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Effect of Sodium Supplements and Climate on Dysnatremia During Ultramarathon Running

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Abstract

Objective: Analyze the effect of sodium supplementation, hydration, and climate on dysnatremia in ultramarathon runners. **Design:** Prospective observational study. **Setting:** The 2017 80 km (50 mile) stage of the 250 km (150 mile) 6-stage RacingThePlanet ultramarathon in 2017 Chilean, Patagonian, and 2018 Namibian, Mongolian, and Chilean deserts. **Participants:** All race entrants who could understand English were invited to participate, with 266 runners enrolled, mean age of 43 years (± 9), 61 (36%) females, average weight 74 kg (± 12.5), and average race time 14.5 (± 4.1) hours. Post-race sodium collected on 174 (74%) and 164 (62%) participants with both the blood sample and post-race questionnaire. **Intervention:** Weight change and finish line serum sodium levels were gathered. **Main outcome measures:** Incidence of exercise-associated hyponatremia (EAH; <135 mmol·L^{-1}) and hypernatremia (>145 mmol·L^{-1}) by sodium ingestion and climate. **Results:** Eleven (6.3%) runners developed EAH, and 30 (17.2%) developed hypernatremia. Those with EAH were 14 kg heavier at baseline, had significantly less training distances, and averaged 5 to 6 hours longer to cover 50 miles (80 km) than the other participants. Neither rate nor total ingested supplemental sodium was correlated with dysnatremia, without significant differences in drinking behaviors or type of supplement compared with normonatremic runners. Hypernatremic runners were more often dehydrated [8 (28%), −4.7 kg (± 9.8)] than EAH [4 (14%), −1.1 kg (± 3.8)] ($P < 0.01$), and EAH runners were more frequently overhydrated (6, 67%) than hypernatremia (1, 11%) ($P < 0.01$). In the 98 (56%) runners from hot races, there was EAH OR = 3.5 [95% confidence interval (CI), 0.9-25.9] and hypernatremia OR = 8.8 (95% CI, 2.9-39.5) compared with cold races. **Conclusions:** This was the first study to show that hot race climates are an independent risk factor for EAH and hypernatremia. Sodium supplementation did not prevent EAH nor cause hypernatremia. Longer training distances, lower body mass, and avoidance of overhydration were shown to be the most important factors to prevent EAH and avoidance of dehydration to prevent hypernatremia.

Key Words: exercise-associated hyponatremia, hypernatremia, ultramarathon, dehydration, heat, sodium, runners

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INTRODUCTION

Ultramarathon running events have increased in popularity around the world, with voluntary electrolyte supplements used by 90% to 96% of participants.[1] Sodium supplements in endurance runners are believed to prevent a myriad of symptoms including nausea, muscle cramping, and impaired performance[1] and are advocated by American College of Sports Medicine Guidelines to help prevent hyponatremia.[2] Although fluid ingestion with sodium may maintain plasma volume better than water alone during exercise,[3] and supplements may help maintain serum sodium levels,[4,5] most evidence suggests that these are not protective against development of exercise-associated hyponatremia (EAH).[1,3,6–8] Exercise-associated hyponatremia is defined as a serum sodium concentration below 135mEq/L. It is recognized as a relatively common issue in endurance running events and has multifactorial causes including excessive fluid intake and inappropriate arginine vasopressin (AVP) secretion.[9] Exercise-associated hyponatremia is not caused by sodium deficits arising from either inadequate sodium intake or sweating.[10]

Exercise-associated hyponatremia most often manifests as nonspecific symptoms such as nausea, vomiting, dizziness, and fatigue that can progress to encephalopathy, seizures, pulmonary edema, or death, with 14 documented fatalities.[9] Symptoms of EAH also mirror those of hypernatremia,[11] which has been found to be more prevalent than EAH in collapsed marathon and ultramarathon runners.[12–14] Greater amounts of sodium supplementation have not been found to induce hypernatremia,[7,15] but prior research on sodium supplementation's impact on hypernatremia had relatively

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few cases limiting insight into the full spectrum of this dysnatremic relationship.[1]

Exertion in hot climates increases hydration requirements, as heat stress stimulates normal physiologic changes such as increased sweating, AVP secretion, and thirst to maintain homeostasis.[16] Furthermore, larger volumes of water intake are needed to compensate for increased fluid losses from exercise in warmer compared with colder conditions.[17] As fluid consumption during exercise contributes more to EAH development than does the lack of sodium supplementation,[9] and the majority of runners with hypernatremia is often dehydrated,[18] it stands to reason that differing climates and their contrasting hydration requirements may independently effect dysnatremia. The objective of this study was to describe the effect of sodium ingestion, hydration, and climate on incidence of EAH and hypernatremia in ultramarathon runners. Our hypothesis was that hot climates, rather than sodium supplementation, would be an independent risk factor for increased incidence of dysnatremia.

METHODS

Setting and Selection of Participants

This study was a prospective observational study during an 80-km (50 mi) stage of a 6-stage 250-km (155 mi) ultramarathon in Chile and Patagonia (2017) and Namibia, Mongolia, and Chile (2018). All participants were offered the same amount of water for any given day [approximately 1.5L per 10-12 km (6-7.5 mi)], had to carry at least 2000 kcal/d (verified during registration), and did not receive any food beyond what they carried. Participants were required to carry all their personal items throughout the entire race, including clothes, sleeping gear, emergency gear, and their own food for the entirety of the race. As the races were of similar distances and required similar logistical and physical demands, they were combined for analyses.[1]

Research Design

All entrants competing in a RacingThePlanet ultramarathon who could understand English were invited to participate in the study. During a mandatory prerace registration, informed consent was obtained and baseline demographics were recorded along with the runner's plan for sodium supplementation type, rate, and hydration strategy. The Stanford University School of Medicine institutional review board approved this study.

Before the start of the 80-km (50 miles) stage of the 6-stage 250-km (150 mile) race, body weight measurements (with shoes and running gear excluding backpack) were obtained with a battery-powered digital scale (SC-505 HoMedics; Commerce Tsp, MI) placed on a solid level surface. Immediately upon completion of the race at the finish line, study participants were re-weighed and an on-site analysis of serum sodium, blood urea nitrogen (BUN), and creatinine were obtained by point-of-care i-STAT (Abbott Point of Care, NJ) from finger-tip blood samples before postrace hydration could occur. Self-reported adherence to sodium supplementation and hydration strategies was obtained at that time. Sodium intake rates were calculated by dividing the total sodium consumption by individual finishing time. Both the point-of-care device and the digital scale were calibrated before taking measurements.

The following definitions were used: hypernatremia >145 mmol·L^{-1}, normonatremia 135 to ≤ 145 mmol·L^{-1}, and hyponatremia <135 mmol·L^{-1}. Hydration status was based on body weight changes with $\geq 0\%$ body weight change as overhydration, <0 to -3% body weight change as euhydration, and $<-3\%$ body weight change as dehydration.[19]

The hot or cold climate category for each race was derived using the 1-km (0.6 mi) resolution NASA MODIS satellite land surface temperature at the race location on the day of the race.[20] Land surface temperatures were adjusted to approximate air temperature using the barren earth correction.[21] Data from adjacent days for Patagonia and Mongolia were necessary as these were the closest days to the race day without cloud cover. Hot races were determined to be those with greater than 75°F (24°C) daytime high temperature.

Statistical Analysis

A descriptive analysis evaluated the participant demographics, baseline pack weight, and prior racing history. Race finishing time, serum sodium, body weight change, and adherence to prerace plan were described. The relationship between dysnatremia and rates of sodium ingestion was estimated with a Pearson product–moment correlation test and linear least-squares regression.

Analyses of univariate comparisons were performed with the Pearson's χ^2 test for categorical variables and analysis of variance for continuous variables. Logistic regression was used to examine multivariate risk factors for odds ratios. Significance was considered for P values <0.05, and 95% confidence intervals (CIs) were used. All analyses were conducted using computerized software (R 3.5.3 software; Vienna, Austria).

RESULTS

Two-hundred sixty-six runners were enrolled in the study, with post-race serum sodium measurements on 174 (74%) and 164 (62%) with full data (with both a blood sample and completed postrace questionnaire). Participant characteristics are described by postrace serum sodium concentrations in Table 1. Study participants diagnosed with EAH weighed approximately 13 to 14 kg (at baseline) more than the other groups, were on average 8 to 9 cm taller, and took 5 to 6 hours longer to complete the 50-mile (80 km) run. The relationship of weight, race time, and postrace sodium is shown in Figure 1. Those with hypernatremia were found to have had significantly greater training distances and maximum distances run per week. Also, those diagnosed with hypernatremia had significantly more elevated finish line BUN to creatinine ratios (BUN/Cr) greater than 20, which is an accepted biochemical definition of intravascular dehydration. Otherwise, there were no statistically significant differences in racer characteristics among those with dysnatremia versus normonatremia.

In those study participants with a measured postrace serum sodium, 11 (6.3%) were hyponatremic, 30 (17.2%) were hypernatremic, and 130 (76.4%) were normonatremic. These groups are shown by hydration status in Table 2. Hypernatremic runners were more often dehydrated than those with EAH ($P < 0.01$), and runners with EAH were more frequently

TABLE 1. Participant Demographics and Variables Categorized by Serum Sodium

Variable	Hypernatremia, Mean (SD)	Hyponatremia, Mean (SD)	Normonatremia, Mean (SD)	Average, Mean (SD)	*P*
Runner characteristics					
Age	39.5 (8.9)	43.7 (10.7)	43.5 (8.7)	42.8 (9)	0.1
Sex					
Female, (%)	10 (16.4)	2 (3.2)	49 (80.3)	61 (35.9)	0.4
Male, (%)	19 (17.4)	9 (8.3)	81 (74.3)	109 (64.1)	
Height, cm	175 (8.5)	183 (7.8)	174.1 (8.7)	174.8 (8.8)	0.01
Weight (starting), kg	72.4 (11.6)	86.5 (7.9)	73.8 (12.5)	74.3 (12.5)	0.01
BMI, kg/m^2	23.6 (2.9)	25.2 (1.5)	24.2 (3.3)	24.2 (3.1)	0.36
Pack weight (starting), kg	9.4 (1.1)	10.5 (2.5)	9.9 (1.9)	9.9 (1.8)	0.22
#Prior marathons	14.3 (21.9)	4.8 (4.9)	8.6 (14.9)	9.32 (16)	0.16
#Prior ultramarathons	10 (12.8)	4.3 (5.6)	6.9 (7.8)	7.3 (8.8)	0.12
Running distance/wk, km	101 (122.1)	67.4 (41.6)	62.3 (30.1)	69.5 (59.8)	0.01
Greatest running distance/wk, km	164.1 (124.5)	80.8 (69.9)	121.5 (90.2)	126.4 (97.3)	0.03
Longest single run	133.2 (133.8)	115.3 (22.2)	117.9 (76.8)	120.4 (87.2)	0.69
Postrace analyses					
Total race time, h	13.3 (2.7)	19.5 (5.7)	14.4 (4)	14.5 (4.1)	0
Serum sodium	150 (4.6)	130.8 (3.3)	139.4 (2.4)	140.7	0
BUN	37.7 (13.8)	28 (15.6)	25.3 (9.7)	27.6 (11.8)	0
Creatinine	1 (0.2)	1.4 (0.9)	1 (0.3)	1 (0.4)	0
BUN/creatinine >20	27 (90%)	6 (55%)	88 (66%)		0.01

overhydrated than those with hypernatremia ($P < 0.01$). A number of variables were compared for the drinking plan and type of sodium supplement ingested with no significant differences found between the normonatremic and dysnatremic groups (Table 3). Comparison of body weight changes, total sodium intake, and intake rate (mg/h) did not significantly differ among groups (Table 4). Total sodium consumption is shown versus rate of sodium consumption in Figure 2. The rate of sodium ingestion was not well correlated with total postrace sodium ($r^2 = -0.007$, −0.0171 to 0.158), hypernatremia ($r^2 = 0.312$, −0.088 to 0.612), or EAH ($r^2 = 0.301$, −0.454 to 0.804) (Figure 3). Total ingested sodium was not significantly correlated with EAH ($r^2 = 0.302$, 95% CI, 0.09-0.61, $P = 0.13$) or hypernatremia ($r^2 = 0.301$, 95% CI, 0.45-0.8, $P = 0.43$).

There were 98 (56%) runners enrolled from hot races and 76 (44%) from cold races. The average daytime temperature for the hot races was 92.8°F (33.8°C) and for the cold races was 57.7 °F (14.2°C). Eighty-eight percent of dysnatremic cases occurred during hot races, and 37% of the hot race runners were dysnatremic versus 7% of cold race participants. The odds ratio of EAH in a hot race was 3.5 (95% CI, 0.9-25.9), and the hypernatremia odds ratio was 8.8 (95% CI, 2.9-39.5) compared with cold races (Figure 4).

DISCUSSION

This study found that neither the rate of sodium supplementation per hour nor the total amount of sodium ingested over an 80-km (50 mi) ultramarathon was correlated with hypernatremia, EAH, or normonatremia. These findings were consistent with prior ultramarathon research,[1,7,22] as was the average sodium consumption rate.[1] The majority of runners was found to be normonatremic despite varied sodium intake, providing further evidence that sodium supplementation is not primarily responsible for the prevention of EAH or development of hypernatremia in ultramarathon runners.

The incidence of hypernatremia was 3 times greater than EAH and twice the prevalence as previously reported in investigations of supplement effects on dysnatremia.[1] Hypernatremia occurs when there is a deficit of total body water relative to sodium content.[23] The principle cause of hypernatremia in this population is unclear but is likely due to volume loss which is reflected in the significantly greater incidence of both biochemical dehydration and total weight loss. Cumulative exertion in endurance running contributes to greater dehydration,[18] and it is possible that the hypernatremic runners had greater fitness and amount of race exertion as they were found to have significantly greater training distances than the other groups. Also, the slowest ultramarathon runners have been found to be least likely to develop biochemical evidence of acute kidney injury (which is predicted by amount of dehydration).[24] Our findings of greater weight loss and faster finishing times in those with hypernatremia compared with those with hyponatremia are similar to those observed in Ironman triathletes.[25] This relationship of fitness, race exertion, dehydration, and hypernatremia is likely connected in ultramarathon runners. Hypernatremia as a dysnatremic entity is less commonly discussed than EAH,[9] and in the most symptomatic endurance athletes, it has predictive morbidity.[12–14] As such, "exercised-induced hypernatremia" deserves recognition as a separate disease entity to help define this dysnatremia for awareness, treatment consideration, and future research.

This was the first study to describe how hot environmental conditions were a strong independent risk factor for hypernatremia, increasing the odds by 9 times over a cold weather

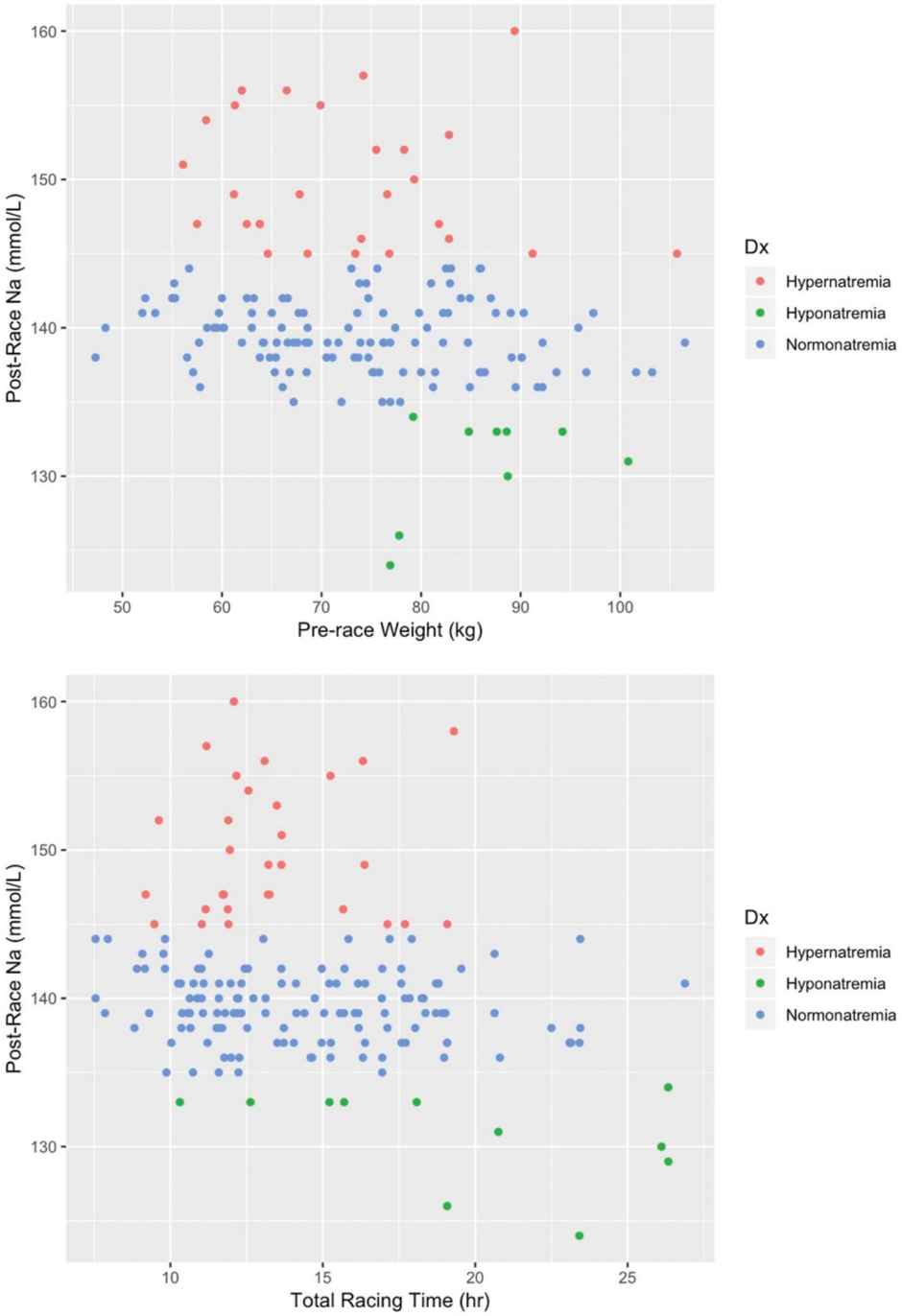

Figure 1. Pre-race weight and total racing time by serum sodium.

race. The greater hypernatremia seen in hot races was likely due to larger amount of insensible fluid losses as hypernatremic runners were dehydrated, consistent with prior observations.[18,25,26] Furthermore, hot weather races have been found to be strongly correlated with greater finish line intravenous fluid hydration requirements in ultramarathons

TABLE 2. Finishers Classified Into Different Groups by Hydration and Serum Sodium

Category	Overhydration	Euhydration	Dehydration	N/A	Total
Hypernatremia	4 (14.3)	16 (57.1)	8 (28.6)	2	30
Hyponatremia	6 (66.7)	2 (22.2)	1 (11.1)	2	11
Normonatremia	25 (21.4)	45 (38.5)	47 (40.2)	16	133
Total	35	53	56	20	

TABLE 3. Comparison of Drinking Plan and Type of Sodium Supplement Ingested by Serum Sodium

Variable	Hypernatremia, N (%)	Hyponatremia, N (%)	Normonatremia, N (%)	*P*
Main determinants of fluid ingestion (plan)				0.72
Thirst	5 (17.2)	1 (9.1)	37 (28.5)	
Predetermined schedule	14 (48.3)	7 (63.6)	50 (38.5)	
Maximum tolerated	2 (6.9)	0	9 (6.9)	
Drink before thirsty	7 (24.1)	2 (18.2)	30 (23.1)	
Drink to urine amount or color	1 (3.5)	1 (9.1)	3 (2.3)	
Other	0	0	1 (0.8)	
Supplement type consumed				0.66
Salt tabs	7 (24.1)	1 (9.1)	24 (18.5)	
Mostly water with some electrolyte mix	2 (6.9)	2 (18.2)	12 (9.2)	
Equal water and electrolytes	2 (6.9)	3 (27.3)	27 (20.8)	
Mostly electrolyte mix	5 (17.2)	1 (9.1)	15 (11.5)	
Salt tabs and electrolyte mix	13 (44.8)	4 (36.4)	52 (40)	
Only water				

in addition to dehydration (as measured by weight loss).[22,26] These findings suggest that hydration requirements dictated by running in hot climates are more predictive of hypernatremia than excess sodium supplementation, similar to consensus guidelines for prevention and treatment of EAH.[9]

The majority of runners with EAH was overhydrated. This is consistent with the accepted paradigm of hydration as the predominant contributing factor for EAH.[19,27] There was a nonsignificant trend toward greater total sodium ingestion in those with EAH. This may seem counter-intuitive, but it has been previously suggested that excessive sodium intake could contribute to overhydration and EAH through osmoreceptor stimulation and increased symptoms of thirst[10] and increased fluid intake in those taking sodium supplements.[28] Considering that double the percent of those with EAH compared with those diagnosed with both normonatremia and hypernatremia drank mostly water with some electrolytes, this resulting hypotonic fluid mix likely contributed to their overhydration. It has been speculated that overhydration may be unnecessary to maintain hydration during endurance exercise in hot conditions.[29] However, as exercise in hot environments often causes sweat output to exceed water intake, and dehydration increases physiologic strain, decreases sweat rates, increases perceived exertion, and increases core temperatures [30,31]; it is not surprising that hydration requirements increased with hot air temperatures. The overhydration found in the hot races likely contributed to over 3 times the odds of EAH compared with cold races, a relationship that has been strongly correlated with air temperature.[22]

Rates of dysnatremia were not differentiated by drinking strategies. Thirst, defined as the feeling or need to drink, is controlled by the hypothalamus and delineated through regulatory pathways that are designed to protect plasma volume and osmolality.[32] Central osmoreceptors monitor the sodium serum concentration and receive input from peripheral baroreceptors and drive the desire to drink and regulate AVP secretion to guard against dehydration or overhydration. Unfortunately, the combination of overhydration secondary to thirst or inappropriate suppression of AVP may lead to water retention, decreased water excretion, and subsequent EAH. Therefore, guidelines now suggest that endurance athletes should be encouraged to drink ad libitum based on thirst and not at scheduled intervals.[32] As our findings that sodium supplementation during long endurance did not prevent EAH, and when combined with overhydration may have contributed to EAH, avoidance of overhydration (particularly in hot climates) should be advised.

One of the limitations of this study was that only runners who understood English were included, which was necessary as there were entrants from more than 25 countries at any one event, which may have inadvertently led to referral bias. Serum sodium concentrations were not collected before the race, which was not logistically feasible but has been an accepted methodologic approach.[1,18,24] Assumption of a normal serum sodium at the start of successive days of racing in healthy multistage marathon runners is accepted practice.[18,24,33] Daily caloric and water intake was not determined or sodium sweat rates, plasma volumes levels, or

TABLE 4. Weight Change, Sodium Intake, and Environment by Serum Sodium

Variable	Hypernatremia, Mean (SD)	Hyponatremia, Mean (SD)	Normonatremia, Mean (SD)	*P*
Body weight change (kg)	−4.7 (9.8)	−1.1 (3.8)	−4.4 (5.3)	0.29
Sodium intake rate (mg/h)	278 (161.9)	329 (194.5)	315 (214)	0.68
Total sodium ingested (mg)	362 (192)	611 (195)	440 (299)	0.08
Temperature of races				
Hot races (Atacama, Namibia)	27 (27.6%)	9 (9.2%)	62 (63.2%)	0
Cold races (Patagonia, Mongolia)	3 (3.9%)	2 (2.6%)	71 (93.4%)	0

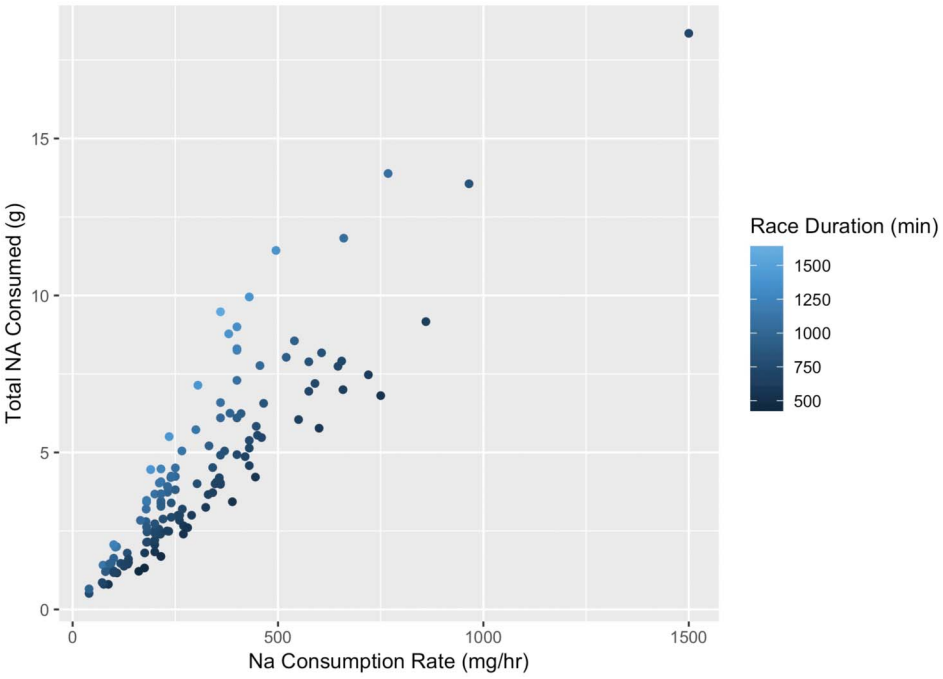

Figure 2. Total sodium consumption is shown versus rate of sodium consumption by race duration.

exact amount of sodium ingestion, which is consistent with prior work on this subject.[1,29] Exact amounts of sodium consumption may have been inaccurate because of recall bias, but this was consistent across all study participants. These measurements would have provided a more accurate reflection of sodium homeostasis and hydration status in this population. The study participants who were diagnosed with dysnatremia did not require medical care, which may limit generalization to other populations.[1] However, as those runners with EAH took 5–6 hours longer to complete the course than the other groups, this could have been a manifestation of their hyponatremic symptoms

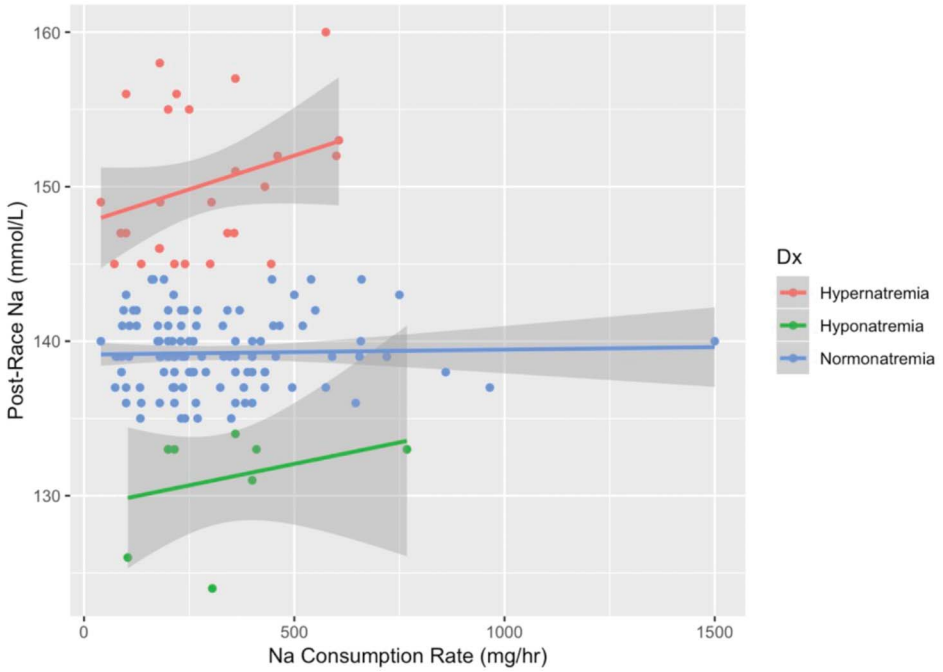

Figure 3. Postrace sodium versus sodium consumption rate by serum sodium.

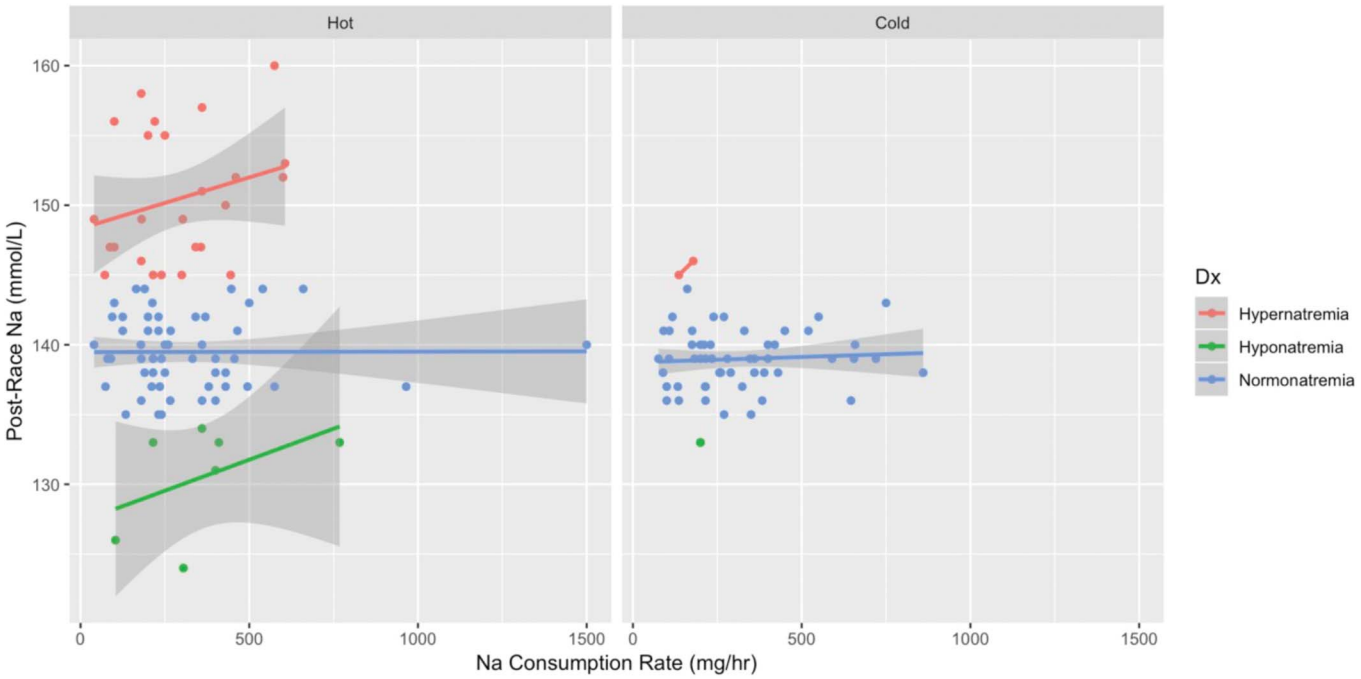

Figure 4. Postrace sodium versus sodium consumption rate by serum sodium and climate.

and enforces the utility of prevention by avoidance of overhydration.

CONCLUSIONS

This was the first study to show that hot race climates were an independent risk factor for hypernatremia and EAH compared with cold endurance running events. The use of sodium supplements did not prevent EAH or induce hypernatremia. Longer training distances, lower body mass, and avoidance of overhydration were shown to be the most important factors to prevent EAH and dehydration and hypernatremia seen in the fastest race finishers.

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