without appreciable dehydration; indeed, if all of their glycogen reserves had been used, they could even have become hyperhydrated.

Under resting conditions, Hunt & Pathak (1960) and Hunt (1961) have noted that gastric emptying proceeds

TABLE III

Fluid Balance over the Course of the Marathon Race

Fluid Intake & Subject	Body Weight		Weight Loss		Fluid Intake	Urine Loss	Food Loss	Sweat* Loss	Rectal Temperature			Potential Dehydration**
	Initial	Final	Kg	%	l	l	Kg	l	Initial °C	Final °C	Δ °C	l
Special Solution												
NC	68.0	65.8	−2.2		1.40	0	0.2	3.40	36.7	38.6	1.9	
NL	60.9	58.4	−2.5		0.82	0	0.2	3.12	36.4	39.0	2.6	
CR	62.1	59.6	−2.5		1.03	0.53	0.2	2.80	37.4	39.7	2.3	
CC	66.7	64.9	−1.8		1.73	0.62	0.2	2.71	37.2	39.3	2.1	
Mean for Group	64.4	62.2	−2.25		1.25	0.29	0.2	3.01	36.9	39.2	2.3	0.70
Erg												
NH	66.5	64.3	−2.2		1.39	0.51	0.2	2.88	37.4	38.3	0.9	
CS	74.4	72.3	−2.1		2.28	0.23	0.2	3.95	36.7	40.0	3.3	
CV	68.5	65.8	−2.7		1.50	0.23	0.2	3.77	36.7	40.2	3.5	
Mean for Group	69.8	67.5	−2.33		1.72	0.32	0.2	3.53	36.9	39.5	2.6	0.78
Water												
NH	69.4	67.6	−1.8		2.29	0.52	0.2	3.37	36.9	39.4	2.5	
CB	64.2	62.1	−2.1		2.07	0.48	0.2	3.49	36.6	39.0	2.4	
Mean for Group	66.8	64.9	−1.95		2.18	0.50	0.2	3.43	36.7	39.2	2.5	0.40
Mean ± S.D. all Subjects	66.7 ±4.1	64.5 ±4.2	−2.22 ±0.30		1.59 ±0.52	0.35 ±0.24	0.2	3.26 ±0.43	36.9 ±0.36	39.3 ±0.63	2.39 ±0.7	0.67

* This is approximated by the sum of (weight loss + fluid intake) — (urine loss + food loss).

** This is approximated by (sweat loss + urine loss) — (fluid intake + 1.35 l metabolic water).

most rapidly following ingestion of saline solutions having an osmolarity of approximately 250 mO/l. In their experiments, both potassium ions and glucose molecules slowed emptying relative to pure water. Hunt explained his findings in terms of a hypothetical pyloric or duodenal osmoreceptor, shrinking when water absorption was restricted by strong glucose solutions, and expanding when penetrated by sodium ions and associated water. It is uncertain how far his hypothesis can be extrapolated to the marathon runner. Hunt's subjects ingested a single, relatively large volume of fluid (750 ml), thus ruling out the possibility of adjustments in tonicity by gastric secretion. Further, most authors have found that vigorous exercise modifies normal patterns of gastric emptying (Campbell et al, 1928; Hellebrandt & Tepper, 1934; Fordtran & Saltin, 1967). The fastest fluid intake attained by our subjects (about 630 ml/hour) was slightly less than the figure of 800-1000 ml/hour previously reported by Costill (1972). His subjects were younger, and his experiment was conducted in the laboratory; runners were required to drink 100 ml every 5 minutes to the point of gastric distention, and he comments it was unlikely that further fluid could have been imbibed beyond the 100 minute experiment; in contrast, our subjects continued to take in fluid throughout the race. The total fluid intake (~2 litres) was similar in Costill's experiment and in ours. Likewise, our data agree with his in showing marginally more absorption of water than of solutions containing 4 g-5 g glucose/100 ml. This does not seem a reflection of palatability — indeed, when given a free choice, the majority of our runners selected the "Erg", the likely basis is the osmolarity of the mixture.

The possible merit of more dilute glucose solutions (2-3 g/100 ml) remains debatable. It is possible that the negative impact of such concentrations on gastric emptying can be offset by low concentrations of sodium ions. However, the glucose content contributes little caloric support to the runner. Even if the entire imbibed dose (perhaps 50g with 2 litres of 2.5% glucose) were metabolized, the caloric yield (< 200 K Cal) would be of

TABLE IV

Changes in blood electrolytes over course of marathon race. Samples obtained (1) immediately prior to race, (2) at mid-point, (3) immediately after race, and (4) one hour later.

Fluid Intake and subject (N = "normal", C=post-coronary)	**Na$^+$ (mE/l.)**					**K$^+$ (mE/l)**					**Cl' (mE/l.)**				
	(1)	**(2)**	**(3)**	**Δ 1→3**	**(4)**	**(1)**	**(2)**	**(3)**	**Δ 1→3**	**(4)**	**(1)**	**(2)**	**(3)**	**Δ 1→3**	**(4)**
Special Solution															
NC	149	146	150	+1.0	149	4.4	4.7	5.0	+0.6	4.1	103	103	104	+1.0	102
NL	143	146	148	+5.0	–	5.0	4.9	5.0	0.0	–	102	104	105	+3.0	–
CR	145	145	147	+2.0	147	5.8	5.1	6.1	+0.3	4.5	105	106	105	0.0	105
CC	144	146	148	+4.0	146	4.7	4.8	5.1	+0.4	4.5	106	108	106	0.0	105
Mean	145.3	145.8	148.3	+3.0	147.3	5.0	4.9	5.3	+0.3	4.4	104.0	105.3	105.0	+1.0	104
Erg															
NH	145	147	148	+3.0	–	4.2	4.8	4.6	+0.4	–	104	106	105	+1.0	–
CS	149	147	149	0.0	–	5.0	5.0	5.1	+0.1	–	105	106	107	+2.0	–
CV	147	144	150	+3.0	–	4.0	4.7	4.7	+0.7	–	100	102	107	+7.0	–
Mean	147.0	146.0	149.0	+2.0	–	4.4	4.9	4.8	+0.4	–	103.0	104.7	106.3	+3.3	–
Water															
NH	145	144	145	+0.0	–	4.6	5.5	5.4	+0.8	–	104	104	103	–1.0	–
CB	144	145	147	+3.0	–	4.7	5.0	5.1	+0.4	–	105	105	103	–2.0	–
Mean	144.5	144.5	146.0	+1.5	–	4.7	5.3	5.3	+0.6	–	104.5	104.5	103.0	–1.5	–
Mean all subjects	145.6	145.6	148.1	2.5		4.71	4.94	5.12	0.41		103.8	104.9	105.0	1.2	
S.D.	±2.2	±1.1	±1.5	±1.7		±0.53	±0.25	±0.44	±0.26		±1.9	±1.8	±1.5	±2.6	

minor importance. It might serve to spare an equivalent quantity of glycogen, but at the same time the body would be denied the 150 ml water of hydration that otherwise would have been liberated from the glycogen. It is furthermore uncertain that the active muscle fibres can absorb glucose from the blood stream when exercising at marathon intensities ($>$ 75% of aerobic power). While Bagby & Gollnick (1975) argue that blood-borne glucose makes a substantial contribution to metabolism in the vigorously exercising rat, others (Van Handel et al, 1975) have found as little as 2% of dilute (2.5 g/100 ml) glucose solutions are absorbed and oxidized in the third hour of quite modest effort ($\sim$50% of aerobic power). Presumably, there are circumstances where high intracellular concentrations of glucose-6-phosphate together with blood-borne catecholamines are sufficient to inhibit the hexokinase activity of the muscle cell membrane.

Despite relatively pleasant weather conditions and vigorous efforts at sustaining body hydration, the majority of the runners showed a substantial elevation of core temperature over the course of the race. Furthermore, there were no great differences of temperature between well-hydrated and less well-hydrated runners. In a competitive situation, it would seem that the thermal advantages of more complete hydration can easily be dissipated by running at a slightly faster pace.

Electrolytes Several imponderables limit the precision of electrolyte balance sheets — we do not know the precise ionic loss in either sweat or urine, nor do we know the extent of any exchange of metallic ions between the normal "sodium space' and intracellular fluids. It is a little surprising that sodium ion concentrations rise in the water drinkers, since they are but little dehydrated, and each litre of sweat replaced by water robs the body of some 30mE of sodium ions. Whatever the explanation, it implies that it is unnecessary and even undesirable to incorporate sodium ions into fluids administered during a race. In our experiments, the "Erg" drinkers received some 39mE of Na$^+$, and the special solution drinkers 32mE of Na$^+$; in consequence, their final plasma composition was 1.0-1.5mEq/l more abnormal than that of the men drinking pure water.

TABLE V

Changes in blood glucose, blood urea nitrogen, bicarbonate and creatine over marathon race. Samples obtained (1) before the race, (2) at the half-way point, (3) immediately after finishing the race, and (4) one hour later

Fluid Intake and subjects (N = "normal", C = post-coronary)	**Blood Glucose (mg/100 ml)**					**Blood Urea Nitrogen (mg/100 ml)**					**Bicarbonate**					**Creatine**				
	(1)	(2)	(3)	Δ 1→3	(4)	(1)	(2)	(3)	Δ 1→3	(4)	(1)	(2)	(3)	Δ 1→3	(4)	(1)	(2)	(3)	Δ	(4)
Special Solution																				
NC	78	123	116	38	78	20	20	21	+1	21	22	20	21	−1	21	1.0	1.2	1.3	0.3	1.2
NL	96	128	110	14	93	13	14	17	+4	–	21	21	23	+2	–	1.0	1.2	1.3	0.3	–
CR	106	120	114	8	86	18	21	20	+2	21	22	21	22	0	20	1.1	1.1	1.1	0.0	1.1
CC	116	114	102	−14	100	18	17	17	−1	18	20	18	20	0	22	1.0	1.0	1.1	0.1	1.1
Mean	99	120.5	110.5	11.5	89.3	17.3	18.0	18.8	+1.5	20	21.3	20.0	21.5	+0.2	21	1.03	1.13	1.20	0.17	1.13
Erg																				
NH	93	96	104	11	–	21	20	22	+1	–	21	21	20	−1	–	1.1	1.1	1.3	0.2	–
CS	75	98	106	31	–	21	29	32	+11	–	20	19	16	−4	–	1.0	1.5	1.9	0.9	–
CV	68	113	97	29	–	22	24	26	+4	–	20	20	18	−2	–	0.9	1.0	1.3	0.4	–
Mean	78.7	102.3	102.3	23.7	–	21.3	24.3	26.7	+5.4	–	20.3	20.0	18.0	−2.3	–	1.00	1.20	1.50	0.50	–
Water																				
NH	65	111	104	39	–	18	20	21	+3	–	23	19	18	−5	–	1.0	1.0	1.1	0.1	–
CB	98	116	125	27	–	13	13	15	+2	–	20	16	20	0	–	0.9	1.0	1.0	0.1	–
Mean	81.5	113.5	114.5	33.0	–	15.5	16.5	18.0	+2.5	–	21.5	17.5	19.0	−2.5	–	0.95	1.00	1.05	0.10	–
Mean, all subjects	88.3	113.2	108.7	20.3		18.2	19.8	21.2	3.0		21.0	19.4	19.8	−1.2		1.00	1.12	1.27	0.27	
S.D.	±17.7	±10.6	±8.5	±17.2		±3.3	±4.9	±5.2	±3.4		±1.1	±1.7	±2.2	±2.2		±0.07	±0.16	±0.26	±0.27	

TABLE VI

Elevation of lactic dehydrogenase and creatine phosphokinase over the course of the marathon. Samples obtained (1) before the race, (2) at the mid-point, (3) at the end of the race, and (4) one hour later

Fluid Intake and subject (N = "normal", C = post-coronary)	**Lactic dehydrogenase Units/100 ml**					**Creatine phosphokinase Units/100 ml**				
	(1)	**(2)**	**(3)**	**Δ**	**(4)**	**(1)**	**(2)**	**(3)**	**Δ**	**(4)**
Special Solution										
NC	114	138	184	70	184	4	6	9	5	10
NL	118	148	176	58	167	3	4	6	3	8
CR	163	217	222	59	238	5	8	11	6	12
CC	134	146	170	36	152	4	6	8	4	8
Mean	132.3	162.3	188.0	55.7	185.3	4.0	6.0	8.5	4.5	9.5
Erg										
NH	173	199	217	44	–	6	8	12	6	–
CS	118	152	182	64	–	4	6	8	4	–
CV	130	154	184	54	–	3	4	6	3	–
Mean	140.0	168.0	194.0	54.0	–	4.3	6.0	8.7	4.4	–
Water										
NH	166	194	257	91	–	7	10	6	–1	–
CB	133	186	279	146	–	4	6	12	+8	–
Mean	149.5	190.0	268.0	118.5	–	5.5	8.0	9.0	3.5	–
Mean, all subjects	138.8	170.4	207.0	69.1		4.4	6.4	8.7	4.3	
S										
S.D.	±22.7	±28.6	±38.8	±32.8		±1.3	±1.9	±2.5	±2.5	

The increase of serum K^+ concentrations over the race reflects a steady ionic leakage from heavily exerted and hypoxic muscle fibres; again, the phenomenon is shown by the water drinkers, and it would thus seem inappropriate to administer potassium ions during a race. The practice would have a little more theoretical justification in the recovery period, when muscle potassium stores are being replenished, although even at this stage, it is difficult to show a specific advantage in subjects receiving potassium fortified solutions (Costill, 1975). The "Erg" solution provided our runners with approximately 21mE of potassium ions over the course of the race, and it is surprising that this group of subjects did not show a greater elevation of potassium levels than those those drinking water or the special solution. Possibly the unwanted potassium ions were not absorbed from the gut. A second factor is that the water-drinkers put forth a greater effort relative to their aerobic powers. Some authors have linked potassium leakage with glycogen depletion (Fenn, 1939); however, the present difference can hardly be ascribed to the glucose content of the ingested fluids, since there was little difference of blood sugar levels between the three groups of subjects.

The chloride figures for the two water drinkers show a slight fall. Factors contributing to this include the replacement of chloride containing sweat by water, and a "chloride shift" associated with intracellular acidosis. From the practical point of view, the "error" in the final plasma composition is again no greater than that occurring in the opposite sense in subjects receiving chloride containing fluids.

Metabolites Since blood sugar levels were sustained at least as well in the subjects drinking water as in those that received "Erg" or special solution, there would seem few metabolic advantages from drinking glucose solutions over the marathon distance. Liver supplies of glycogen were plainly not exhausted, and the slight fall of average blood glucose figures from the mid-point to the end of the race ($P < 0.3$) did not suggest that reserves were substantially depleted.

As in our previous studies, all subjects showed an increase of blood urea, suggesting some protein breakdown. Since most subjects secreted some urine, it is not possible to quantitate the protein breakdown; in the Boston marathon, we estimated this at less than 50g

(200 Kcal). Although the rise of blood urea was a little greater in the water drinkers, we do not suggest the glucose solutions had any appreciable protein sparing effect since they did not elevate the blood glucose, nor were there significant differences of plasma creatine levels between water and glucose drinkers.

Enzymes The large increases of serum enzymes have been reported in other series of marathon runners, including our Boston and Hawaii contestants. However, it is perhaps worth stressing that this effect of recent vigorous exercise could lead to an erroneous diagnosis of myocardial infarction in a middle-aged patient, particularly if there is a history of some previous ischaemic heart disease.

Choice of fluid for the athlete The American College of Sports Medicine has recently published a "position-paper" recommending that replacement fluids for the marathon runner contain less than 2.5 g/100 ml of glucose, less than 20 mE of Na^+, and less than 5 mE K^+. The present paper, while not contradicting this recommendation, suggests there may be much in favour of the use of plain water. Specifically:

(a) Glucose solutions are not necessary to sustain blood glucose levels — indeed, by slowing gastric emptying and possibly also by sparing body glycogen reserves, they may encourage dehydration, leading to a poorer relative performance than that attained by water drinkers.
(b) Potassium ions are not needed to sustain serum potassium levels during a race (although they may have value in the recovery period when muscle potassium reserves are being replenished). Like glucose, potassium ions also have an adverse effect on gastric emptying.
(c) Sodium ions are not needed during a race; indeed, the most normal levels of serum Na^+ are seen in subjects drinking water.

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