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# Effects of Acute Caffeine Consumption on Sodium-Aided Hyperhydration

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## Abstract

When utilized separately, pre-exercise hyperhydration or consumption of caffeine have both been shown to be ergogenic. Acute caffeine consumption has also been shown to promote diuresis in some situations, but this effect has not been studied when caffeine is used in conjunction with sodium-aided hyperhydration. We measured urine production during hyperhydration strategies performed with and without caffeine. Fifteen euhydrated subjects performed five strategies by consuming 20 mL water/kg bm alone (NT), or with a placebo (PL), 5 mg/kg bm caffeine (Caf), 110 mg/kg bm NaCl (Na), or 5 mg caffeine +110 mg NaCl/kg bm (CafNa). Total urine excretion was measured for 2 h following treatment consumption and expressed as a percentage of the total water consumed. Total two-hour urine excretion values were 103 16% (NT), 102 15% (PL), 116 18% (Caf), 68 14% (Na) and 85 14% (CafNa) of water consumed. No significant difference in urine excretion was detected between NT and PL. Caf resulted in significantly more, and Na in significantly less, urine excretion compared to all other strategies. CafNa resulted in significantly less urine excretion than NT, PL, and Caf, but significantly more excretion than Na. The results suggest that hyperhydration can be achieved when an acute caffeine dose is consumed in conjunction with sodium-aided hyperhydration; however, the level of hyperhydration is significantly less than attained when an equal dose of water and sodium are consumed without caffeine.

**Keywords:** Diuresis; Hydration; Ergogenic

**Abbreviations:** NT: No Treatment; PL: Placebo Treatment; Caf: Caffeine Treatment; Na: Sodium Treatment; CafNa: Caffiene+Sodium Treatment; USG: Urine Specific Gravity

## Introduction

Endurance athletes may use a wide variety of supplements and nutritional strategies to improve exercise performance. Caffeine use among endurance athletes is common [1] and numerous investigations have supported its efficacy as an ergogenic aid [2]. Likewise, pre-exercise hyperhydration has been shown to decrease rates of dehydration and improve physiological responses to, and performance of, exercise in hot environments [3-6]. Because both acute caffeine consumption and pre-exercise hyperhydration have been shown to improve exercise performance, endurance athletes may want to simultaneously utilize these procedures. However, caffeine may have acute diuretic effects in euhydrated individuals, which may cause some athletes to forgo its use prior to exercise in the heat.

Previous investigations have indicated that hypohydration can reduce exercise performance in the heat and lead to serious heat-related illnesses [7,8]. While consumption of fluid during exercise can effectively reduce rates of dehydration, some individuals such as soldiers or endurance athletes participating in unsupported training sessions, may not have access to adequate fluid supplies and/or may have sweat rates that exceed the maximum rate of gastric emptying for water [9,10]. These individuals are especially at risk for developing hypohydration. In such cases, the development of hypohydration during exercise can be curtailed by employing pre-exercise hyperhydration [4,6]. Previous investigations have revealed that when euhydrated subjects attempt to attain pre-exercise hyperhydration by consuming pure water or dilute fluid, most of the consumed fluids are not retained and no significant level of hyperhydration is achieved [4,11]. However, consuming a concentrated sodium beverage (164 mmol $Na^+$/L) has been shown to promote significant pre-exercise hyperhydration [4] and plasma volume expansion [12], resulting in improved physiological responses and performance during subsequent endurance exercise.

Caffeine has been shown to increase performance when taken prior to endurance exercise [13], with effective doses ranging from 3 to 9 mg/kg bm [2]. While the diuretic effect of caffeine appears to be influenced by hydration status and activity level [14], caffeine has been shown to promote diuresis when consumed in ergogenic amounts with large volumes of dilute, low-sodium fluids in resting, euhydrated individuals [15]. The observed diuretic effect of caffeine under these circumstances could hinder or prevent pre-exercise hyperhydration. However, it is unknown what level of diuresis may occur when caffeine is consumed in conjunction with a sodium-aided hyperhydration strategy. It is believed that caffeine promotes diuresis by increasing sodium excretion in the nephron [16], making it conceivable that consumption of an acute dose of sodium may reduce caffeine-induced diuresis in individuals who are attempting to become hyperhydrated. Thus, we sought to determine the effects of an acute, ergogenic dose of caffeine on urine production during hyperhydration strategies when fluids are consumed with and without sodium.

## Methods

Prior to subject recruitment, the procedures of this investigation were reviewed and approved by the institutional review board of the University of Texas – Permian Basin. Pilot work suggested that 12–15 subjects would be required to achieve suitable statistical power (0.80). Fifteen active male subjects (21 2 years, 176 6 cm, 80.2 10.1 kg) with no known digestive, vascular, or renal diseases signified their willingness

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to participate in this study by providing written informed consent. Following the informed consent process, subjects were weighed to the nearest 0.1 kg while wearing shorts and a t-shirt and familiarized with their role in the investigation. Subjects then returned to the laboratory on five separate occasions to undergo five different hyperhydration strategies. Each hyperhydration strategy was immediately followed by a two-hour urine collection period during which total urine excretion was measured. The hyperhydration strategies involved consumption of two energy bars (Clif Bar & Company, Emeryville, CA) each containing 27 g carbohydrate and 105 mg sodium as a simulated "pre-event snack", 20 mL/kg bm of distilled water, and one of five treatments: no treatment (NT), placebo (PL), 5 mg caffeine/kg bm (Caf), 110 mg NaCl/kg bm (Na), and 5 mg caffeine+110 mg NaCl/kg bm (CafNa) applied in a randomly assigned, double-blind, crossover design. All water and treatment doses were based on the subject's body mass obtained during their initial visit. During the NT strategy, subjects consumed only the pre-event snack and water. At least 72 h, but no more than seven days, elapsed between the application of each of the five strategies and each individual subject performed all of his five hyperhydration strategies at similar times of day.

## Experimental Procedures

Prior to each laboratory visit, subjects followed a diet and exercise protocol that required them to refrain from alcohol, caffeine, and other methylxanthines for 72 h. The subjects consumed a standardized, low sodium (~2400 mg) diet and refrained from exercise for 24 h prior to each visit. Prior to participating in the hyperhydration strategies, subjects were counselled on proper food choices and were given lists of caffeine containing foods and high-sodium foods to avoid and of low-sodium alternatives. Adherence to the dietary restrictions was monitored by diet logs that were completed by the subjects as they consumed foods and liquids throughout the day.

Subjects were 4 h post prandial prior to each visit and were required to be consistently euhydrated upon arrival at the laboratory. In addition to the aforementioned activity and dietary restrictions, likelihood of consistent euhydration was enhanced by having the subjects consume 0.5 L of water four and 2 h prior to arrival in the laboratory. To assess hydration status, subjects performed a complete bladder void upon arrival at the laboratory. From this void, a small sample of urine was used to assess urine specific gravity (USG) using a refractometer (Atago, Bellevue, WA). USG restrictions required subjects' USG to be less than 1.020 to assure euhydration [17] and, to ensure consistent hydration level, none of a subject's USGs from any of his five visits could vary by more than 0.010. If USG requirements were met, the subject's diet record was then examined and he was asked if he followed the dietary and activity restrictions. If any of the USG, dietary, or activity requirements were not met, the subject was rescheduled.

If dietary, USG, and activity requirements were met, subjects then began their hyperhydration strategy. Each strategy involved the consumption of the two energy bars, 20 mL/kg bm distilled water, and the experimental treatment. The energy bars, water, and treatments were taken in two equal doses. Subjects were allowed 5 min to consume each dose with 10 min between doses. Immediately following the consumption of the second dose, subjects underwent a two-hour urine collection period. During this period, subjects rested quietly in a climate-controlled laboratory (21-23°C and 40-50% relative humidity) while total urine excretion was collected and measured using a graduated cylinder. At the end of the two hour period, subjects were required to perform a complete, measured bladder void.

## Preparation of Experimental Treatments

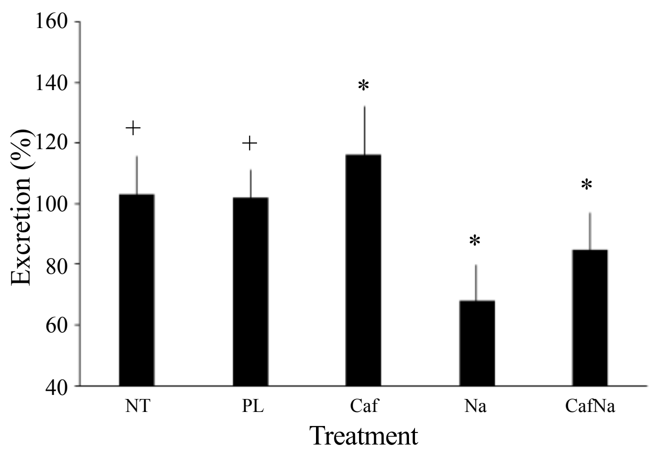
Sodium was provided via commercially available, non-iodized sodium chloride. Food-grade caffeine was provided in powder form (Fisher Scientific, Waltham, MA). The placebo consisted of commercially available, sodium-free cornmeal. Treatment doses were weighed to the nearest 0.1 mg using an Ohaus Adventurer SL scale (Ohaus Corporation, Parsippany, NJ) calibrated to manufacturer's specification and placed in "0" sized gelatin capsules. With the exception of NT where no capsules were consumed, the number of capsules was consistent among each hyperhydration strategy and treatments were visually indistinguishable to the subjects and investigators.

### Statistics

All statistics were performed with SPSS 22 (IBM, Armonk, NY). Total urine excretion for each of the five strategies was expressed as percent of total water consumed. USG values and total urine excreted for each of the five hyperhydration strategies were analyzed for differences using separate one-way repeated measure ANOVAs with Sidak post hoc analyses when appropriate. Level of significance was set a-priori at $p<0.05$. All values are expressed as *Means SD*.

## Results

Mean USG values were 1.006 0.003 (NT), 1.006 0.002 (PL), 1.006 0.004 (Caf), 1.007 0.003 (Na) and 1.005 0.004 (CafNa). No significant differences were detected between initial USG values of any of the protocols with p values ranging from 0.31 to 1.00. Furthermore, all subjects met USG requirements indicating that they were well and similarly hydrated for each trial. Two-hour urine excretion levels, expressed as a percentage of the amount of water consumed during the hyperhydration strategy, are presented in Figure 1. No significant difference in urine excretion levels was detected between the NT and PL strategies ($p=1.00$) and urine excretion levels indicated that these strategies resulted in a net fluid loss of approximately 0.6 mL/kg bm (NT) and 0.4 mL/kg bm (PL). The Caf strategy resulted in significantly greater urine excretion levels compared to all other strategies ($p=0.008$ *vs.* NT, $p=0.025$ *vs.* PL, $p<0.001$ *vs.* Na and CafNa) and urine excretion level during Caf indicated a net fluid loss of approximately 3.2 mL/kg




NT: No Treatment; PL: Placebo; Caf: Caffeine; Na: Sodium; CafNa: Caffeine+Sodium

*Significantly different from all other strategies (p<0.05).

+Significantly different from Caf, Na, CafNa (p<0.05).

**Figure 1:** Two-hour urine excretion as a percentage of water consumed.

bm. The Na strategy resulted in significantly lower urine excretion level compared to all other strategies (p<0.001 *vs.* NT, PL, Caf, p=0.005 *vs.* CafNa) and urine excretion level during Na indicated that this strategy promoted a net fluid retention of 6.4 mL/kg bm. Urine excretion level during the CafNa strategy was significantly different from all other strategies (p=0.004 *vs.* NT, p=0.005 *vs.* PL, p<0.001 *vs.* Caf, p=0.005 *vs.* Na). Urine excretion level indicated that the CafNa strategy promoted a net fluid retention of 3.0 mL/kg bm. Urine excretion analyses revealed a statistical power of 1.00 with a partial $\eta^2$ of 0.73.

## Discussion

To our knowledge, this is the first published investigation that evaluated the effects of an ergogenic dose of caffeine on urine production during pre-exercise hyperhydration strategies. The urine production data suggested that hydration status would be negatively affected if an ergogenic dose of caffeine and large bolus of water were taken 2 h prior to the start of exercise. Conversely, if the same amount of caffeine and water were co-consumed with 110 mg NaCl/kg bm, hyperhydration would be present at the advent of exercise. However, the level of hyperhydration achieved from CafNa strategy would be significantly less than what is achieved when an identical sodium-aided hyperhydration strategy is performed without caffeine.

Previous works have demonstrated that co-consumption of sodium with water in the hours before exercise decreases urine production and increases fluid retention and plasma volume when compared to the consumption of equal volumes of dilute fluid [4,12]. In these investigations, subjects consumed 10 mL/kg bm of a high-sodium beverage (164 mmol Na+/L). Total resting urine production during the high-sodium trial of Sims et al. [4] was approximately 5.5 mL/kg bm, or about 55% of the total volume consumed, meaning that subjects retained approximately 4.5 mL of fluid/kg bm (if fluid loss due to sweating and insensible means are ignored). In comparison, during the Na trial of the current investigation, subjects consumed 20 mL $H_2O$/kg bm with 110 mg NaCl/kg bm. The NaCl was provided in capsules to blind the subjects to the various treatments, but if it were mixed with the water, the sodium concentration of the resulting beverage would have been 186 mmol $Na^+$/kg bm. Under this hyperhydration strategy, urine production was 65% of the fluid consumed and subjects retained approximately 6.4 mL fluid/kg bm. Differences in the hyperhydration protocols of the current study and that of Sims et al. [4] may account for the greater absolute fluid retention levels in the current investigation. Sims et al. [4] administered a total of 10 mL fluid/kg bm to subjects in seven equal doses over the course of a 60 min hyperhydration period. Urine excretion was measured throughout the hyperhydration period and for an additional 45 min after the final fluid dose was consumed. In contrast, subjects from the current study consumed a bolus of 20 mL fluid/kg bm, 110 mg NaCl/kg bm and a small, low-sodium snack followed by a 120 min urine collection period. The sodium to water ratios were similar between the two investigations but the volumes of water, the temporal aspects of its consumption, and the consumption of a snack all could have contributed to the difference in fluid retention.

The differences in fluid retention between the Na strategy of the current study and that of Sims et al. [4], illustrates the need for systematic investigations of the effects of different fluid doses and the timing of the consumption of fluids on sodium-aided hyperhydration. Such studies could help to identify and standardize optimal fluid dosing strategies for individuals who work in hot environments.

The current results also suggested that hyperhydration can be attained when caffeine is consumed in conjunction with sodium and water, albeit at lower levels compared to when sodium and fluid are consumed without caffeine. However, further work is needed to optimize caffeine dosing strategies when it is used in conjunction with sodium-aided hyperhydration. Little is known about the temporal relationship between the consumption of caffeine and the advent of its ergogenic and diuretic effects. In studies of its ergogenic effects, caffeine is typically administered approximately 30-60 min prior to exercise [18]; however, few systematic studies of optimal timing of caffeine consumption have been performed, and the results of these investigations have been contradictory. Skinner et al. [19] found an ergogenic effect of caffeine when it was taken 60 min prior to a 40 km cycling performance test but no effect when caffeine was consumed 120-150 min prior to exercise. In contrast, Ryan et al. [20] observed improved endurance performance when caffeine was consumed 5 min prior to exercise but not when it was consumed 60 or 120 min before exercise. Finally, Bell and McLellan [21] noted similar ergogenic effects on exercise time to exhaustion when subjects consumed caffeine at either 1, 3, or 6 h before the beginning of exercise.

Even less is known about the temporal relationship between acute consumption of caffeine and the advent of diuresis. Nussberger et al. [22] detected a significant increase in urine production in euhydrated subjects during the hour immediately following consumption of caffeinated coffee. Comparatively, these authors did not see a significant increase in urine production after subjects consumed an equal volume of decaffeinated coffee. In contrast, results from a four-hour hypehydration protocol by Wemple et al. [15] indicated no caffeine-induced diuresis during the first hour following the consumption of a low-sodium, caffeinated sports drink. These authors had subjects consume an initial bolus of 8 mL of fluid/kg bm and either 2 mg caffeine/kg bm or placebo followed by a 60 min rest period during which no fluids or caffeine were consumed. For the remaining 3 h of the trials, subjects either continued to rest or performed moderate - intensity exercise while consuming 3 mL of fluid/kg bm and 0.75 mg caffeine/kg bm or placebo every 20 min for the duration of the trial. While no diuretic effect of caffeine was observed during the first hour of the trials, urine output was significantly higher during the final 3 h of the resting trials in which subjects consumed caffeine. It is worth noting that Wemple et al. [15] did not observe caffeine induced diuresis when their subjects exercised during the final 3 h of their protocol. These results and those of others suggest that the diuretic effect of caffeine is absent [23], or substantially reduced [24], during exercise.

A better understanding of the temporal aspect of diuretic and performance issues surrounding the consumption of caffeine and fluid could lead to optimal consumption strategies for individuals who are seeking to improve exercise performance in hot environments. The current investigation suggests that pre-exercise sodium-aided hyperhydration can be achieved when acute and simultaneous caffeine consumption occurs; however, the level of hyperhydration is partially, but significantly, mitigated by acute caffeine consumption. Ryan et al. [20] has suggested that the ergogenic effects of caffeine can be obtained when caffeine is taken 5 min prior to the start of a one-hour cycling performance test. This observation, when taken in conjunction with those who have shown that the diuretic effect of caffeine is minimized during exercise, suggests that the ergogenic effects of caffeine might be obtainable with little impact on sodium-aided hyperhydration if caffeine is consumed in close proximity to the start of exercise.

The results demonstrate that hyperhydration can be attained when caffeine is co-consumed with sodium and 20 mL water/kg bm. However, the level of hyperhydration is significantly less than when an equal dose of water and sodium are consumed without caffeine. While it does appear that caffeine consumption and sodium-aided hyperhydration can be utilized simultaneously, athletes should consider their specific situation before deciding if the ergogenic effects of caffeine are worth the compromises that caffeine consumption will have on a sodium-aided hyperhydration strategy. Finally, the current data, and those of previous investigators, suggest that further research should be performed into the ergogenic and diuretic effects of caffeine so that optimal, combined caffeine consumption and hyperhydration strategies can be developed.

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