NASA Technical Memorandum 4650

Drink Composition and Cycle-Ergometer Endurance in Men: Carbohydrate, Na^+, Osmolality

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Summary

Cycle-ergometer endurance performance was determined in 5 untrained men (22–39 yr, 62.4–100.5 kg, 29–55 mL $\times$ min^{-1} $\times$ kg^{-1} peak oxygen uptake) after consuming Nothing (N) or two fluid formulations (10 mL $\times$ kg^{-1}, 555–998 mL). Performance 1 (P1), a multi-ionic-glucose rehydration drink, contains 55 mEq/L Na^+, 416 mg/dL citrate, 2,049 mg/dL glucose, and 365 mOsm/kgH_2O. HyperAde (HA), a sodium chloride-citrate hyperhydration drink, contains 164 mEq/L Na^+, 854 mg/dL citrate, <0.5 mg/dL glucose, and 253 mOsm/kgH_2O. Endurance at a load of 87–91 percent of peak $\dot{V}O_2$ was 30.50 ± SE 3.44 min with HA; 24.55 ± 1.09 min with P1 ($p > 0.10$ from HA); and 24.68 ± 1.50 min with N ($p < 0.05$ from HA). The attenuated endurance performance with P1 and N could not be attributed to differences in exercise metabolism, change or absolute level of rectal and mean skin temperature, or change in perceived exertion. The greater increase in resting plasma volume with HA, compared with P1 or N, probably contributed to the greater endurance with HA.

Introduction

Supplemental consumption of mainly carbohydrate calories (glucose), in conjunction with fluid, increases endurance and work performance. Relatively few studies have combined effects of both of these important nutritional factors on physical performance. Early and more recent findings indicate that enhanced glucose ingestion does not increase treadmill exercise endurance in the heat (ref. 1) or during cycle ergometer exercise at presumably room temperature (ref. 2). On the other hand, increased fluid (water) intake (ref. 1) and the ensuing expansion of plasma and extracellular volume (ref. 3) significantly contribute to increased endurance.

The present study compares exercise endurance performance when using HA and PI, pre-exercise drinks from a former study (ref. 4), or N. HA is composed of higher electrolyte, no glucose, and lower osmotic concentration; PI contains lower electrolyte, higher glucose, and higher osmotic concentration.

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Methods

Subjects

Five men (22–39 yr, 182 ± SD 8 cm ht, 74.20 ± 16.50 kg, 2.87 ± 0.40 L/min peak $\dot{V}O_2$) (table 1) gave written informed consent to participate in this study approved by the Ames Research Center Human Research Experiments Review Board and the San Francisco State University Human Subjects Committee. The subjects passed a comprehensive medical examination including history, blood and urine analyses, and a treadmill exercise test. All were nonsmokers and none took nonprescribed drugs.

Procedure

The experimental design involved three sitting, cycle ergometer endurance tests to exhaustion at weekly intervals. Each test was preceded by consumption of a commercial rehydration drink (P1), a specially formulated hyperhydration drink (HA) (table 2), or Nothing (N). The experimental protocol (fig. 1) consisted of intermittent drinking (10 mL/kg) during the 90 min sitting resting phase, a 15-min period to move to the cycle and readjust sensors, and an endurance test (sitting, cycle ergometer exercise) at 87 to 91 percent of peak oxygen uptake to exhaustion. The three treatments were applied semirandomly. Resting blood volume was measured two months previously (ref. 4).

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Table 1. Individual anthropometric and peak metabolic data for the three endurance treatments

	Anthropometric data							Peak metabolic data						
Subject	Age, yr	Ht, cm	Wt., kg	S.A., m^2	Plasma volume, mL	Blood volume, mL	Blood volume, mL/kg	Exercise load, kgm/min	Heart rate, b/min	$\dot{V}_{E_{STPD}}$, L/min	$\dot{V}_{E_{BTPS}}$, L/min	$\dot{V}O_2$, L/min	$\dot{V}O_2$, mL/min/kg	R_E
CAL	24	186	67.42	1.90	3,609	6,286	94	1,400	193	104.24	125.50	2.64	39	1.34
DUW	39	192	100.51	2.30	4,574	7,994	82	1,700	162	109.85	132.04	2.92	29	1.11
GUF	36	170	55.27	1.63	2,454	4,208	73	1,500	170	98.60	118.71	2.61	47	1.33
PED	22	181	62.42	1.80	2,709	4,498	71	1,800	210	85.91	103.09	3.56	55	1.19
REA	34	183	85.41	2.08	2,702	4,626	54	1,200	187	106.50	128.01	2.64	31	1.27
$\overline{X}$	31	182	74.20	1.90	3,210	5,522	75	1,520	184	101.02	121.50	2.87	40	1.25
±SD	8	8	16.50	0.24	880	1,603	15	239	19	9.39	10.20	0.40	11	0.10
±SE	3	4	7.40	0.11	394	717	7	107	8	4.20	4.50	0.18	5	0.04

Table 2(a). Drink composition (package label data per 2000 ml)

	HA[a]	P1[b]
Sodium chloride, gm	9.00	–
Sodium citrate, gm	15.44	3.87
Dextrose, gm	–	41.12
Aspartame, gm	0.72	–
Total	25.16	222.28
Ionic concentration, mEq/L, % wt./vol.		
Na^+	157/0.36	19.61/0.04
K^+	–	5.01/0.02
Cl^-	76/0.27	4.98/0.02
Mg^{++}	–	0.40/0.01
Ca^{++}	–	1.96/0.02
P^{++++}	–	0.51/0.01
Total	233/0.63	32.47/0.11
Carbohydrate, % wt./vol.		
Glucose	–	1.85
Fructose	–	2.43
Maltodextrin	–	5.44
Total	–	9.72

[a]HA: HyperAde—NaCl/NaCitrate (0.036 percent Na^+).
[b]P1: Performance 1, Shaklee U.S., Inc., San Francisco, California.

Table 2(b). Measured drink solute concentration

	HA[a]	P1[b]
Na^+, mEq/L	163.7	44.7
K^+, mEq/L	<0.1	5.6
Osmolality, mOsm/kgH_2O	253	365
Glycerol, mg/dL	1.0	2.0
Glucose, mg/dL	<0.5	2049
Citrate, mg/dL	854	416

[a]HA: HyperAde—NaCl/NaCitrate (0.036 percent Na^+).
[b]P1: Performance 1, Shaklee U.S., Inc., San Francisco, California.

After eating at least two hours previously, the subjects arrived at the laboratory consistently in the morning or afternoon. They urinated (–105 min), inserted a rectal thermistor 16 cm, and were weighed in shorts on a digital scale (±5 g, model 5780, National Controls, Inc., San Carlos, California); dry shorts were weighed separately. Skin temperature probes and EKG and laser-Doppler sensors were attached during the resting phase. Body weight was measured at –105 min, –15 min, and after the endurance test (fig. 1).

Drinks and Drinking

The subjects consumed the drinks (10 mL/kg, 555–998 mL, table 3), divided into 7 portions, at 10-min intervals from –105 min to –35 min of the resting phase (fig. 1). HA contained a high salt content apparent to the subjects. HA and P1 were formulated and packaged in the laboratory of Shaklee U.S., Inc. Both were in powder form and were mixed with water each test day.

Table 3. Individual drink volume (10 mL/kg) for the resting phase of the three endurance treatments

Subject	Drink volume HA[a]	P1[b]	N[c]
CAL	675	679	0
DUW	997	998	0
GUF	556	555	0
PED	631	627	0
REA	857	860	0
$\overline{X}$	743	744	0
±SD	161	162	0
±SE	72	73	0

[a]HA: HyperAde.
[b]P1: Performance 1.
[c]N: Nothing.

Physiological Measurements

After three familiarization sessions, peak oxygen uptake ($\dot{V}O_2$ peak, table 1) was measured with the subjects in the sitting position on a model 846 ergometer (Quinton Instruments Co., Seattle, Washington). The respiratory measurement system utilized a low-resistance, low-dead-space Rudolph valve (model 2700, Hans Rudolph, Inc., Kansas City, Missouri), a Tissot-tank calibrated electronic spirometer (model S-301 Pneumoscan, K. L. Engineering Co., Slymar, California), and a 3-liter mixing chamber. Expired gas from the mixing chamber was sampled at 0.5 L/min and then drawn through anhydrous calcium sulfate (Hammond Drierite Co., Xenia, Ohio) to oxygen and carbon dioxide analyzers (Applied Electrochemistry models S-3AI and CD-3A, respectively; Ametek, Thermox Instruments Division, Pittsburgh, Pennsylvania). The analyzers were calibrated with gases standardized with the Lloyd-Haldane apparatus. Analog data, processed with an analog-to-digital converter, (VISTA system IBM model 17002, Vacumed, Ventura, California) were transmitted to an IBM (model AT) computer. Output metabolic data were printed each 15 sec; peak data comprised the mean of the final four 15-sec values.

Skin blood velocity was measured on the left temple and left anterior-medial thigh with a laser Doppler system (model BPM 403A, LaserFlo Blood Perfusion Monitor, TSI, Inc., St. Paul, Minnesota).

Heart rate was determined with a cardiotachometer (model 78203C, Hewlett-Packard, Waltham, Massachusetts) via two skin electrodes (Silvon No. 01-3630 Ag/AgCl, NDM, Dayton, Ohio) located on the anterior shoulders and the third over the fifth intercostal space.

Rectal and skin temperatures were measured with series 400 thermistors (Yellow Springs Instrument Co., Yellow Springs, Ohio). Skin thermistors, attached with holders permitting free movement of air (ref. 5), were located at six sites: arm, forearm, thigh, calf, chest, and back. A Squirrel meter/logger (Grant model 1200, Science/Electronics, Inc., Miamisburg, Ohio) monitored sensor inputs. Mean skin temperature ($\overline{T}_{sk}$) (refs. 6 and 7) was calculated: $\overline{T}_{sk}$ = 0.06 (Tarm) + 0.13 (Tforearm) + 0.21 (Tthigh) + 0.21 (Tcalf) + 0.19 (Tchest) + 0.20 (Tback).

Room dry-bulb temperature and relative humidity were 20.8 ± SD 1.1°C, 54.4 ± 5.2 percent at rest, respectively; and 21.3 ± 0.9°C, 55.7 ± 3.5 percent with exercise, respectively. A fan increased air flow from 23–29 ft/min over the subject at rest to 54–64 ft/min during exercise (table 4).

Two months previously, plasma volume (PV) was measured with a modified Evans blue dye (T-1824, New World Trading Corp., DeBary, Florida) dilution technique from the 10-min post-dye injection blood sample (ref. 8). Plasma was eluted through prepacked chromatographic columns (model PD-10, Sephadex G-25M, Pharmacia LKB, Uppsala, Sweden) and the elutriate was read on a spectrophotometer at 615 mμ. Blood volume = PV [100/(100 – (Hct × 0.96 × 0.91))]. Percent change in plasma volume after drinking for the three treatments during the resting phase was also determined two months previously (ref. 4).

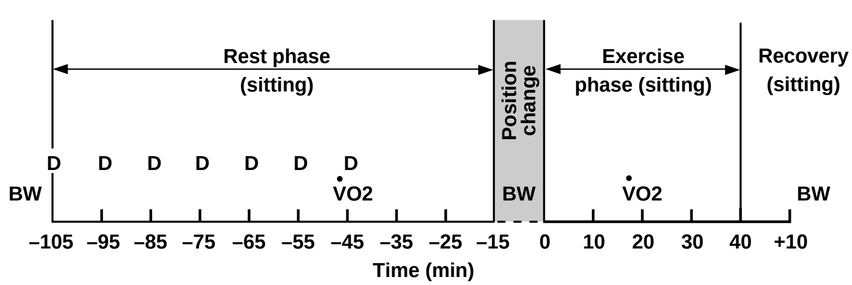

Figure 1. Experimental protocol. BW = body weight, $\dot{V}O_2$ = oxygen uptake, and D = drinking (1/7 of total volume).

Table 4. Mean environmental parameters during rest and exercise phases for the three endurance treatments

	HA[a]	P1[b]	N[c]
Rest phase[d]			
Dry bulb temperature, °C			
$\overline{X}$	20.8	21.7	20.8
±SD	1.1	1.1	0.5
±SE	0.5	0.5	0.2
Relative humidity, percent			
$\overline{X}$	54.4	52.8	50.0
±SD	5.2	10.5	6.0
±SE	2.3	4.7	3.0
Wind speed, ft/min			
$\overline{X}$	23.0	28.0	29.0
±SD	9.0	5.0	2.0
±SE	4.0	2.0	1.0
Barometric pressure, mmHg			
$\overline{X}$	766.2	765.2	766.8
±SD	0.4	1.1	1.3
±SE	0.2	0.5	0.6
Exercise phase[e]			
Dry bulb temperature, °C			
$\overline{X}$	21.3	22.0	21.2
±SD	0.9	1.2	0.6
±SE	0.4	0.5	0.2
Relative humidity, percent			
$\overline{X}$	55.7	55.0	52.0
±SD	3.5	6.4	3.0
±SE	1.6	2.8	2.0
Wind speed, ft/min			
$\overline{X}$	61.0	64.0	54.0
±SD	15.0	10.0	5.0
±SE	7.0	4.0	2.0
Barometric pressure, mmHg			
$\overline{X}$	766.1	765.2	766.1
±SD	0.6	1.2	1.0
±SE	0.3	0.5	0.5

[a]HA: HyperAde.
[b]P1: Performance 1.
[c]N: Nothing.
[d]Rest phase data are means of –65 and –35 min values.
[e]Exercise phase data are at 10 min.

Table 5. Individual exercise load, relative oxygen uptake, endurance, and perceived exertion for the three endurance treatments

Subject	Exercise	Relative $\dot{V}O_2$			Terminal heart rate			Endurance			Rated perceived exertion (RPE)					
	load,	Percent	Percent	Percent	b/m	b/m	b/m	min	min	min	5 min	End[d]	5 min	End	5 min	End
	kpm/min	HA[a]	P1[b]	N[c]	HA	P1	N	HA	P1	N	HA	HA	P1	P1	N	N
CAL	900	87	85	95	186	177	189	25.50	21.50	21.67	13	19	11	19	13	18
DUW	1,100	89	86	87	144	151	122	22.50	23.75	21.00	14	17	14	18	14	18
GUF	1,100	97	92	90	162	161	169	41.50	27.50	29.00	13	20	15	18	13	18
PED	1,300	88	91	81	191	197	190	35.00	23.50	26.58	15	19	15	17	13	19
REA	900	92	84	83	181	175	181	28.00	26.50	25.17	11	18	12	18	12	18
$\overline{X}$	1,060	91	88	87	173	172	170	30.50	24.55	24.68[e]	13	19	13	18	13	18
±SD	167	4	4	6	19	17	28	7.69	2.43	3.36	1	1	2	1	1	0
±SE	75	2	2	2	9	8	13	3.44	1.09	1.50	1	1	1	0	0	0

[a]HA: HyperAde.
[b]P1: Performance 1.
[c]N: Nothing.
[d]At exhaustion.
[e]$p < 0.05$ from HA.

Exercise load was 900 to 1300 kpm/min ($\overline{X}$ = 1060 ± 75 kpm/min) and relative oxygen uptake 87 ± 2 to 91 ± 2 percent (table 5).

Perceived exertion was determined with a modified rated perceived exertion (RPE) scale (ref. 9) in increments from 7 (very, very light) to 20 (very, very hard). The subject terminated exercise at volitional fatigue, usually when he could no longer maintain the 70 rpm cadence on the cycle.

Statistical Analysis

Data were analyzed with Student's t-test for paired samples; the null hypothesis was rejected at $p < 0.05$. Variability was expressed as ±SE.

Results and Discussion

Endurance

Mean endurance was significantly longer ($p < 0.05$) with HA (30.50 ± 3.44 min) than with N (24.68 ± 1.50 min), but not with P1 (24.55 ± 1.09 min) (fig. 2, upper panel). All subjects except DUW had longer endurance with HA when compared with P1 or N (table 5).

Plasma Volume

Mean (±SE) percent change in plasma volume from –105 min to –15 min of the resting phase was about 7.8 ± 2.4 percent with HA, 5.0 ± 2.6 percent with P1, and 1.2 ± 2.4 percent with N (fig. 2, lower panel; ref. 4).

Rated Perceived Exertion

No significant difference in RPE level existed between those at 5 min of exercise (13, 13, 13) and those at the end of exercise (19, 18, 18) for the three treatments (table 5).

Heart Rate

Rate of increase in mean heart rate was not different (fig. 3), and terminal heart rates were essentially the same for the three treatments at 173, 172, 170 beats/min (table 5). Therefore, the level of stress was essentially similar at termination.

Metabolism

Mean metabolic data $\left(\dot{V}_E, R_E, \dot{V}O_2\right)$ did not differ significantly among the three treatments during the rest or exercise phases (table 6). Metabolism from the prior meals probably explained the mildly elevated resting respiratory exchange ratio (R_E) of 0.88 to 0.93. Exercise R_E was at the appropriate level of 1.01 to 1.02. Absolute exercise oxygen uptake (2.49 ± 0.10 to 2.60 ± 0.13 L/min, table 6), relative oxygen uptake (87 ± 2 to 91 ± 2 percent of $\dot{V}O_2$ peak, table 5), and heart rate were not significantly different among the three treatments, thereby eliminating metabolic inequality as a factor for the different endurance time.

Rectal Temperature (Tre)

Mean Tre was within the normal resting range of 36.8 ± 0.2 to 36.9 ± 0.2°C (fig. 4); it increased by 1.31 ± 0.31°C with HA, by 0.98 ± 0.19°C with P1, and by 1.01 ± 0.20°C with N, with no significant difference among them. Mean termination Tre was 38.10 ± 0.25°C (HA), 37.88 ± 0.11°C (P1), and 37.76 ± 0.12°C (N); therefore, it appears the higher terminal Tre with HA was due to longer exercise time. Because a Tre of only 38°C is attained after one hour of exercise at a relative oxygen uptake of 50 percent (ref. 10), hyperthermia was not the cause for cessation of work.

Mean Skin Temperature $\left(\overline{T}_{sk}\right)$

The $\overline{T}_{sk}$ exhibited the characteristic decrease with onset of exercise (fig. 5, upper panel), and then increased to slightly above the resting (time zero) level after 20 to 25 min of exercise (fig. 5, lower panel).

Skin Blood Velocity

Forehead skin blood velocity (non-exercising site) was within the normal range at rest, and increased after 8 to 10 min of exercise to reach equilibrium levels between 1.2 to 1.6 $\text{Hz} \times 10^2$ at 20 to 25 min of exercise (fig. 6, upper panel). Prior to termination of all three treatments, forehead velocity decreased, suggesting shunting of skin blood flow away from "inactive" areas.

Thigh skin blood velocity (exercising site) was also within the normal range at rest, also increased after 8 to 10 min of exercise, but did not attain equilibrium as did forehead flow (fig. 6, lower panel). No precipitous drop in

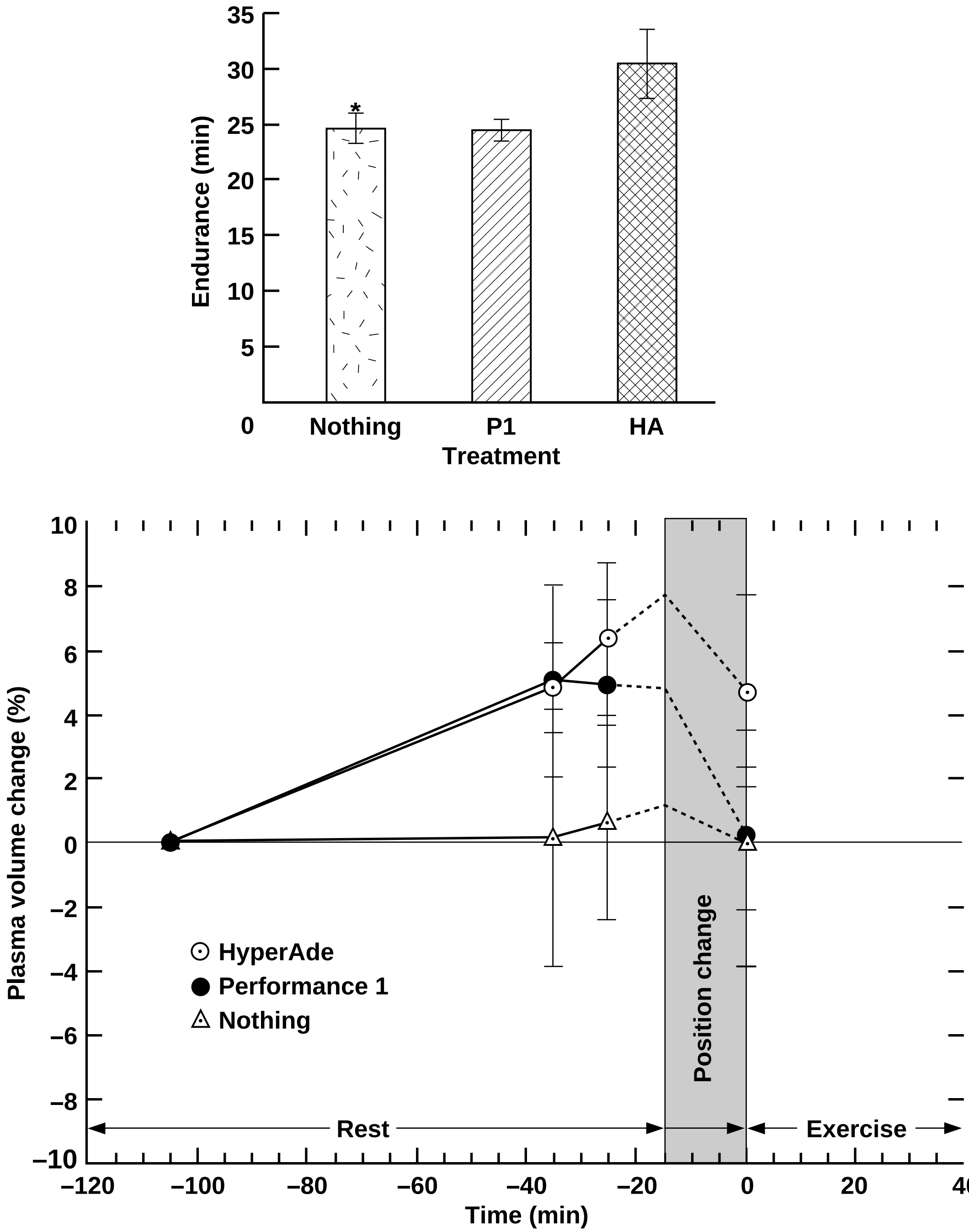

Figure 2. Mean (±SE) ergometer endurance (upper panel) and change in plasma volume during rest (lower panel) for the three endurance treatments.

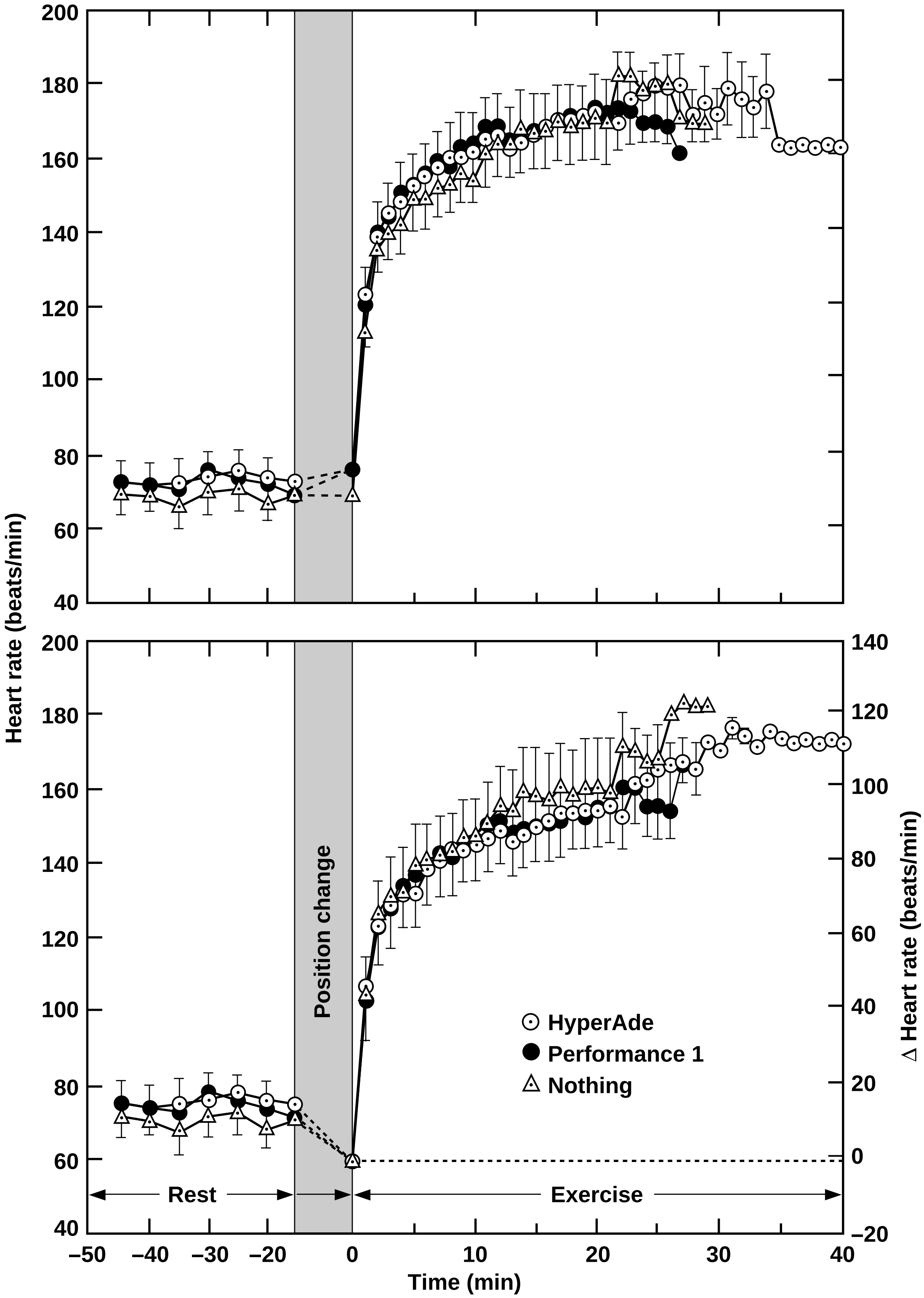

Figure 3. Mean (±SE) heart rate during rest and exercise (upper panel) and change in exercise heart rate (lower panel) for the three endurance treatments. Data without ±SE are from one subject.

Table 6. Mean metabolic data for the rest and exercise phases of the three endurance treatments

	HA[a]	P1[b]	N[c]
Rest phase[d]			
$\dot{V}_{E_{STPD}}$, L/min			
$\overline{X}$	8.71	10.60	8.08
±SD	2.55	3.03	2.91
±SE	1.14	1.36	1.30
R_E			
$\overline{X}$	0.88	0.93	0.87
±SD	0.07	0.03	0.12
±SE	0.03	0.01	0.05
$\dot{V}O_2$, L/min			
$\overline{X}$	0.33	0.38	0.28
±SD	0.07	0.07	0.09
±SE	0.03	0.03	0.04
$\dot{V}O_2$, mL/min/kg			
$\overline{X}$	4.6	5.2	3.8
±SD	0.6	0.7	0.5
±SE	0.3	0.3	0.2
Exercise phase[e]			
$\dot{V}_{E_{STPD}}$, L/min			
$\overline{X}$	73.39	69.73	72.69
±SD	8.04	7.21	4.64
±SE	3.60	3.23	2.08
R_E			
$\overline{X}$	1.02	1.01	1.01
±SD	0.07	0.05	0.07
±SE	0.03	0.02	0.03
$\dot{V}O_2$, L/min			
$\overline{X}$	2.60	2.53	2.49
±SD	0.29	0.38	0.23
±SE	0.13	0.17	0.10
$\dot{V}O_2$, mL/min/kg			
$\overline{X}$	35.3	35.8	35.4
±SD	10.3	10.3	8.6
±SE	4.6	4.6	3.8

[a]HA: HyperAde.
[b]P1: Performance 1.
[c]N: Nothing.
[d]Resting phase data are means of –40 min values.
[e]Exercising phase data are means of 20 min values.

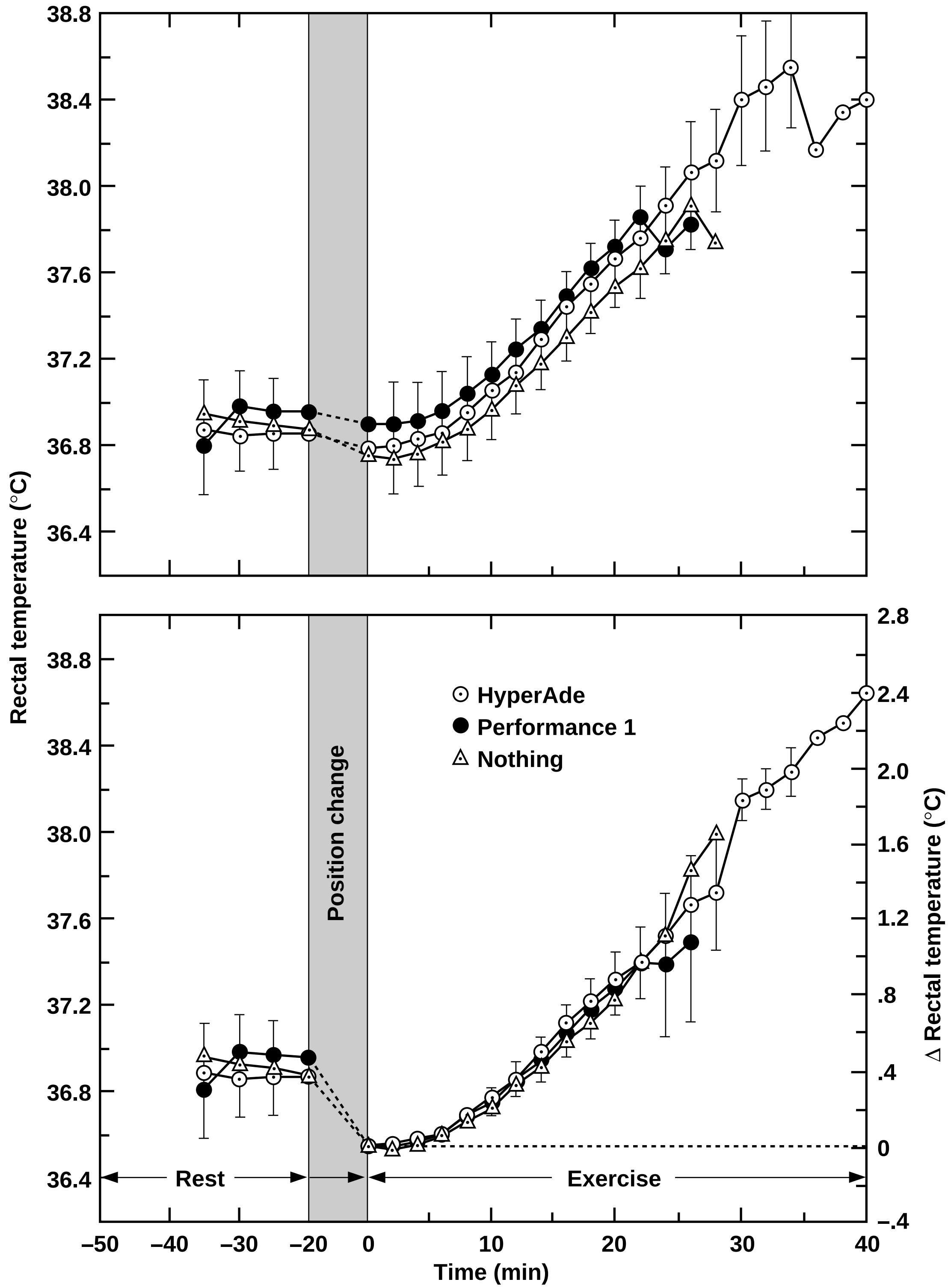

Figure 4. Mean (±SE) rectal temperature during rest and exercise (upper panel) and change in exercise rectal temperature (lower panel) for the three endurance treatments. Data without ±SE are from one subject.

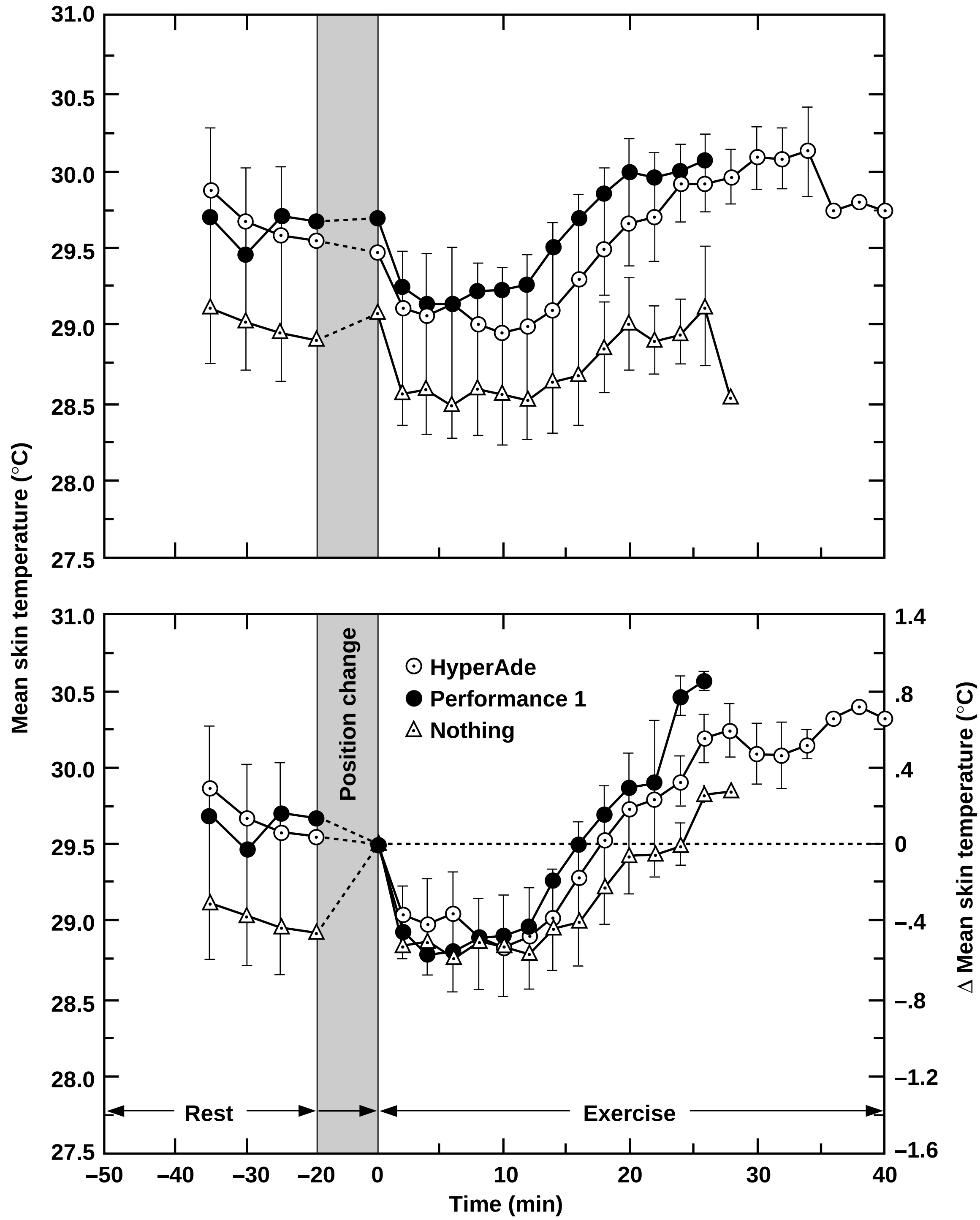

Figure 5. Mean (±SE) of the mean skin temperature during rest and exercise (upper panel) and change in exercise mean skin temperature (lower panel) for the three endurance treatments. Data without ±SE are from one subject.

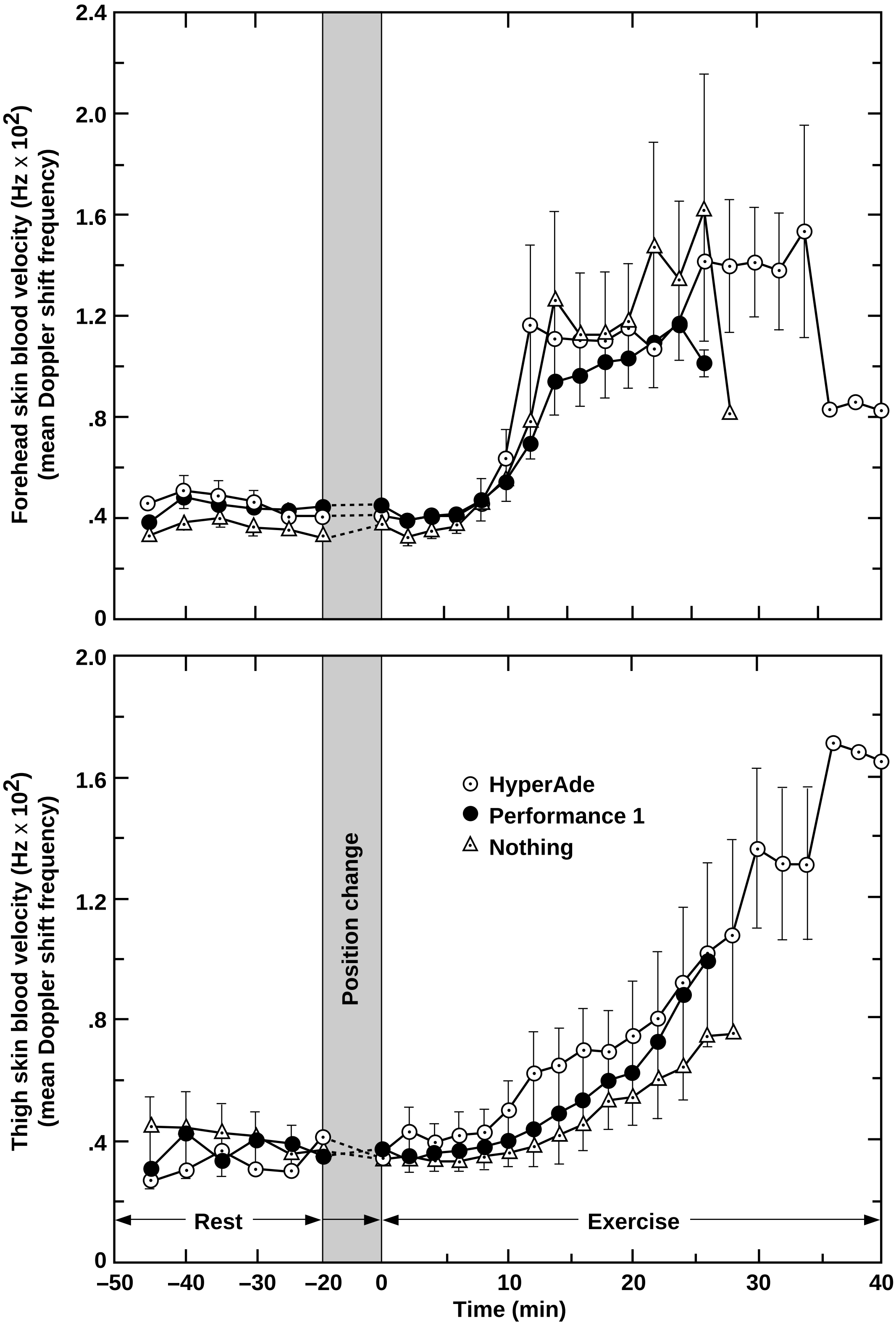

Figure 6. Mean (±SE) forehead skin blood velocity (upper panel) and thigh skin blood velocity (lower panel) during rest and exercise for the three endurance treatments. Data without ±SE are from one subject.

thigh flow occurred before termination, suggesting blood shifted from non-exercising skin sites to aid heat transportation from exercising muscles to the periphery for dissipation.

Conclusion

The reduced endurance with P1 and N could not be attributed to change in perceived exertion, exercise metabolism, blood flow, or rectal and mean skin temperatures. The greater endurance with HA was probably facilitated by noncarbohydrate factors related to the significant increase in pre-exercise plasma volume.

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13. ABSTRACT ***(Maximum 200 words)***

Cycle-ergometer endurance performance was determined in 5 untrained men (22–39 yr, 62.4–100.5 kg, 29–55 mL $\times$ min^{-1} $\times$ kg^{-1} peak oxygen uptake) after consuming Nothing (N) or two fluid formulations (10 mL $\times$ kg^{-1}, 555–998 mL). Performance 1 (P1), a multi-ionic-glucose rehydration drink, contains 55 mEq/L Na^+, 416 mg/dL citrate, 2,049 mg/dL glucose, and 365 mOsm/kgH_2O. HyperAde (HA), a sodium chloride-citrate hyperhydration drink, contains 164 mEq/L Na^+, 854 mg/dL citrate, <0.5 mg/dL glucose, and 253 mOsm/kgH_2O. Endurance at a load of 87–91 percent of peak $\dot{V}O_2$ was 30.50 ± SE 3.44 min with HA; 24.55 ± 1.09 min with P1 ($p > 0.10$ from HA); and 24.68 ± 1.50 min with N ($p < 0.05$ from HA). The attenuated endurance performance with P1 and N could not be attributed to differences in exercise metabolism, change or absolute level of rectal and mean skin temperature, or change in perceived exertion. The greater increase in resting plasma volume with HA, compared with P1 or N, probably contributed to the greater endurance with HA.

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