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Research article

Effects of Oral Sodium Supplementation on Indices of Thermoregulation in Trained, Endurance Athletes

Elizabeth L. Earhart, Edward P. Weiss ✉, Rabia Rahman and Patrick V. Kelly
Saint Louis University, Department of Nutrition and Dietetics, Saint Louis, MO, USA

Abstract
Guidelines recommend the consumption of sodium during exercise to replace losses in sweat; however, the effects of sodium on thermoregulation are less clear. To determine the effects of high-dose sodium supplementation on indices of thermoregulation and related outcomes, 11 endurance athletes participated in a double-blind, randomized-sequence, crossover study in which they underwent 2-hrs of endurance exercise at 60% heart rate reserve with 1800 mg of sodium supplementation (SS) during one trial and placebo (PL) during the other trial. A progressive intensity time-to-exhaustion test was performed after the 2-hr steady state exercise as an assessment of exercise performance. Sweat rate was calculated from changes in body weight, accounting for fluid intake and urinary losses. Ratings of perceived exertion (RPE) and heat stress were assessed using verbal numeric scales. Cardiovascular drift was determined from the rise in HR during the 2-hr steady state exercise test. Skin temperature was measured with an infrared thermometer. Dehydration occurred in both SS and PL trials, as evidenced by substantial weight loss (2.03 ± 0.43% and 2.27 ± 0.70%, respectively; $p = 0.261$ between trials). Sweat rate was 1015.53 ± 239.10 $ml \cdot hr^{-1}$ during the SS trial and 1053.60±278.24 ml/hr during the PL trial, with no difference between trials ($p = 0.459$). Heat stress ratings indicated moderate heat stress ("warm/hot" ratings) but were not different between trials ($p = 0.825$). Time to exhaustion during the SS trial was 6.88 ± 3.88 minutes and during the PL trial averaged 6.96 ± 3.61 minutes, but did not differ between trials ($p = 0.919$). Cardiovascular drift, skin temperature, and RPE did not differ between trials (all $p > 0.05$). High-dose sodium supplementation does not appear to impact thermoregulation, cardiovascular drift, or physical performance in trained, endurance athletes. However, in light of the possibility that high sodium intakes might have other adverse effects, such as hypertension, it is our recommendation that athletes interpret professional recommendations for sodium needs during exercise with caution.

Key words: Salt, sweat, hydration, heat stress, heart rate, electrolyte.

Introduction

The physiological effects of decreased plasma volume and low serum sodium concentration have been studied extensively in endurance performance. It is clear that appropriate hydration plays a role in thermoregulation and cardiovascular changes during exercise (von Duvillard et al., 2004). Although increases in sodium intake are encouraged to offset sodium losses in the form of sweat (ACSM exercise and fluid replacement guidelines recommend 20-30 mEq $sodium \cdot L^{-1}$ (~460-690 $mg \cdot L^{-1}$) fluid during exercise), high serum sodium concentrations reduce sweat rates and thus, could impair thermoregulation (Cosgrove and Black, 2013; Sawka et al., 2007; Shibasaki et al., 2009). Based on recommendations and perceptions, many endurance athletes consume salt supplements while exercising, despite the possibility that salt may impair thermoregulation during prolonged endurance exercise.

During endurance exercise, sweat rates of athletes typically average 1.0-1.5 L of fluid per hour. The amount of sodium lost during exercise averages 0.8 grams per liter of sweat, but can vary with genetics, diet, heat acclimatization and hydration status (Sawka et al., 2007). One proposed mechanism by which sodium alters sweat rate is due to its impact on active cutaneous vasodilation through changes in plasma osmolality. As core body temperature increases during exercise, skin blood flow and sweat rate increase. Subsequently, heat dissipation occurs. Increased plasma osmolality, either by ingestion of sodium or dehydration, raises the core body temperature threshold at which sweating occurs, delaying cutaneous vasodilation and lowering sweat rate (Wendt et al., 2007). Previous studies have addressed the effects of pre-exercise sodium loading on sweat rate and core body temperature, however the results were conflicting. One study showed no significant differences in sweat rate or core temperature during cycling with an isotonic sodium load vs. a hypotonic placebo in male cyclists (Coles and Luetkemeier, 2005). Two other studies with nearly identical protocols found that a concentrated sodium beverage delayed the rise in core body temperature, and lowered sweat rate when compared to a low sodium beverage in female cyclists, but the same effect was not seen with male cyclists (Sims et al., 2007a; 2007b).

The primary purpose of this research study was to determine the effects of high-dose salt consumption during long-duration endurance exercise on indices of thermoregulation in trained, endurance athletes. Earlier research studies focused on largely on pre-exercise sodium intake and used lower doses of sodium supplementation (~300-700 $mg \cdot hr^{-1}$). Additionally, the method of sodium delivery was typically through oral fluid ingestion or intravenous injections in a laboratory setting, as opposed to tablets or capsules, which more closely resemble real-world practices. Because thermoregulation impacts other areas of endurance performance, a secondary purpose of the study was to examine the effects of salt supplementation on cardiovascular drift, perceived rating of exertion and time to exhaustion. It was hypothesized that high-dose salt supplementation during 2 hours of endurance exercise would decrease sweat rate, increase perceived

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heat stress, decrease the magnitude of cardiovascular drift, decrease the rating of perceived exertion, and increase time to exhaustion.

Methods

Participants

The experimental protocol was approved by the Saint Louis University Institutional Review Board, and informed consent was obtained from all participants. Participants could include males and females, aged 18-60 years. Participants met the qualifications for the study if they were considered at low risk for medical complications based on the American College of Sports Medicine's Risk Classification (ACSM, 2010). Screening indicated participants' current use of salt tablets for training. Participants were also required to be "trained, endurance athletes" based on current training status. Specifically,they must have been running greater than or equal to 30 miles (~48 km) each week, road-cycling greater than or equal to 150 miles (~241 km) each week, off-road cycling greater than or equal to 70 miles (~113 km) per week, or an equivalent combination of these or another form of endurance exercise (i.e. swimming). The participants must have been training for a minimum of 6 months prior to the study and must have been able to perform 2-hour bouts of endurance exercise at least once every 1-2 weeks to ensure that they could tolerate the test protocol.

Study design

The study was a randomized, crossover design and was operationalized into measures of sweat rate, heat stress, skin temperature, cardiovascular drift (heart rate), rating of perceived exertion, and time to exhaustion.

Testing occurred on two separate occasions, with the participants completing one placebo (PL) test and one experimental test with sodium supplementation (SS). The number of days between tests ranged from 7 to 26 days (13.5 ± 6.45 days). The requirement for time between tests was a minimum of 7 days (Sims et al., 2007b). The PL and SS trials were double blinded and randomized to avoid bias and sequencing effects. During the SS trial, participants received 5 capsules containing sodium chloride. Each capsule contained 360 mg sodium, 540 mg chloride. One capsule was given immediately prior to starting the test and every 25 minutes thereafter (at minute 25, 50, 75, and 100). Participants received a total of 900 mg/hour of sodium. This rate was chosen to supply roughly half of the average amount of sodium lost in 1-1.5 L of sweat in one hour and a greater amount than that used in previous studies that showed no effect (Volpe, 2007, Janik et al., 2009). The PL trial received an equal number of capsules containing cornstarch on the same ingestion schedule. Participants received 0.4-0.8 $L \cdot hr^{-1}$ hr of water based on body weight (0.4 $L \cdot hr^{-1}$ for body weights of 50-<70 kg, 0.6 L/hr for body weights of 70-<90kg, 0.8 L/hr for body weights >/=90 kg), as this is the amount of fluid recommended to prevent significant dehydration (>2% body weight loss during exercise) or over-hydration during distance events (ACSM, 2010). They were instructed to consume all of the provided water during the course of the 2-hour test; although most participants consumed a portion of the provided water with the capsules, there was no specific requirement for this. Allowing the subjects to drink the water ad libitum during the trials was done to mimic a real-world training setting in which participants would consume as much water as they determined to be sufficient when taking the capsules.

Diet & exercise control

Participants were required to keep a log of their food and beverage intake for 48 hours prior to the first test. They were instructed to consume the same food and beverages for the 48 hours before the second test. Participants were educated by a registered dietitian to follow a sodium-restricted diet (<2300 mg) and to drink a minimum of 1.9 liters per day of water or non-alcoholic, non-caffeinated fluids for the 48 hours prior to each test. The rationale for a low-sodium diet was to ensure that there was a large relative increase in sodium intake with supplementation, which would be expected to maximize the effects on outcomes. Participants were instructed to keep an exercise log for the 48 hours prior to both tests, keeping each of the 48 hours as similar as possible; including the avoidance of any strenuous exercise that would impair their ability to test.

Exercise protocol

Trials consisted of 2-hour bouts of treadmill running (PPS series treadmill, Woodway USA, Inc., Waukesha, WI) or cycling at steady state intensity, as used previously in an unpublished study (Janik et al., 2009). Cycling participants were allowed to use their own bikes set on indoor trainers that were equipped with power meters (PowerTap, CycleOps Inc., Madison, WI). Both modes of exercise, running and cycling, were included in the study to increase recruitment potential for participants and there is no reason to believe that runners and cyclists would respond differently to the intervention. The target intensity was determined for each individual based on 60% of his or her estimated heart rate reserve (HRR) (Target HR = 0.6*(HRmax-HRrest) + HRrest). Work rate was determined by incrementally increasing workload (speed on the treadmill, power output for cycling) until 60% HRR was achieved. Runners began the test by self-selecting a pace that they would be able to comfortably hold a conversation while walking or jogging for 3 minutes; the speed was increased by 0.16-0.32 km per hour each minute until target HR was reached. Cyclists began the test at a self-selected pedal rate to achieve a power output of 50 watts for 3 minutes; power was increased by 25 watts each minute until target HR was reached. This final workload (speed and/or wattage and pedal rate) was held constant for the remainder of the test. During the second trial for each participant, the exercise progression and steady state work rate was replicated and was not dependent on HR response. Temperature and humidity were recorded for each trial and kept within a narrow range.

Sweat rate

Participants were weighed on a balance beam scale (Detecto, Inc., Webb City, MO) prior to exercise, in dry, lightweight clothing or a hospital gown, before and after urinating to account for urinary water loss, and after exercise. Post-exercise weight was determined after participants towel-dried to remove as much sweat as possible and changed into dry, lightweight clothing or a hospital gown. Fluid intake was monitored throughout each test, ensuring that participants consumed all of the water provided. The calculation used for sweat loss was as follows: Sweat Loss (mL) = ((Initial body weight (g) – Final body weight (g)) + Fluid intake (g) – Urinary water excretion (g). While this approach for measuring sweat rate did not account for respiratory water losses, respiratory water losses would likely have been similar between trials, as it depends on ventilation rate and ambient air humidity, which were similar in both study conditions.

Heart rate & cardiovascular drift

Heart rate was measured at rest and every 15 minutes during exercise with a wristwatch-type heart rate monitor (FS2c HR monitor, Polar Electro, Kempele, Finland). The absolute rise in heart rate after participants reached 60%HRR was calculated as an index of cardiovascular drift.

Thermal sensation

Heat stress was recorded using an a thermal sensations rating scale ranging from “unbearably cold” (0.0) to “comfortable” (4.0) to “unbearably hot” (8.0), and was recorded every 30 minutes during each test (Tyler and Sunderland, 2011). Participants were verbally educated on how to interpret the thermal sensations scale prior to the first test. Skin temperatures were taken using a non-contact, infrared thermometer (Dermatemp$_{TM}$ Infrared Temperature Scanner Model #DT1000, Exergen Corp, Newton, MA). Temperatures of the biceps, calf, chest and thigh were recorded at rest, 60 minutes, and post-exercise (Sims et al., 2007a; 2007b).

Perceived exertion

Rating of perceived exertion was determined using Borg’s Scale, with 6 indicating “no exertion at all” and 20 indicating “maximal exertion” (Borg, 1998). Participants were verbally educated on how to interpret Borg’s Scale prior to the first test. Recordings were taken every 15 minutes during each test (ACSM, 2010).

Time to exhaustion

Time to exhaustion was determined with a time trial performance conducted immediately after the 2-hour bout of exercise. For cycling participants, power output was systematically increased by 25 watts each minute. For treadmill participants, the time trial was administered by increasing treadmill grade by 1.0% each minute with speed remaining constant. Time to exhaustion was recorded as the time to volitional exhaustion; peak HR and peak RPE were recorded.

Statistical analysis

The data were analyzed using between-trial paired t-tests for all outcome measures. Significance was based on p-value ≤ 0.05. Data are presented as means ± SD unless otherwise indicated. Analyses were performed with statistical functions in Microsoft Excel 2007.

Results

Participants

A total of 14 participants were recruited and consented to participate in the study. Two running participants (1 male, 1 female) completed the first test, but withdrew from the study before completing the second test due to schedule conflicts. A third participant (female cyclist) was forced to stop prior to completing the second test due to gastrointestinal distress upon ingestion of the first capsule, which was determined to be sodium after un-blinding the data. Data were analyzed for the 11 remaining participants (4 males, 7 females). Two participants chose to cycle for the 2-hr exercise tests, while 9 participants opted to run on the treadmill. All 11 participants had a background in endurance training; participants’ endurance training level varied from half-marathon training to full Ironman triathlon training and ultra-distance running. The majority of tests were separated by 1-2 weeks (13.5 ± 6.45 days). Three participants completed the tests more than two weeks apart (21, 22, and 26 days between tests). Characteristics of the participants are shown in Table 1.

Table 1. Participants (n =11) characteristics. Values are means (±SD).

Age (y)		30.45 (12.04)
BMI (kg·m^{-2})		22.72 (2.70)
Height (m)	**Male**	1.80 (.01)
	Female	1.64 (.05)
Weight (kg)	**Male**	81.12 (4.19)
	Female	57.69 (9.24)
WC (cm)	**Male**	81.63 (4.31)
	Female	68.71 (5.47)

BMI, body mass index. WC, Waist Circumference

Table 2. Study outcomes. Values are means (±SD).

	Salt Trial (SS) (n = 11)	Placebo Trial (PL) (n = 11)
Card Drift (bpm)	14.59 (12.60)	14.95 (13.47)
Sweat Rate (ml·hr^{-1})	1016 (239)	1054 (278)
Weight loss (%)	2.03 (0.43)	2.27 (.70)
Ch Skin Temp (°C)		
Biceps	-1.05 (1.64)	-1.87 (1.55)
Calf	-1.90 (1.52)	-2.15 (1.59)
Thigh	-1.13 (2.09)	-2.05 (1.37)
Chest	-2.29 (1.72)	-1.94 (1.52)
Peak HR	181 (13)	180 (12)
Peak RPE	16.4 (5.63)	18.00 (1.15)

Card, Cardiovascular. Ch Skin Temp, Change in Skin Temperature. RPE, Rating of Perceived Exertion.

Body weight & sweat rate

Between-trial initial body weight was not significantly different (SS trial 67.06 ± 14.22 kg; PL trial = 65.91 ± 14.19 kg), indicating that hydration, diet, and training levels remained fairly constant between trials. Weight loss over the duration of the tests indicates that dehydration did occur in both SS and PL trials. However, the weight loss did not differ significantly between trials ($p = 0.261$). Mean sweat rate was not significantly different between trials ($p = 0.459$) (Table 2). Sweat rate was significantly greater than zero ($p < 0.0001$ for both trials).

Skin temperature

Skin temperatures of the biceps, chest, calf, and thigh were not significantly different between the SS and PL trials at any of the recorded time points during the tests (0 minutes, 60 minutes, and post-time trial). Net change in skin temperatures of all sites from rest to post-time trial did not differ significantly between SS and PL trials (Table 2).

Thermal sensations & Rating of Perceived Exertion (RPE)

Mean thermal sensation ratings for heat stress were not significantly different between the SS and PL trials with both averaging 5.4 on the scale of 0.0 – 8.0. This corresponds to a verbal rating of "warm/hot." Over the course of the tests, thermal sensations ratings did not differ significantly between SS and PL trials (Figure 1). Thermal sensations ratings at 120 minutes were significantly greater than resting values ($p < 0.0001$ for both trials).

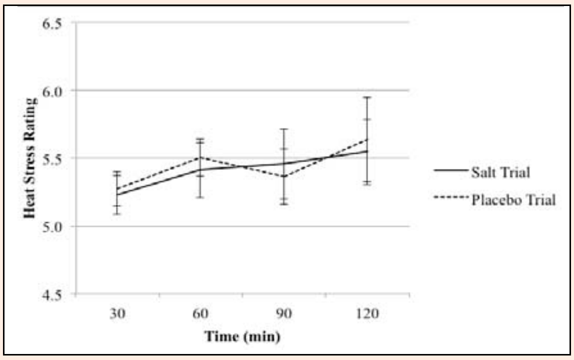

Figure 1. Change in Heat Stress during 2-hr bout of endurance exercise. Data are plotted as means ± SE.

Mean RPE did not differ significantly between SS and PL trials (12.97 ± 1.27 and 12.86 ± 1.31, respectively). This corresponds to a verbal rating of "somewhat hard." Over the course of the tests, RPE did not differ significantly between SS and PL trials (Figure 2).

Heart rate & cardiovascular drift

The target intensity was 60% HRR, however the observed intensity ranged from 55-78% HRR (64.09 ± 7.08% HRR) due to increases or decreases in heart rate in the first few minutes after achieving the target HR. After reaching the target intensity, HR continued to increase throughout the 2-hr period of steady state exercise (Table 2); the magnitude of increase was statistically significant in both trials (SS, $p = 0.004$; PL, $p = 0.003$). The magnitude of cardiovascular drift during the 2-hr bout of steady-state exercise was not different between trials ($p = 0.886$). Furthermore, over the course of the 2 hours, heart rate did not differ significantly between SS and PL trials at any time point (Figure 3).

Exercise performance

Time to exhaustion was not significantly different between SS and PL trials ($p = 0.919$). The mean time to exhaustion for the SS trial was 6.88 ± 3.88 minutes, while the mean for the PL trial was 6.96 ± 3.61 minutes (Table 2).

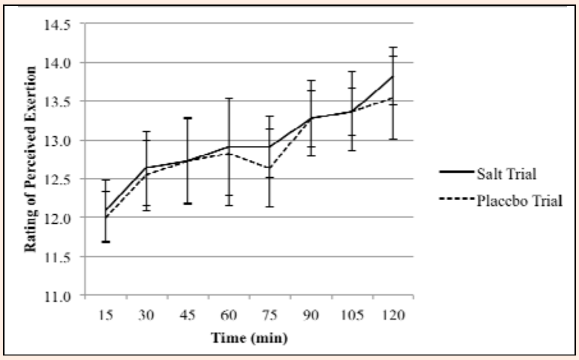

Figure 2. Change in RPE during 2-hr bout of endurance exercise. Data are plotted as means ± SE.

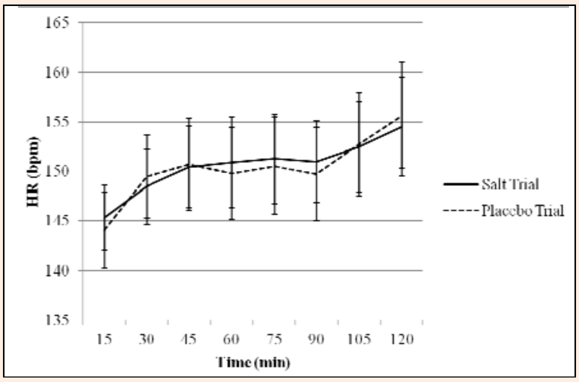

Figure 3. Change in HR during 2-hr bout of endurance exercise. Data are plotted as means ± SE.

Ambient conditions

Room temperature and humidity did not differ significantly between trials. Mean temperature during SS and PL trials was 21.04 ± 0.62°C and 21.29 ± 0.33°C, respectively. Mean humidity during SS and PL trials was 34.5 ± 11.00% and 34.88 ± 10.60%, respectively.

Side effects

Two cycling participants, whose data were included in the analysis, reported feelings of nausea during the SS trial upon ingestion of the salt capsules; one of these participants also reported cramping later in the evening after completion of the SS trial. One cycling participant, whose data were not included in analysis, was unable to complete the SS trial due to nausea and vomiting upon ingestion of the first salt capsule at the beginning of the test. No side effects were reported in any of the running participants, and no side effects were reported during any of the PL trials. Side effects were not explicitly measured or collected.

Discussion

Results from the present study indicate that high-sodium (900 $mg \cdot hr^{-1}$) salt supplementation did not have a significant effect on indices of thermoregulation during long-duration, endurance exercise of moderate to vigorous intensity, as evidenced by no effect on sweat rate, perceived heat stress, or skin temperatures. Furthermore, salt supplementation did not significantly affect cardiovascular drift, rating of perceived exertion, or time to exhaustion.

This research supports the findings of a field study conducted at an Ironman competition in which ad libitum salt consumption (~550 $mg \cdot hr^{-1}$) did not have a significant impact on weight change, perceived exertion or performance (Hew-Butler et al., 2006). Coles and Luetkemeier found no effect of pre-exercise sodium ingestion on measures of thermoregulation, including core body temperature and sweat rate, during a shorter duration exercise test (45-minute cycling test, followed by a 15-minute time trial) (Coles and Luetkemeier, 2005). However, findings from the present study refute two other studies, one that tested moderately trained, male runners, and the other that tested endurance trained, female cyclists. These earlier studies showed that sweat rates were significantly lower with ingestion of high-sodium fluid, although the lengths of the tests were shorter than the present study (~75-98 minutes at 70% VO_2peak), and the intervention fluids were administered pre-exercise (Sims et al., 2007a; 2007b).

As mentioned previously, the participants in the present study were required to be trained endurance athletes. However, a range of training levels still existed, with some participants being more endurance-trained than others. It is known that training results in certain physiological adaptations, including changes in response to heat stress with acclimatization. One such adaption is an increased sweat response and sweat rate with changes in core body temperature (Shibasaki et al., 2006). Therefore, variations in the level of training among participants may have caused some heterogeneity in responses to the intervention. Furthermore, while all participants completed the study within a 7-26 day time window (mean ± SD, 13.5 ± 6.45 days), it is possible that that changes in training status and the degree of acclimatization between study trials might have confounded the results. Lastly, the time course of the study spanned from spring to summer, and sweat rates vary with changes in environmental conditions (Torii et al., 1992). However, the likelihood of this being a confounding factor is minimal, as the study procedures were performed in a laboratory where temperature and relative humidity remained consistent throughout the study (mean 21.22°C and 36.55%, respectively).

The current study assessed perceived heat stress using a thermal sensations rating scale and showed no difference in the ratings between the SS and PL trials. It might be argued that these heat stress ratings did not differ between trials because the exercise was not performed in a heat chamber. However, mean thermal ratings were 5 to 6 on a 0 to 8 scale, indicating that the participants perceived a substantial heat stress. Furthermore, mean weight losses of 2.03% in the SS trial and 2.26% in the PL trial (despite meeting water consumption recommendations), and respective sweat rates of 1.02 $L \cdot hr^{-1}$ and 1.03 $L \cdot hr^{-1}$, provide physiologic evidence of heat stress. It is noteworthy that a 2% change in body weight is reflective of significant dehydration (hyperosmolar hypohydration) and this has been shown to reduce active cutaneous vasodilation (Shibasaki et al., 2009), which preserves blood pressure but further exacerbates heat stress.

Sodium supplementation is thought to alter heat stress through mechanisms involving serum osmolality. However, another factor besides sodium intake that affects osmolality is water consumption, via hemoconcentration and/or hemodilution. During dehydration, blood volume decreases to a greater extent than serum sodium levels, thereby creating hyperosmotic state and decreasing sweat rates despite increases in core temperature (Sawka et al., 1985). Furthermore, hyperosmolality after an infusion of hypertonic saline has been shown to decrease sweat rate and increase the core temperature threshold for cutaneous vasodilation during heat stress (Shibasaki et al., 2009). The high-dose sodium that was administered during the present study would have been expected to increase serum osmolality and thus decrease sweat rates. In this context, it is surprising that sweat rates did not differ between PL and SS trials.

In addition to serum osmolality being a determinant of sweat rates, blood volume also affects sweat rates, albeit to a lesser extent than osmolality (Sawka et al., 1985). Isosmotic hypovolemia (volume depletion without alterations in osmolality) has been demonstrated to reduce sweat rates, which is an effect thought to be important for preserving blood volume during exercise (Fortney et al., 1981). In the present study, the ~2% weight losses during exercise suggest that hypovolemia may have occurred and this may have decreased sweat rates during the 2-hr exercise bout. However, based on the comparable changes in body weight, changes in blood volume would likely have been similar between trials and therefore would not contribute to differences in sweat rates. In contrast to isotonic hypovolemia, isotonic hypervolemia (induced with water or glycerol) does not alter sweat rates (Fortney et al., 1981; Latzka et al., 1997). In the light of significant decreases in body weight during exercise in the present study, it is highly unlikely that hypervolemia occurred. Therefore, while hypervolemia from overhydration can lead to hemodilution and hyponatremia (Rosner, 2008), which may have important health consequences, it is not an important factor in the interpretation of sweat rate results from the present study.

There are several possible explanations for why the results did not reach significance or demonstrate an effect on the endurance performance parameters that were measured. One possibility is that the sample was too small. The *a priori* goal in our study was to determine if salt supplementation had a clinically relevant effect on sweat rate as the primary outcome variable (a clinically relevant change in sweat rate was defined as 10% or 142 ml/hr based on previous unpublished research from our laboratory). A post-hoc power analysis indicated that power for the present study was 0.85 for a 1-tailed test and 0.74 for a two-tailed test, suggesting that statistical power was adequate for detecting a clinically relevant effect, if such an effect was present.

Prior to each test, participants were required to follow a sodium-restricted (<2300 mg·day^{-1}) diet and record all food and beverage intake for 48 hours. Self-reported food diaries carry some degree of error in accuracy, and the amount of dietary sodium and fluid intake may have varied between tests. Although the food diaries were not analyzed to quantify exact nutrient intakes, they were compared on a qualitative basis, and with the exception of some small-to-modest variations in dietary intakes between trials the participants largely consumed the same diet prior to the two trials. The same limitation is true for the recorded exercise logs that participants were required to fill out for 48 hours prior to testing; again, based on qualitative review of the exercise logs, the participants reported similar activity patterns before the two study trials.

Skin temperature was measured using a non-contact infrared thermometer. The measurements were taken on the biceps, calf, thigh, and chest, although temperature readings are subject to variations due to air movement, sweat on the skin, and other unknown variables. While not feasible for the current study, future studies may benefit from measuring core body temperature as a more optimal indication of changes in thermoregulation.

Conclusion

In summary, high sodium (900 mg·hr^{-1}) salt supplementation did not have a significant effect on sweat rate, cardiovascular drift, heat stress, skin temperature, rating of perceived exertion, or time to exhaustion in trained endurance athletes. Based on these findings, high sodium intake during endurance exercise does not have adverse effects on thermoregulation as we had proposed. Nonetheless, it is still possible that high sodium intake during exercise may have other adverse effects, such as hypertensive blood pressure responses. In this context, we believe that professional recommendations for endurance athletes to consume high levels of sodium as currently recommended by ACSM guidelines should be interpreted with caution.

Acknowledgments
We are appreciative of the study participants for their time and cooperation. EE and EW designed the study. EE and EW collected the data and supervised its collection. EE and EW analyzed and interpreted the data. EE wrote the manuscript. None of the authors had a conflict of interest.

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Key points

- Based on current professional recommendations to replace sodium losses in sweat during exercise, some endurance athletes consume salt or other electrolyte supplements containing sodium during training and competition, however the effects of sodium on thermoregulation are less clear.
- High-dose sodium supplementation does not appear to impact thermoregulation, cardiovascular drift, or physical performance in trained, endurance athletes.
- The possibility remains that high sodium intakes might have other adverse effects. It is our recommendation that athletes interpret professional recommendations for sodium needs during exercise with caution.

AUTHORS BIOGRAPHY

Elizabeth L. EARHART
Employment
Saint Louis University, Saint Louis, MO, USA
Degree
MSc
Research interests
Nutrition and physical performance
E-mail: eearhart@slu.edu

Edward P. WEISS
Employment
Saint Louis University, Saint Louis, MO, USA
Degree
PhD, MSEd
Research interests
Nutrition and exercise for weight loss, the prevention of diabetes and cardiovascular disease, and the slowing of primary aging; nutrition for optimizing exercise performance
E-mail: eweiss4@slu.edu

Rabia RAHMAN
Employment
Saint Louis University, Saint Louis, MO, USA
Degree
MSc
Research interests
Pediatric nutrition, use of social media in nutrition counseling and nutrition education, international nutrition
E-mail: rahmanr@slu.edu

Patrick V. KELLY
Employment
Saint Louis University, Saint Louis, MO, USA
Degree
PhD
Research interests
Statistician
E-mail: kellypv@slu.edu

✉ **Edward P. Weiss, PhD, MSEd**
Saint Louis University, Allied Health Professions Building, 3076, 3437 Caroline Street St. Louis, MO 63104, USA