Hypervolemia and Blood Alkalinity: Effect on Physiological Strain in a Warm Environment

Michael D. Nelson, Lynneth A. Stuart-Hill, and Gordon G. Sleivert

Purpose: To evaluate the influence of acute hypervolemia, achieved through the ingestion of a sodium citrate–rich beverage, on cardiovascular strain and thermoregulatory function, during moderate-intensity aerobic exercise in a warm environment. Sodium citrate’s ability to increase buffering capacity was also assessed. Methods: Twelve endurance-trained athletes completed two blind randomized treatment trials, separated by a minimum of seven days, on a cycle ergometer under heat stress (30.9°C, 64% RH). The subjects ingested 12 mL·kg⁻¹ of (1) Gatorade, the control (CNT), or (2) sodium-citrate plus Gatorade (NaCIT: 170 mmol Na⁺·L⁻¹) before cycling at 15% below ventilatory threshold (VT) for 62 minutes. Core and skin temperature, expired gas samples, heart rate, and perceived exertion were measured throughout exercise. Blood samples were taken before drinking each beverage, before commencing exercise, and throughout the exercise bout. Results: Plasma volume (PV) was significantly expanded in the NaCIT trial (3.6 ± 5.5%) and remained significantly higher throughout exercise in the NaCIT trial compared with the CNT trial (P ≤ .05). No significant differences were found in heart rate, in core and skin temperature, or in the metabolic data between the treatment groups. NaCIT significantly increased [HCO₃⁻], base excess, and pH throughout the trial. Conclusion: Acute oral ingestion of high-sodium citrate beverages before moderate exercise induces mild levels of hypervolemia and improves blood-buffering capacity in humans; however, mild hypervolemia during 62 minutes of moderate exercise does not reduce physiological strain or improve thermoregulation.

Keywords: sodium citrate, buffering, hypervolemia, blood volume

Acute oral ingestion of sodium with the intention of expanding plasma volume has received an increasing amount of attention in the literature in recent years. To the best of our knowledge, only one other group of investigators have examined the effects of hypervolemia on exercise performance under severe environmental conditions. Much of the work that exists has focused primarily on clinical plasma volume expanders and/or during exercise in temperate conditions.

Nelson and Stuart-Hill are with School of Exercise Science, Physical and Health Education, Victoria, BC, and Sleivert is with Canadian Sport Centre Pacific, Victoria, BC, Canada.
In a study conducted by Grant et al., plasma volume was expanded by infusing three different saline solutions. Plasma volume was found to remain higher throughout rest and exercise in the hypervolemic conditions (control < low < high), while increasing stroke volume by 14%.

Clinical plasma volume expanders, infused into the venous system, are highly impractical and can be quite costly. Greenleaf et al. were able to increase plasma volume by ~7.9% following the ingestion of a high-sodium beverage (~164 mEq·L⁻¹). Although plasma volume was increased, cardiovascular strain and thermoregulatory function was not significantly altered during 70 minutes of sub-maximal exercise.

In a more recent study, Coles and Luetkemeier found that a 3.1% increase in plasma volume improved time-trial performance; however, no influence was observed in core temperature, heart rate, or total body sweat rate regardless of plasma volume (PV) expansion. This was also the case in other studies using similar protocols and environmental conditions. It is believed that because these studies were done in temperate conditions, the excess PV was not used to aid in heat dissipation, owing to the mild stress placed upon the subject. When prolonged exercise is performed in warm conditions, blood volume decreases as a result of profuse sweating, which could compromise heat dissipation. Extreme conditions may therefore allow for changes in physiological strain or exercise performance to be observed.

Sodium citrate has traditionally been used with the intent of improving the body’s alkalinity. In an attempt to maintain the electrical neutrality, the body naturally decreases the concentration of hydrogen [H⁺] ions and increases the amount of bicarbonate [HCO₃⁻] within the blood. The subsequent reduction in H⁺ induces alkalosis and causes an efflux of H+ and lactate [La−] via a pH-sensitive monocarboxylate transporter from the working muscles into the venous blood. Previous studies investigating the hypervolemic effect of sodium loading, either have not used a sodium species that can increase [HCO₃⁻] or have neglected to quantify this effect.

The purpose of this study was to further examine whether hypervolemia, via acute sodium citrate ingestion, reduces cardiovascular strain and improves thermoregulation during steady-state moderate-intensity exercise in a warm environment. We hypothesized the acute sodium ingestion would increase plasma volume and reduce thermoregulatory and cardiovascular strain, while also increasing the buffering capacity of the athletes. We chose a moderate-intensity steady-state exercise protocol, which gradually increased body temperature, to study the effects of hypervolemia on thermoregulation and cardiovascular strain. This approach is different from previous studies that have shown that exercise performance can be improved when using a similar sodium-loading protocol.

**Methodology**

**Participants and Experimental Design**

Twelve healthy moderately trained male athletes volunteered for the study. All subjects had previous cycling experience. The inclusion criteria for the study required the subjects to be comfortable cycling for an hour, and subjects were cur-
rently training a minimum of 60 minutes per day, three times per week. All subjects provided informed consent and were advised of their right to withdraw from the study at any time without future implications. Ethics approval was obtained from the Human Research Ethics Committee at the University of Victoria. Participant characteristics were as follows (mean ± SD): mass 76.7 ± 9.7 kg; age 24.3 ± 4.2 years; height 180.0 ± 6.6 cm; % body fat 8.7 ± 4.4; VO2max 56.4 ± 5.0 mL·kg⁻¹·min⁻¹. All testing was done between the months of February and April (average daily maximum temperature of 6 to 13°C) to control for heat acclimatization.

Each subject reported to the laboratory a minimum of 7 days before the beginning of the experiment to test for fitness and set the intensity of the experimental trials. Anthropometric measures (height, weight, sum of 7 skinfolds) were taken upon arrival to the laboratory. Following a standardized (100 W) 5-minute warm-up, the participants completed an incremental test on an electrically braked cycle ergometer (Lode Excalibur Sport, Groningen, The Netherlands) to test for maximum rate of oxygen consumption (VO2max) and maximum heart rate (HRmax). Power output increased by 30 W every 2 minutes until ventilatory threshold (VT); following VT, the workload was increased every minute until volitional exhaustion. Ventilatory threshold was defined as a rise in VE/VO2 without a rise in VE/VCO2.

Expired gas samples were collected using a mounted face mask; a True One metabolic cart (Parvo Medics, USA) was used to measure expired gases. The gas analyzers were calibrated before each test using known gas concentrations, and the flow rate was calibrated using a 3-L syringe. Heart rate (HR) was continuously monitored using a telemetric heart rate monitor (Polar, Finland) throughout the incremental test. Following the incremental test, the subjects were allowed to drink fluids ad libitum and rest in the laboratory for approximately 30 minutes. During this time, temperature and humidity in the heat chamber was increased to 30°C and 60%, respectively. To familiarize the subjects to the temperature and exercise conditions, they were asked to cycle in the heat chamber at the intensity determined/required for the two treatment trials (15% below VT; ~60% VO2peak). Water was provided ad libitum during this trial for subject comfort.

**Experimental Protocol**

The two trials were administered in a blind, randomized fashion, separated by a minimum of seven days. All testing was done at the same time of day. All subjects were asked to prepare for each trial as they would for a race, which meant keeping training and diet consistent and refraining from vigorous exercise 24 hours before each trial.

Upon arrival to the laboratory, subjects provided a urine sample; a urine specific gravity (Usg) > 1.020 g·mL⁻¹ was chosen to define a hypohydrated state and subjects were not allowed to participate until adequately hydrated. Before entering the environmental chamber, the subjects were given 20 minutes to ingest either 12 mL·kg⁻¹ of Gatorade (CNT) or sodium citrate + Gatorade (NaCIT) (Table 1). Both solutions were kept between 4 to 6°C to aid with palatability. Ninety minutes was given to allow for fluid absorption; this took place outside the environmental chamber. Exercise commenced 100 minutes postingestion after nude body mass
was measured and following a standardized 5-minute warm-up at 100 W in the
heat chamber.

All subjects participated in two treatment trials lasting 62 minutes on the
previously described cycle ergometer. The total test time was a result of collecting
expired gas samples every 10 minutes for 4 minutes, as collection began at 8 min-
utes (10-minute average) (Figure 1). In both trials, subjects rode for 62 minutes in
a controlled environment (30.9 ± 0.4°C and 63.8 ± 1.4% humidity and 26.9 ± 0.2
WBGT). Temperature in the chamber was continuously monitored (Questemp 36,
Quest Technologies, Oconomowoc, WI). A large fan was placed directly in front
of the subject for both trials to aid with heat convection. Subjects ingested 250 mL
of tap water (15–17°C) following the collection of expired gas samples (every 10
minutes) for a total of 1250 mL. The subjects rode at 15% below VT (~60% V_{O2peak}). This intensity was chosen to allow the subjects to complete at least 60
minutes of exercise, while reducing the likelihood of exceeding the ethical core
temperature cut-off of 39.5°C. Immediately after exercise, nude body mass was
recorded; body mass was recorded to the nearest 0.02 kg (Model HL120, Avery
Berkel, Taiwan).

Expired gas samples were collected using a mounted mouthpiece every 10
minutes for a total of 4 minutes (reported as 3-minute averages ± SD). The meta-
bolic cart was calibrated before each trial according to the above laboratory
procedures.

### Fluid Analysis

Capillary blood samples (~95 μL) were collected directly into I-STAT ECG 8+ cartr
idges from the first 9 subjects recruited. Fingertip blood samples were drawn
before fluid ingestion (baseline sample), after fluid ingestion (90 min), and during
exercise (every 20 minutes). Baseline blood samples were taken after 20 minutes
of seated rest to ensure splenic replenishment of red blood cells. All blood sam-
ples were standardized for posture, both on and off the ergometer. The whole
blood was immediately analyzed for sodium (Na), hematocrit (Hct), hemoglobin
(Hb), pH, bicarbonate (HCO3−) and base excess (BE), using an I-STAT clinical
analyzer (Abbott Point of Care, East Windsor, NJ). Hematocrit (Hct) and hemo-
globin (Hb) were used to calculate the %ΔPV according to the formula by Dill
and Costill.

Urine specific gravity was measured before exercise to verify that all partici-
pants began each trial in a euhydrated state. Urine specific gravity was measured
via a handheld clinical refractometer (Model PAL-10S, ATAGO, Tokyo, Japan). If
subjects were found to be hypohydrated, 500 mL of tap water was ingested. Fol-

| Table 1 Solute Composition of the Two Blinded Treatment Solutions Ingested 100 Minutes Before the Exercise Bout |
|-------------------------------------------------|-------------------------------------------------|
| Sodium (mEq·L⁻¹)                                | NaCIT  0.2 g·kg⁻¹ | CNT Gatorade |
| Carbohydrate (%)                                | 170.3          | 18.3        |
|                                                | 6.6            | 6.6         |
## Table 2 Mean (± SD) Physiological, Psychophysical, and Hematological Responses to Moderate-Intensity Exercise in a Warm Environment

<table>
<thead>
<tr>
<th></th>
<th>0 min</th>
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<td>NaCIT</td>
<td>37.0 ± 0.3</td>
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<td>37.8 ± 0.3</td>
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<td>NaCIT</td>
<td>135.7 ± 9.7</td>
<td>146.7 ± 12.8</td>
<td>155.1 ± 11.4</td>
<td>158.7 ± 12.5</td>
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<td>155.9 ± 14.5</td>
<td>161.2 ± 14.9</td>
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<td>3.5 ± 0.8</td>
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<td>4.5 ± 0.8</td>
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<td><strong>VO₂ (L/min)</strong></td>
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<td>——</td>
<td>2.8 ± 0.3</td>
<td>2.8 ± 0.3</td>
<td>2.9 ± 0.3</td>
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<td>——</td>
<td>0.98 ± 0.03</td>
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<td><strong>Hb (g·L⁻¹)</strong></td>
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<td>NaCIT</td>
<td>143.8 ± 9.9</td>
<td>140.4 ± 9.3</td>
<td>148.6 ± 8.3</td>
<td>145.3 ± 10.6*</td>
<td>147.3 ± 11.8</td>
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<tr>
<td>CNT</td>
<td>144.0 ± 7.9</td>
<td>147.0 ± 8.1</td>
<td>154.8 ± 7.4</td>
<td>159.5 ± 15.6*</td>
<td>152.8 ± 15.1</td>
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<td><strong>Hct (%)</strong></td>
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<tr>
<td>NaCIT</td>
<td>0.42 ± 0.02</td>
<td>0.41 ± 0.02</td>
<td>0.44 ± 0.02</td>
<td>0.43 ± 0.02*</td>
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<tr>
<td>CNT</td>
<td>0.42 ± 0.02</td>
<td>0.43 ± 0.02</td>
<td>0.46 ± 0.02</td>
<td>0.47 ± 0.02*</td>
<td>0.45 ± 0.02</td>
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<td><strong>ΔBV (%)</strong></td>
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<tr>
<td>NaCIT</td>
<td>0</td>
<td>2.4 ± 3.3*</td>
<td>−3.2 ± 3.4*</td>
<td>−1.0 ± 4.3*</td>
<td>−2.4 ± 7.1</td>
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<tr>
<td>CNT</td>
<td>0</td>
<td>−2.0 ± 2.9*</td>
<td>−7.0 ± 1.7*</td>
<td>−9.7 ± 5.1*</td>
<td>−5.8 ± 3.8</td>
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<tr>
<td><strong>Na⁺ (mmol·L⁻¹)</strong></td>
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<tr>
<td>NaCIT</td>
<td>138.4 ± 1.9</td>
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<tr>
<td>CNT</td>
<td>137.6 ± 2.5</td>
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<td>140.2 ± 1.9</td>
<td>141.8 ± 4.5</td>
<td>139.3 ± 3.3</td>
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</table>

ΔBV is calculated based on Dill and Costill.16

* Significant difference between trials.
Following the ingestion of the water, the third urine sample was collected and remeasured for $U_{sg}$. The authors believed that the first void of the bladder (2nd urine sample) following the ingestion of a large bolus of water would increase the likelihood of obtaining a false-positive because the urine may be diluted owing to the large bolus; however, other fluid spaces may remain dehydrated.

The osmolality of the treatment solution was measured, in triplicate, via freezing point depression (Advanced Instruments, Model 3300, Norwood, MA).

**Thermal Strain**

Core temperature and skin temperature were measured using rectal thermometers (Mon-a-Therm General Purpose, Mallinckrodt, St. Louis, MO) and biomedical ceramic chip thermisters (MA 100, 10KO negative temperature coefficient, Thermometrics, NJ) every 5 minutes throughout the exercise protocol, using an 8-channel data logger (SmartReader 8 Plus, ACR Systems, Surrey, BC, Canada). Subjects self-inserted the rectal thermistor into the anal canal to a depth of 10 cm. The same thermistor was used for each participant for each condition (sterilized between uses). The ceramic chip thermistors were placed on the left side of the body and secured using adhesive tape. Skin temperature was continuously measured and recorded at the same intervals as core temperature at four sites. Mean skin temperature ($T_{sk}$) was calculated using the Ramanathan formula.\(^{18}\)

**Cardiovascular and Physiological Strain**

Heart rate was recorded (Polar heart rate monitor) every 5 minutes throughout the trial. Physiological strain experienced by the subjects during each trial was calculated using the physiological strain index (PSI).\(^{19}\) Combining both heart rate and rectal temperature, the index starts at 0 (no/little strain) and progresses to a maxi-
Sodium Citrate, Hypervolemia, and Heat Stress

Psychophysical Strain

Thermal comfort and thermal sensation were measured based on the work of Gagge, Stolwijk, and Hardy.\textsuperscript{20} Subjects also provided their rating of perceived exertion using a modified Borg scale (0–10).\textsuperscript{21} Psychophysical strain indices were recorded every 10 minutes in a consistent order. All subjects were instructed how to use each scale before the commencement of exercise, and each subject practiced using the scales during the preliminary heat acclimation trial.

Body Mass Changes

Nude body mass was recorded immediately before exercise, and immediately after exercise to determine \(\%\Delta\) in body mass, which was later used as an estimate of total sweat loss. Fluid ingestion and excretion were accounted for before calculating sweat loss. Subjects toweled dry before being weighed. A digital scale was used to record body mass, accurate to 0.02 kg.

\[
\text{Sweat loss} = \text{Body mass loss} + \text{fluid intake}
\]

\[
\text{Deficit} = \left(\frac{\text{body mass}_{\text{before}} - \text{body mass}_{\text{after}}}{\text{body mass}_{\text{after}}}\right) \times 100
\]

Analysis

A repeated-measures analysis of variance (RM-ANOVA) was used to identify differences between trials for the dependent variables. Two-way ANOVA (treatment \(\times\) time) was used to identify differences between blood parameters. A paired samples \(t\) test was used to define differences between treatments for fluid losses. All values are reported as the mean \(\pm\) standard deviation (SD) with significance set at \(P \leq .05\). Statistical analysis was performed using SPSS 15.0 software for Windows (SPSS, Chicago, IL).

Results

Two subjects did not complete the entire 62 minutes. One subject voluntarily withdrew from one trial at 40 minutes, and the second subject reached the ethical core temperature cut-off (39.5\(^\circ\)C) during both trials and was stopped by the investigator. Data were analyzed and reported to the minimal time completed during both trials. All other data were removed. Therefore, all physiological data are reported as \(n = 12\) to 40 minutes; from 40 to 50 minutes, \(n = 11\); and after 50 minutes, \(n = 10\). Hematological data are reported as \(n = 9\); at 60 minutes, \(n = 7\).

Hematological Response

Plasma volume was significantly \((P < .05)\) expanded by 3.6 (\(\pm\) 5.5\%) from resting baseline samples in the NaCIT trial. Plasma volume was reduced from baseline by 3.6 (\(\pm\) 5.5\%) from resting baseline samples in the NaCIT trial.
4.1 (± 5.9) % in the control trial. Plasma volume was maintained in the NaCIT trial above the CNT trial throughout the exercise bout until 40 minutes of exercise (Figure 2). There were no significant differences between treatments across time for plasma sodium (Table 2).

Blood [HCO₃⁻] was significantly elevated from baseline to 90 minutes in the NaCIT trial compared with the CNT trial. This was also replicated in blood base excess (BE) concentrations (Figure 3). Bicarbonate and BE were reduced throughout exercise in both treatments; however, the NaCIT trial better maintained [HCO₃⁻] and BE throughout the exercise bout compared with the CNT trial ($P < .05$). In accordance with these findings, pH was significantly elevated in the NaCIT trial compared with the CNT trial before starting the exercise bout (~90 minutes) and at 60 minutes (Figure 3).

**Body temperature**

Rectal temperature ($T_r$) was similar before the start of both trials ($37.0^\circ C ± 0.3$; Table 2). A significant ($P = .000$) time effect was found, with $T_r$ steadily increasing in both treatment trials similarly (Table 2). Skin temperature also showed a significant time effect as it increased throughout the exercise bout in both trials. A positive trend was witnessed in the NaCIT trial, showing a slightly elevated $T_{sk}$ throughout the exercise bout (25 minutes, $P = .10$, and 35 minutes, $P = .12$) (Figure 4).

![Figure 2](image-url) — Plasma volume changes (%) of nine subjects after the ingestion of the two treatment solutions. Plasma volume was estimated from Hb and Hct changes from baseline (time 0 min). *Significant difference between treatments. ‡Significantly different from previous value. $P < .05$. Two subjects did not complete the 62-min protocol; therefore, $n = 7$ at 60 minutes.
Cardiovascular Strain and Metabolic Response

As shown in Table 2, heart rate (HR) significantly increased in both trials by an average of 29 bpm (134 ± 12 bpm to 164 ± 15 bpm) throughout the exercise period (0 to 60 minutes). Heart rate was similar across each of the trials and steadily increased at a similar rate. Physiological strain index (PSI) significantly changed across time ($P < .01$) with no significant differences observed between treatments (Figure 5). No differences existed between expired gas samples or ventilation rate.

Figure 3 — Mean (± SD) bicarbonate (top) and base excess (middle) whole-blood concentrations (mmol/L) and blood pH (bottom) for nine subjects after the ingestion of two treatment solutions. *Significant difference between treatments. $P < .05$. Two subjects did not complete the 62-min protocol; therefore, $n = 7$ at 60 minutes.
Psychophysical Strain

Rating of perceived exertion (Table 2), thermal comfort, and thermal sensation all showed a significant time effect ($P < .01$). No differences were found between treatments. Rating of perceived exertion tended to be elevated in the CNT trial, and two-way ANOVA revealed a small difference between the trials ($P = .06$) at time 30 minutes.

Hydration Status

Body mass was successfully maintained throughout the heat stress protocol. Mean subject body mass decreased in both trials, from $77.5 \pm 9.8$ kg before starting the warm-up, to $77.1 \pm 9.7$ kg upon leaving the heat chamber. On average, subjects
lost 0.5 ± 0.5% of their total body mass during the two trials. Average deficit for the two trials was calculated to be 1.6 ± 0.4 L in the HCIT trial and 1.7 ± 0.5 L in the CNT trial.

**Discussion**

The current study evaluated the effects of hypervolemia via acute sodium ingestion during steady-state cycling in a warm environment. Acute sodium ingestion before exercise was found to expand resting plasma volumes similarly to that found in previous studies using similar sodium-loading protocols. Body temperature, cardiovascular strain and metabolic responses to steady-state exercise under heat stress were found to be similar to control values after acute sodium ingestion. It was hypothesized that the expansion of PV before starting a single exercise bout under heat stress would reduce cardiovascular strain and promote heat dissipation due to an increase in blood availability and an increase in stroke volume and/or in end-diastolic volume. Other studies investigating hypervolemia and exercise performance have used similar concentrations of sodium (164 mEq·L⁻¹) and found similar PV trends as was witnessed in the current study.

Blood [HCO₃⁻], BE, and pH were found to increase following the ingestion of NaCIT. Other research examining the effects of NaCIT on athletic performance has also shown similar results. Our findings suggest that the NaCIT treatment has both a hypervolemic and an alkaline effect.

Plasma volume was expanded by 3.6% in the NaCIT trial and was reduced by 4.1% in the control trial. Coles and Luekemeier previously showed a similar
trend, reporting a 3.1% expansion of PV in the high-sodium trial compared with the placebo who suffered a 4.7% reduction in resting baseline plasma volume. In the current study, PV was better maintained in the NaCIT trial compared with the CNT trial until the final 20 minutes of exercise. This would suggest a greater availability of plasma content for evaporative sweat loss; as well as for the maintenance of both skin and muscle blood flow. The preservation of plasma volume and subsequently the improvement in blood osmolality will also likely reduce the osmotic inhibitory input controlling thermoregulation and reduce the secretion of arginine vasopressin (AVP) and thirst sensation.4 With a different exercise protocol, one similar to Sims et al.,3,4 exercise performance could have been increased given the similar changes in PV between the three studies and the likelihood of thermoregulatory preservation in the NaCIT trial.

It is possible that the sodium beverage used to expand plasma volume was not optimal to promote rapid gastric emptying (459 mOsm·kg⁻¹ H₂O). Although we were able to expand PV to a level previously reported by other investigators, our laboratory has been able to increase PV by an average of 7.1 (± 5.9)% (unpublished data) using a similar 90-minute absorption time but a much lower osmolality. In an effort to make the treatment as practical as possible, the investigators opted to mix NaCIT with Gatorade (12 mL·kg⁻¹) as opposed to mixing concentrations of sodium and glucose in the laboratory.

Greenleaf and Brock24 have shown that following the ingestion of hypertonic and isotonic beverages under different environmental conditions, total extracellular fluid volume (ECV) expansion was lower or less than the fluid intake volume when a hypertonic solution was ingested. They also have shown that when an isotonic solution is ingested, total ECV expansion is greater than the fluid intake volume. This was the primary premise of the current study, which assumed that PV expansion would come about through the uptake of fluid from the gut as it followed both sodium and glucose across the intestinal wall.

Despite a positive maintenance of plasma volume in the NaCIT trial, physiological strain was not reduced as previously found.3,4 The present findings are in agreement with the majority of previous studies, which found no differences in cardiovascular strain, thermoregulation, or perceived exertion in a thermoneutral environment.1,2,7 Average sweat loss and skin temperature were unchanged across treatments, which supports the similar core temperature response found between trials. It is unknown if a greater PV expansion (>4%) would increase skin temperature enough to improve thermoregulation (peripheral heat dissipation). However, as mentioned above, it is likely that the maintenance of PV found in the current study could have contributed to a greater time to exhaustion or exercise performance.3,4 An increased amount of available plasma will likely reduce osmolality, and the hyperosmotic inhibitory response to thermoregulation, AVP secretion and fatigue response as measured by Sims et al.4

Sims et al.3,4 reported a reduced cardiovascular drift and heart rate, which supports the work of Berger et al.,25 who showed an increase in VO₂peak, oxygen pulse, and improved SV and cardiac output following PV expansion. Although the present findings showed a trend that favored the above studies, the differences were very small and tended to be overshadowed by large standard deviations. It should also be noted that Berger et al.25 intravenously infused a PV expander (~500 to 650 mL); equivalent to a 14% expansion of PV. Their primary reason for the changes
observed were due to the Frank–Starling mechanism, a principle that the current study was trying to achieve, but we were likely unsuccessful as a result of the marginal increase in PV.

The results observed in the current study likely reflect the exercise protocol chosen. Sims et al.\textsuperscript{3,4} used a time to exhaustion protocol and were able to show a significant reduction in physiological strain. It is possible that, in the current study, exercise was terminated before differences could be observed. This would suggest that sodium citrate loading does not have a direct cardiovascular or thermoregulatory effect on moderate-intensity exercise lasting less than 60 minutes.

The current study is the first of its kind to take into account the potential buffering capacity of sodium citrate, when ingested for the purpose of hypervolemia. It is important to note the significant increases in \([HCO_3^-]\) and BE found in the current study after ingesting only 0.2 g·kg\(^{-1}\) of NaCIT. It is not uncommon for athletes to ingest up to 0.5 g·kg\(^{-1}\) of NaCIT or NaHCO\(_3^-\) if intending to improve the body’s alkalinity. It is apparent that when ingesting relatively low concentrations of NaCIT both a hypervolemic as well as an alkaline effect can be achieved.

The potential benefits of NaCIT are therefore twofold. Athletes exercising for extended periods of time, or when exercise is performed in warm environments, will likely experience an attenuation of PV loss. However, exercise performed above anaerobic threshold will likely gain a secondary response from the improvement in blood alkalinity. A decrease in pH is believed to affect the interaction of actin and myosin through the inhibition of calcium release from the sarcoplasmic reticulum.\textsuperscript{26,27} Increases in lactate have also been shown to reduce the contractile ability of muscle and impair muscle tension via impaired cross-bridge cycling.\textsuperscript{28} It is well established that an increase in \([HCO_3^-]\) and BE before exercise will lead to an improvement in athletic performance\textsuperscript{9,10} and that NaCIT loading may facilitate with lactate and H\(^+\) transport away from the muscle,\textsuperscript{29} thereby reducing the inhibitory effects of extreme metabolic acidosis on rate-limiting enzymes.\textsuperscript{30}

Our results clearly show a significant increase in \([HCO_3^-]\), BE, and pH after the acute ingestion of 0.2 g·kg\(^{-1}\) of NaCIT. To our knowledge, this is the first study that has examined both the hypervolemic effects of sodium loading, as well as the potential alkaline effects of specific-sodium species. It is evident, based on the present results, that acute NaCIT loading will improve both plasma volume and blood alkalinity before exercise.

**Conclusions**

NaCIT ingestion before exercise appears to expand plasma volume and improve buffering capacity. The ability for oral PV expanders to reduce physiological strain and improve thermoregulation during moderate-intensity steady-state exercise in warm environments remains unclear. The current study was able to show many positive trends; however, more work is needed to better define the role that NaCIT could serve in an athletic population. The most important finding of the current study was the ability for the NaCIT to maintain plasma volume for the majority of heat-stressed exercise, and increase the buffering capacity of the athletes. NaCIT did not alter core temperature, heart rate, \(\text{VO}_2\), RER, \(\text{VE}\), or perceived exertion. It is therefore concluded that the marginal physiological changes brought
about by sodium citrate loading were not large enough to alter thermoregulation or cardiovascular strain during moderate-intensity exercise in a warm environment.

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