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PRE-EXERCISE HYPERVOLEMIA AND CYCLE ERGOMETER ENDURANCE IN MEN

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Time to exhaustion at 87 - 91% of peak $\dot{V}O_2$ was measured in 5 untrained men (age: 31 ± 8 years, body mass: 74.20 ± 16.50 kg, body surface area: 1.90 ± 0.24 m², peak $\dot{V}O_2$: 2.87 ± 0.40 l min⁻¹, plasma volume: 3.21 ± 0.88 l; means \pm SD) after consuming nothing (N) or two fluid formulations (10 ml \cdot kg⁻¹, 743 ± 161 ml): Performance 1 (P1), a multi-ionic carbohydrate drink, containing 55 mEq \cdot l⁻¹ Na⁺, 4.16 g \cdot l⁻¹ citrate, 20.49 g \cdot l⁻¹ glucose, and 365 mOsm \cdot kg⁻¹ H₂O, and AstroAde (AA), a sodium chloride-sodium citrate hyperhydration drink, containing 164 mEq \cdot l⁻¹ Na⁺, 8.54 g \cdot l⁻¹ citrate, <5 mg \cdot l⁻¹ glucose, and 253 mOsm \cdot kg⁻¹ H₂O. Mean (\pm SE) endurance for N, P1 and AA was 24.68 ± 1.50 , 24.55 ± 1.09 , and 30.50 ± 3.44 min, respectively. Percent changes in plasma volume (PV) from -105 min of rest to zero min before exercise were $-1.5 \pm 3.2\%$ (N), $0.2 \pm 2.2\%$ (P1), and $4.8 \pm 3.0\%$ (AA; $P < 0.05$). The attenuated endurance for N and P1 could not be attributed to differences in exercise metabolism ($\dot{V}E$, RE, $\dot{V}O_2$) from the carbohydrate or citrate, terminal heart rate, levels of perceived exertion, forehead or thigh skin blood flow velocity, changes or absolute termination levels of rectal temperature. Thus, the higher level of resting PV for AA just before exercise, as well as greater acid buffering and possible increased energy substrate from citrate, may have contributed to the greater endurance. *(Biol. Sport 14:103-114, 1997)*

Key words: Fluid intake composition - Electrolytes - Glucose - Citrate - Exercise

Introduction

Exercise performance may be impaired when body (fluid) mass is reduced by 1.0 - 1.8% [8,36]. It is well established that fluid ingestion is necessary to maintain extended physical exercise, particularly in a hot environment [1,15,25,33]. It is unclear whether additives such as carbohydrates (sucrose, fructose, glucose, glucose polymers, maltodextrin), electrolytes (Na⁺, K⁺, Cl⁻, Mg²⁺, Ca²⁺, P⁴⁺), buffering agents such as citrate, or glycerol are useful for extending exercise endurance [25,29].

Some evidence indicates that feeding carbohydrates before and/or during exercise [3,11, 23,28,29,31], and infusion of dextran in saline before exercise [21], increase exercise endurance; but other data [23,24,29,32,33,37] indicate that carbohydrate loading has no effect on endurance. Below *et al.* [3] found that fluid and carbohydrate ingestion increased endurance performance independently, and that their effects were additive. Maughan *et al.* [23] reported greater endurance with an isotonic glucose-electrolyte (Na^+ , K^+ , Cl^- , HCO_3^-) solution compared with water or nothing.

On the other hand, some evidence indicates that ingestion of saline vs. water [2,33], or infusion of isotonic saline vs. no infusion [7], have no effect on endurance. However, Walsh *et al.* [36] have found increased endurance after ingestion of $20 \text{ mmol} \cdot \text{l}^{-1}$ NaCl vs. no fluid intake, before and during a moderately heavy exercise. Here again, carbohydrate depletion was probably not a critical factor. While glycerol ingestion can increase body mass and total body water [9,22,35], there is essentially no evidence that glycerol taken with water [11,24], or with a carbohydrate-electrolyte beverage [30], affects physical performance parameters or endurance. Apparently endurance has not been studied intensively following citrate ingestion [34].

The purpose for this study was to determine whether pre-exercise hypervolemia induced by consumption of two fluid formulations (AstroAde or Performance 1) would increase exercise endurance when compared with no fluid intake. Various fluid formulations were tested in a prior study for their ability to hyperhydrate six euhydrated men at rest [17]. One month later, 5 of those subjects participated in the present study where submaximal exercise endurance (87 - 91% $\dot{V}\text{O}_2$ peak) was measured following consumption of either Performance 1 or AstroAde, the formulations with a greater hypervolemic effect than other ones [17].

Material and Methods

Subjects: Five men gave written informed consent to participate in this study which was approved by the Ames Research Center (ARC) and the San Francisco State University Human Subject's Committees, and conducted in the ARC Laboratory for Human Environmental Physiology. The subjects passed a comprehensive medical examination including medical history, blood and urine analyses, and a treadmill exercise test. All were non-smokers and none took drugs. Their mean (\pm SD) anthropometric and physiological characteristics were: age 31 ± 8 years, body height 182 ± 8 cm, body mass 74.20 ± 16.50 kg, body surface area (BSA) 1.90 ± 0.24 m², plasma volume 3.21 ± 0.88 l, blood volume 75 ± 15 ml kg⁻¹. Peak metabolic data were: load 1520 ± 239 kg \cdot min⁻¹, heart rate (HR) 184 ± 19 beats \cdot min⁻¹, $\dot{V}\text{E}_{\text{BTPS}}$ 121.5 ± 10.2 l \cdot min⁻¹, $\dot{V}\text{O}_2$ 2.87 ± 0.40 l \cdot min⁻¹ or 40 ± 11 ml \cdot min⁻¹ kg⁻¹, R_E 1.25 ± 0.10 .

Procedure: The experimental design involved three seated, cycle ergometer endurance tests to exhaustion at 7-day intervals and conducted at the same time of day for each subject. Each test was preceded by consumption of a multi-electrolyte carbohydrate rehydration drink (Performance 1, P1), a specially formulated non-carbohydrate hyperhydration drink (AstroAde, AA; see Table 1), or nothing (N), applied in a counter-balanced design. The experimental protocol (Fig. 1) consisted of intermittent drinking (10 ml kg⁻¹) during the 90 min sitting resting phase, a 15-min period to move to the cycle to equilibrate and re-adjust sensors, and then the endurance test - cycle ergometer exercise at 87 to 91% of $\dot{V}O_2$ peak until exhaustion (volitional fatigue and failure to maintain the 70 rpm cadence). Resting baseline plasma volume (PV) was measured two months before testing.

Constituent	AA	P1
Na ⁺ (mEq·l ⁻¹)	164	55
K ⁺ (mEq·l ⁻¹)	<0.1	5.3
Osmolality (mOsm·kg ⁻¹ H ₂ O)	253	365
Glucose (g·l ⁻¹)	<0.005	20.49
Citrate (g·l ⁻¹)	8.54	4.16

Table 1
Measured concentrations of drink solutes
AA - AstroAde; P1 - Performance 1

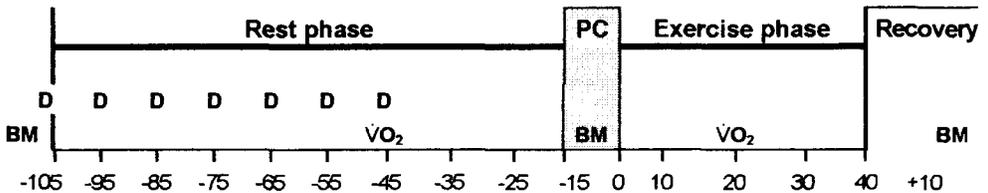


Fig. 1
Experimental protocol. Measurements: BM - Body mass; $\dot{V}O_2$ - Oxygen uptake; D - Drinking (1/7 of total volume); PC - Position change

The subjects reported at the laboratory at least two hours after having eaten. Upon arrival (-105 min) they urinated, inserted a rectal thermistor 16 cm, and were weighed in shorts on a digital scale (5780, National Controls, Inc., San Carlos CA) with an accuracy of 5 g; dry shorts were weighed separately. Skin temperature thermistors, EKG electrodes and laser-Doppler sensors were attached. Body mass was measured at -105 min, -15 min, and immediately after the endurance test (Fig. 1). Wet shorts were weighed after exercise and body mass was corrected accordingly.

Mean (\pm SD) room dry-bulb temperature and relative humidity were: $20.8 \pm 1.1^\circ\text{C}$ and $54.4 \pm 5.2\%$, respectively, at rest and $21.3 \pm 0.9^\circ\text{C}$ and $55.7 \pm 3.5\%$, respectively, during exercise. Fan-air flow over the subject was $7.0 - 8.8 \text{ m} \cdot \text{min}^{-1}$ at rest and $16.4 - 19.5 \text{ m} \cdot \text{min}^{-1}$ at 10 min during exercise. Barometric pressure ranged from 765.2 ± 1.1 to 766.8 ± 1.3 Torr.

Fluid formulations and drinking: Both AA and P1, prepared in powder form and packaged in the Shaklee Laboratories, were mixed with water on every test day. Performance 1 contained $32.5 \text{ mEq} \cdot \text{l}^{-1}$ of various ionic constituents (Na^+ , K^+ , Cl^- , Mg^{2+} , Ca^{2+} , P^{4+}), 9.72% carbohydrates (glucose, fructose, maltodextrins), and $1.9 \text{ g} \cdot \text{l}^{-1}$ of sodium citrate; AA contained only NaCl, sodium citrate, Aspartame (sweetener) and no carbohydrates; drink osmolalities were 365 (P1) and 253 (AA) $\text{mOsm} \cdot \text{kg}^{-1} \text{ H}_2\text{O}$ (Table 1). The subjects drank these two formulations ($10 \text{ ml} \cdot \text{kg}^{-1}$, $743 \pm 72 \text{ ml}$, range = 555 - 997 ml), divided into seven aliquots, at 10 min-intervals from -105 min to -35 min of the rest phase (Fig. 1). The intake of sodium citrate was $5.7 \text{ g} \cdot \text{kg}^{-1}$ body mass with AA, and $1.4 \text{ g} \cdot \text{kg}^{-1}$ with P1.

Physiological measurements: After three familiarisation sessions, the heart rate, submaximal $\dot{V}\text{O}_2$ and associated metabolic data were measured with a standard procedure [16] at -45 min of the rest phase, and at 20 min during exercise (Fig. 1).

Skin blood flow velocity was measured on the left forehead (temple) and left anterior-medial thigh with a LaserFlo blood perfusion monitor (BPM 403A, TSI Inc., StPaul MN).

Rectal and skin temperatures were measured with thermistors (Series 400, Yellow Springs Instrument Co., Yellow Springs OH). Signals from the rectal thermistor and skin thermistors, attached with holders that permitted free movement of air, were monitored via computer with a Squirrel meter-logger (Grant 200, Science/Electronics Inc., Miamisburg OH). Mean skin temperature was estimated from the formula [18]:

$$\bar{T}_{\text{sk}} = 0.06 \cdot T_{\text{arm}} + 0.13 \cdot T_{\text{forearm}} + 0.21 \cdot T_{\text{thigh}} + 0.21 \cdot T_{\text{calf}} + 0.19 \cdot T_{\text{chest}} + 0.20 \cdot T_{\text{back}}$$

Resting plasma volume (PV) was measured 2 months previously with a modified Evans blue dye (T-1824, New World Trading Corp., DeBary FL) dilution technique from the 10-min post-dye injection blood sample [13]. Plasma was applied to pre-packed chromatographic columns (PD-10, Sephadex G-25M, Pharmacia LKB, Sweden) and the eluate was read at 615 nm. The following formula was employed:

$$\text{Blood volume} = \text{PV} \cdot [100 / (100 - \text{Hct} \cdot 0.96 \cdot 0.91)]$$

Percent change in PV was calculated with the Hb and Hct transformation equation; haemoglobin was measured by cyanomethemoglobin method with the use of Coulter Hemoglobinometer (Coulter Electronics, USA), and hematocrit (Hct) from the mean values of four microcapillary tubes centrifuged for 10 min at 11500 rpm and read with a modified tube reader [13].

Perceived exertion: A modified rated perceived exertion (RPE) scale [4], in increments from 7 (very, very light) to 20 (very, very hard), was used at 5 min intervals during and immediately after exercise.

Statistical analysis: Data were analysed with Student's t-test for dependent samples. Significance level was $P \leq 0.05$. The results were expressed as means \pm SE, unless indicated otherwise.

Results

Mean time to exhaustion with AstroAde (30.50 ± 3.44 min) was greater than those with Performance 1 (24.55 ± 1.09 min) or Nothing (24.68 ± 1.50 min; cf. Table 2 and Fig. 2, left panel). Mean percent difference in plasma volume (%DPV) values just before position change at -15 min were approximately +7.8% ($P < 0.05$) with (AA), +4.8% ($P < 0.05$) with P1 and +1.6% with N (Table 2; Fig. 2, left panel). After the subjects sat on the cycle for 15 min, the %DPV had decreased with all treatments: AA from +7.8 to $+4.8 \pm 3.0\%$, P1 from +4.8 to $+0.2 \pm 2.2\%$, and N from +1.6 to $-1.5 \pm 3.2\%$, just before the exercise commenced.

Table 2

Mean (\pm SD) values of exercise load, endurance and rated perceived exertion for the 3 treatments studied

Exercise load ($\text{kpm} \cdot \text{min}^{-1}$)	Endurance			Perceived exertion					
	AA	P1	N	AA		P1		N	
				5 min	End	5 min	End	5 min	End
1060 ± 167	$30.50 \pm 7.69^*$	24.55 ± 2.43	24.68 ± 3.36	13 ± 1	19 ± 1	13 ± 2	18 ± 1	13 ± 1	18 ± 0

AA - AstroAde; P1 - Performance 1; N - Nothing; End - Exhaustion; * Significantly different from the respective value for N ($P < 0.05$)

Mean rated perceived exertion scores among the three treatments at 5 min during exercise were 13 points, and 18 - 19 points at the end of exercise (Table 2). Mean end exercise heart rates (170 ± 13 to 173 ± 9 $\text{beats} \cdot \text{min}^{-1}$) were not different, while the mean heart rate changes during exercise (AA = 77 ± 19 ; P1 = 96 ± 10 ; N = 102 ± 16 $\text{beats} \cdot \text{min}^{-1}$) were not significantly different from each other (Fig. 3): heart rate after AA tended to be lowest and after N - highest, as would be expected.

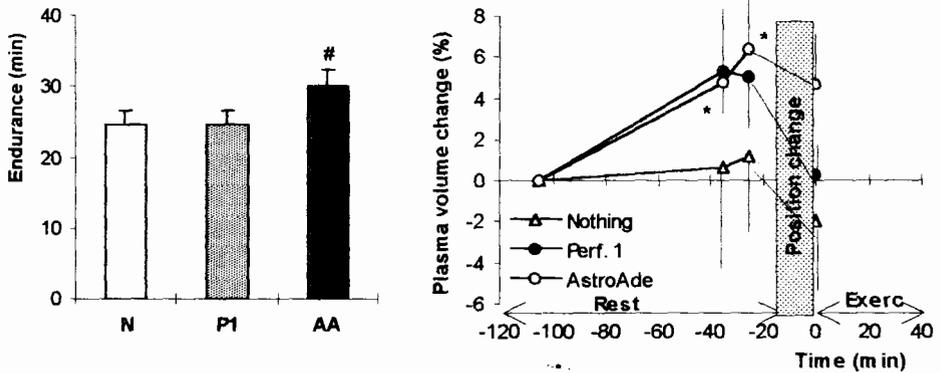


Fig. 2

Mean (\pm SE) duration of endurance ergometer work (left panel) and relative changes in plasma volume at rest and during exercise following the 3 treatments (right panel): N (nothing), P1 (Performance 1) and AA (AstroAde).

Significantly different from the value in N; * Significantly different from zero (all $P < 0.05$).

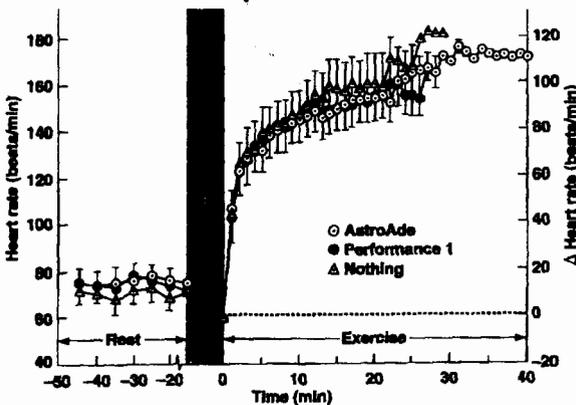


Fig. 3

Mean (\pm SE) values at rest and changes in the heart rate during exercise following the 3 treatments.

Data without SE bars are from one subject. Note time discontinuity on X-axis. Values between 0 and 40 min are differences (Δ).

There were no significant differences in the endurance exercise metabolic parameters for the three treatments: ventilation (STPD; 69.73 - 73.39 $l \cdot min^{-1}$), R_E (1.01 - 1.02) and $\dot{V}O_2$ (2.49 - 2.60 $l \cdot min^{-1}$ or 35.3 to 35.8 $ml \cdot min^{-1} \cdot kg^{-1}$) were uniformly consistent and appropriate for this relative exercise intensity.

Mean resting rectal temperature (T_{re}) for the three treatments was within the normal range of 36.8 to 37.0°C (Fig. 4, upper panel). The rate of rise for all T_{re} was virtually identical for the first 20 min of exercise. Mean end exercise temperatures were 37.76 \pm 0.12°C (N), 37.88 \pm 0.11°C (P1), and 38.10 \pm 0.25°C (AA).

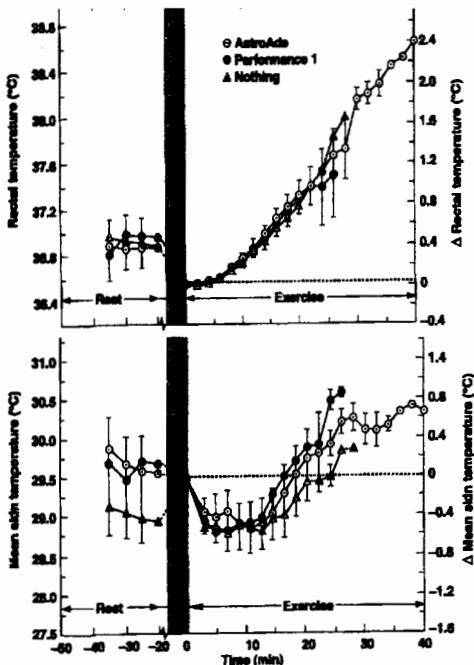


Fig. 4

Mean (\pm SE) values at rest and changes during the exercise following the 3 treatments: rectal temperature (upper panel) and mean skin temperature (lower panel).

Data without SE bars are from one subject. Note time discontinuity on X-axis. Values between 0 and 40 min in the left panels are differences (Δ).

Subject PED with the highest peak $\dot{V}O_2$ also had the highest termination T_{re} : 38.22°C (N), 38.28°C (P1) and 38.94°C (AA). In general, the longer the subject exercised the higher was his termination T_{re} ; but termination levels of T_{re} (all below 39°C) did not appear to limit endurance.

Average values of resting \bar{T}_{sk} for the three treatments were also within the normal range of 29 to 30°C (Fig. 4, lower panel). Mean skin temperature decreased uniformly over the initial 10 min of exercise from the increased air flow and sweat evaporation, and increased continuously thereafter. Mean termination \bar{T}_{sk} values for the 5 subjects were not different: 29.18 \pm 0.35°C (N), 30.08 \pm 0.16 (P1) and 29.83 \pm 0.35°C (AA). Changes in \bar{T}_{sk} appeared to plateau near termination with N increasing to about zero, AA to about +0.5°C, and P1 to about +0.8°C.

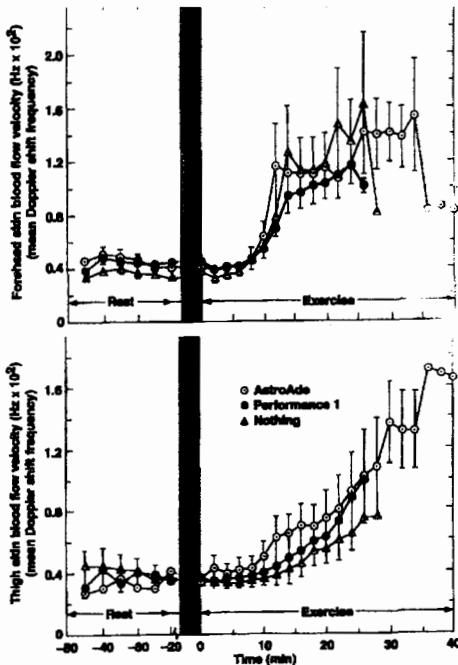


Fig. 5

Mean (\pm SE) values at rest and during exercise in skin blood flow velocity following the 3 treatments: forehead (temple) - upper panel and thigh - lower panel.

Resting velocity of blood flow in the forehead (temple) skin varied from 0.3 to 0.5 Hz·10² (Fig. 5, upper panel). It was essentially unchanged for the first 8 min of exercise, and then increased to reach 1.2 - 1.6 Hz·10² near termination. Mean terminal velocities were alike for all treatments: 1.04±0.28 (AA), 1.01±0.15 (P1) and 1.21±0.32 Hz·10² (N). Subject PED with the highest peak $\dot{V}O_2$ had terminal velocities of 2.12 (AA), 1.54 (P1), and 2.37 Hz·10² (N); they were 1.5 - 2.0 fold greater than those of other subjects.

Thigh skin blood flow velocity at rest also varied from 0.3 to 0.5 Hz·10² (Fig. 5, lower panel). It was also essentially unchanged for the first 8 min of exercise, and then increased to reach 1.0 - 1.4 Hz·10², slightly lower than forehead termination levels.

Average values of resting \bar{T}_{sk} for the three treatments were also within the normal range of 29 to 30°C (Fig. 4, lower panel). Mean skin temperature decreased uniformly over the initial 10 min of exercise from the increased air flow and sweat evaporation, and increased continuously thereafter. Mean termination \bar{T}_{sk} values for the 5 subjects were not different: 29.18±0.35°C (N), 30.08 ±0.16 (P1) and 29.83±0.35°C (AA). Changes in \bar{T}_{sk} appeared to plateau near termination with N increasing to about zero, AA to about +0.5°C, and P1 to about +0.8°C.

Discussion

The ultimate test of any rehydration or hyperhydration fluid formulation is whether it indeed does what it was designed to do. Most formulations have been designed to enhance restoration of body fluid losses from sweating during exercise [25,29] with the well documented conclusion that body dehydration decreases exercise performance [1,33].

Both AA and P1 significantly increased resting plasma volume in the present study when consumed within 5 min as a bolus [14], and when taken intermittently in aliquots during the pre-exercise rest period. So the timing of our fluid administration did not appear to alter the level of resting hypervolemia.

The significantly greater endurance (by 20%) with AstroAde was unexpected because it contained no energy substrates except citrate. The lower and similar endurance recorded with P1 and N was also unexpected because P1 contained multi-carbohydrates in addition to a lower level of citrate. In agreement with the results of other studies, these attenuated endurance times could not be attributed to differences in exercise metabolic variables ($\dot{V}O_2$, $\dot{V}E$, R_E), to terminal heart rates or levels of perceived exertion, or to thermal factors such as skin blood flow velocities and the change or absolute termination levels of mean skin and rectal temperatures.

Increased endurance and work performance following citrate ingestion [6,20,26,27] has been attributed to its alkalisng (buffering) effect on the exercise-induced acidosis.

McNaughton [26] reported a greater work output and peak power during a one-min ergometer endurance test with sodium citrate given at a dose of 0.5 g kg^{-1} per 400 ml fluid, when compared with doses of 0.1 to 0.4 g kg^{-1} , and significantly increased peak power during 120 and 240 s exercise trials, but not during 10 - 20 s trials with 0.5 g kg^{-1} sodium citrate [27].

The doses of sodium citrate consumed during the rest phase in the present study were 5.7 g kg^{-1} with AA and 1.4 g kg^{-1} with P1, both greater than those doses used previously. Plasma citrate concentrations before drinking at -105 min and after drinking just before exercise (0 min) were 17 ± 2 and $23 \pm 3 \text{ g l}^{-1}$, respectively, with P1, and 18 ± 2 and $34 \pm 3 \text{ g l}^{-1}$, respectively, with AA. It is clear that plasma citrate concentrations are not quantitatively related to intake doses. While pre-drinking plasma citrate concentrations were similar with AA and P1 (18 and 17 g l^{-1} , respectively), the over 4-fold greater intake of sodium citrate with AA resulted in an increase in plasma citrate concentration only 1.5-fold, which makes questionable the use of intake doses alone, rather than plasma concentration, when studying physiological effects.

Because citric acid can be converted to glucose in the liver, an increased carbohydrate availability in addition to the endogenous carbohydrate stores, may have contributed to the increased endurance following AA ingestion. But P1, which was associated with a somewhat lower plasma citrate concentration, contained 9.7% of mixed, available carbohydrates (glucose, fructose, maltodextrin) at a plasma glucose level of 20.49 g l^{-1} . Thus, it appears that an enhanced carbohydrate availability did not improve endurance.

Fluid ingestion *per se* appears to significantly reduce the net muscle glycogen utilisation during prolonged submaximal exercise (at 67% peak $\dot{V}O_2$ for 2 h) [19] which would tend to prolong endurance; but equal fluid ingestion volumes with the AA and P1 treatments would negate this mechanism. Another possible explanation for the greater endurance with AA could be from its hypervolemic effect on cardiovascular efficiency, e.g. a greater cardiac output.

These results indicate that the greater endurance with AA cannot be attributed to different levels of perceived exertion, or to some metabolic ($\dot{V}E$, $\dot{V}O_2$, R_E), cardiovascular (heart rate, peripheral blood flow velocity), or body temperature (T_{sk} , T_{re}) responses. Perhaps factors activated by the greater pre-exercise hypervolemia, induced by the greater ionic content of AstroAde, contributed to the increased endurance.

One rather unique situation is that of astronauts in microgravity who are euhydrated with a concomitant 1 - 4% reduction in total body water [12]. This total body hypohydration and hypovolemia have been associated with, and probably contribute to, the general re-entry syndrome (GRS) characterised by fatigue, adverse pre-syncopal signs and symptoms including gastrointestinal discomfort with occasional emesis and syncope, and gen-

eral debilitation during and after landing [10]. There is some evidence that consumption of NaCl and water before re-entry attenuates the GRS during re-entry and ameliorates adverse orthostatic cardiovascular responses after landing [5].

It is possible that the facilitation of long-duration exercise performance will be enhanced by consumption of fluids of different compositions, both before and during exercise, to accommodate the changing physiological conditions.

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