Effect of Preexercise Soup Ingestion on Water Intake and Fluid Balance During Exercise in the Heat


Purpose: To determine whether chicken noodle soup before exercise increases ad libitum water intake, fluid balance, and physical and cognitive performance compared with water.

Methods: Nine trained men (age 25 ± 3 yr, VO2peak 54.2 ± 5.1 ml · kg⁻¹ · min⁻¹; M ± SD) performed cycle exercise in the heat (wet bulb globe temperature = 25.9 ± 0.4 °C) for 90 min at 50% VO2peak, 45 min after ingesting 355 ml of either commercially available bottled water (WATER) or chicken noodle soup (SOUP). The same bottled water was allowed ad libitum throughout both trials. Participants then completed a time trial to finish a given amount of work (10 min at 90% VO2peak; n = 8). Cognitive performance was evaluated by the Stroop color–word task before, every 30 min during, and immediately after the time trial.

Results: Ad libitum water intake throughout steady-state exercise was greater in SOUP than with WATER (1,435 ± 593 vs. 1,163 ± 427 g, respectively; p < .03). Total urine volume was similar in both trials (p = .13), resulting in a trend for greater water retention in SOUP than in WATER (87.7% ± 7.6% vs. 74.9% ± 21.7%, respectively; p = .09), possibly due to a change in free water clearance (–0.32 ± 1.22 vs. 0.51 ± 1.06 ml/min, respectively; p = .07). Fluid balance tended to be improved with SOUP (–106 ± 603 vs. –478 ± 594 g, p = .05). Likewise, change in plasma volume tended to be reduced in SOUP compared with WATER (p = .06). Only mild dehydration was achieved (<1%), and physical performance was not different between treatments (p = .77). The number of errors in the Stroop color–word task was lower in SOUP throughout the entire trial (treatment effect; p = .04).

Conclusion: SOUP before exercise increased ad libitum water intake and may alter kidney function.

Keywords: hyperhydration, sodium, cognitive function, performance

Inadequate fluid intake during exercise in the heat reduces skin blood flow and sweat rates to preserve cardiovascular function and results in exacerbated heat gain and loss of temperature regulation (Gonzalez-Alonso, Mora-Rodriguez, & Coyle, 2000; Hamilton, Gonzalez-Alonso, Montain, & Coyle, 1991; Montain & Coyle, 1992; Nadel, Cafarelli, Roberts, & Wenger, 1979; Nadel, Fortney, & Wenger, 1980; Sawka, Young, Francesconi, Muza, & Pandolf, 1985). The increase in body heat contributes to fatigue at similar body temperatures regardless of trained or heat-acclimated state (Gonzalez-Alonso et al., 1999; Nielsen et al., 1993). However, when voluntary dehydration is prevented by forced water intake equal to water losses in sweat, sweat rate, cardiovascular function, and temperature regulation are improved (Hamilton et al., 1991; Montain & Coyle, 1992; Sawka et al., 1985). Physical (Armstrong, Costill, & Fink, 1985; Cheuvront, Carter, Castellani, & Sawka, 2005) and cognitive (Cian, Barraud, Melin, & Raphel, 2001; Gopinathan, Pichan, & Sharma, 1988; Lieberman, 2007; Sharma, Sridharan, Pichan, & Panwar, 1986) performance are also negatively affected by dehydration, with performance decrements observed with mild dehydration as low as 2%. These physical and cognitive performance decrements may be more pronounced when tasks are performed in the dehydrated state under significant heat stress (Cheuvront et al., 2005; Sharma et al., 1986). Further investigations into novel techniques that promote fluid intake during exercise and offset the negative impact of dehydration on cardiovascular function, body-temperature regulation, and physical and cognitive performance are needed.

Preexercise hyperhydration is one technique that has been investigated to improve fluid balance, cardiovascular function, and temperature regulation during subsequent exercise. However, hyperhydration with water alone has yielded equivocal results (Greenleaf & Castle, 1971; Nadel et al., 1980). The addition of glycerol, an intravascular osmotic agent, to water has been shown to decrease urine output and promote whole-body fluid expansion compared with water hyperhydration alone (Anderson, Cotter, Garnham, Casley, & Febbraio, 2001; Goulet, Robergs, Labrecque, Royer, & Dionne, 2006;
Lyons, Riedel, Meuli, & Chick, 1990). However, glycerol hyperhydration during exercise may (Anderson et al., 2001; Lyons et al., 1990) or may not (Goulet et al., 2006; Latzka et al., 1997) improve temperature regulation and increase sweat rate. In 2007, the American College of Sports Medicine called for studies investigating sodium-containing beverages, snacks, or small meals before exercise in an attempt to promote fluid intake and offset voluntary dehydration during exercise (Sawka et al., 2007). In response to this call for research, Johannsen, Lind, King, and Sharp (2009) examined the effect of chicken-noodle-soup ingestion (167 mmol/L Na+) before exercise on ad libitum water intake and fluid balance during 90 min of exercise and a subsequent performance task. That study demonstrated that 355 ml of soup 45 min before exercise increased ad libitum water intake, thus promoting greater fluid balance than an equal quantity of carbohydrate-electrolyte solution or water before exercise. However, all trials were performed in a temperate environment (wet bulb globe temperature [WBGT] 16.2 ± 1.6 °C), and no improvement in physical performance was observed (Johannsen et al., 2009). Sims, van Vliet, Cotter, and Rehrer (2007) showed that a high-sodium-containing beverage (164 mmol/L Na+) before exercise in the heat increased plasma volume, reduced thermoregulatory strain, and improved physical performance compared with a low-sodium beverage (10 mmol/L). However, no further fluid was allowed during exercise, potentially limiting the scope of the results under normal exercise conditions where individuals would likely have access to water ad libitum.

The purpose of this investigation was to determine whether preexercise ingestion of chicken noodle soup increases ad libitum water intake and urinary water retention and, therefore, improves fluid balance during exercise in the heat compared with an equivalent volume of water ingested before exercise. Furthermore, we sought to determine whether the improvement in fluid balance with ingestion of chicken noodle soup before exercise resulted in enhanced physical and cognitive performance during exercise under a significant environmental heat stress (WBGT ~26 °C). Last, we studied the effect of chicken noodle soup on ratings of perceived thirst. We hypothesized that chicken noodle soup before exercise in heat stress would result in greater ad libitum water intake and urinary water retention, leading to improved fluid balance compared with water intake before exercise. Second, we expected that the improvement in fluid balance would result in improved physical and cognitive performance. We expected ratings of perceived thirst to be similar in both trials, even though we expected water intake to be greater after soup ingestion.

Methods

Participants

Nine healthy, trained (peak oxygen uptake [VO2peak] = 54.2 ± 5.1 ml · kg⁻¹ · min⁻¹) college-age men (M ± SD; 25 ± 3 years, 75.8 ± 6.8 kg, 174.0 ± 5.0 cm) volunteered for this study. Before any physical testing, participants completed a medical-history questionnaire that was reviewed by the primary investigators. College-age, physically active (≥3 days/week of ≥30 min), nonsmoking, nondiabetic men were recruited for this study. Main exclusion criteria included poor general overall health, self-reported history of hypertension or heart attack, or being on medication that affects water regulation. This study was approved by the Iowa State University institutional review board, and all participants gave informed, written consent.

Preliminary Testing

After study consent was provided, body mass and height were measured, and participants completed a graded exercise test to exhaustion on a cycle ergometer (Monark Exercise AB, Vansbro, Sweden) to determine VO2peak. To reduce the time required to reach VO2peak in our trained cyclists, we used a two-phase protocol: a linear phase and a max phase. Specifically, participants pedaled at a comfortable rate (82 ± 3 rpm) with the resistance set at 0.5 kp for 3 min, then increased the resistance 0.5 kp every 3 min for the first four workloads (linear phase). After the initial linear phase, pedaling resistance was increased by 0.5 kp every minute (max phase) until volitional fatigue. Respiratory gases were monitored with online oxygen and carbon dioxide analyzers (Physio-dyne Instrument Corp., Quogue, NY). All of the estimated power outputs to achieve ~50% VO2peak were interpolated within the linear phase and calculated from steady-state data.

Experimental Protocol

Two trials were completed in a randomized order and were separated by at least 1 week (Figure 1). The trials varied according to the beverage ingested 45 min before exercise and the amount of water ingested during exercise. The beverages ingested before exercise were commercially available bottled water (WATER) or chicken noodle soup (SOUP; Campbell Soup Co., Camden, NJ, USA). The soup was provided after normal preparation and included all components. Table 1 shows the nutrient profiles of the two experimental beverages. The water was provided at room temperature, and soup was heated to ~50 °C. Three-day diet (food and fluid) and physical activity diaries were kept and replicated before the subsequent trial. Participants refrained from strenuous physical activity and drank an extra liter of water the day before each trial.

On entering the laboratory, participants voided and provided a urine sample. A rectal thermometer (YSI 401, Dayton, OH) was inserted to a depth of 10 cm past the anal sphincter, and participants were fitted with a heart-rate monitor (Polar, Electro Oy, Finland). Nude body mass was recorded to the nearest 0.05 kg (Befour, Inc., Saukville, WI). Resting cognitive performance was evaluated. A Teflon indwelling catheter was placed into an antecubital vein, and an 8-ml fasted (>8
hr) resting blood sample was drawn without stasis. All blood samples were placed in lithium heparin tubes (BD Biosciences, San Jose, CA) from which hematocrit and hemoglobin concentration were measured immediately before centrifuging at 400 \( \text{g} \) for 10 min. Resultant plasma was analyzed for osmolality and sodium, potassium, and chloride concentrations. Remaining plasma was frozen and stored at \(-20^\circ\text{C}\) for later determination of plasma glucose concentrations. Participants indicated their rating of perceived thirst (visual-analog scale: 0 = not thirsty at all to 10 = very, very thirsty), then ingested 355 ml of the experimental beverage. No additional fluid was allowed before exercise.

After 35 min of rest at room temperature (22.6 ± 1.0 °C, 31.4% ± 8.5% relative humidity), total urine volume was collected, nude body mass was recorded, and baseline measurements were retaken. Exactly 45 min after ingestion of the experimental beverage, participants began 90 min of exercise in a controlled, heated environment (34.3 ± 0.3 °C, 32.0% ± 2.7% relative humidity) at a workload prescribed to elicit 50% \( \text{VO}_2\text{peak} \). A blood sample was drawn, thirst was recorded, and cognitive performance was evaluated every 30 min during exercise. Rectal temperature was monitored continuously, and exercise was discontinued if the temperature exceeded 39.5 °C. Expiratory gases were sampled during the last 5 min of each 30-min interval. Participants were provided ad libitum water (commercially available bottled water) during exercise that was kept at the same temperature as the environmental chamber. Water intake (volume and timing) was determined by pre- minus postdrink bottle mass recorded to the nearest 0.01 g. Participants were blinded to the quantity and timing of water ingested with each drink.

After 90 min of exercise, total urine volume was collected and nude body mass was recorded. Five minutes after cessation of steady-state exercise, a time trial began that consisted of the time to complete the estimated work accumulated in 10 min of exercise at 90% \( \text{VO}_2\text{peak} \). Participants were given no encouragement or indication of time, rpm, or work accumulated during the time trial except when they had completed 50% and 100% of the prescribed work. They were provided water ad libitum during the time trial. Total urine volume was collected and nude body mass was recorded after the time trial. Perceived thirst and cognitive performance were evaluated before participants left the laboratory.

Cognitive performance was assessed as the average response time for correct responses and number of error trials in a computerized version of the Stroop color–word test (Wang Neuropsychological Laboratory, San Luis Obispo, CA). This is a well-established cognitive test (reliability .86, .82, and .73; Golden, 1975) in which one is required to select relevant information from the environment (Golden & Golden, 1975; Pardo, Pardo, Janer, & Raichle, 1990). This type of processing is similar to what may be required during an athletic competition because it is sensitive to both the speed and the accuracy of decision making and requires selective attention (Carter, Mintun, & Cohen, 1995). In this test, a word (green, blue, or red) is presented on a

---

**Figure 1** — Experimental protocol. Steady-state exercise was prescribed as 90 min at 50% \( \text{VO}_2\text{peak} \). TT = time trial—time to finish a prescribed amount of work equal to 10 min at 90% \( \text{VO}_2\text{peak} \).

**Table 1  Beverage Composition**

<table>
<thead>
<tr>
<th></th>
<th>Water</th>
<th>Soup</th>
</tr>
</thead>
<tbody>
<tr>
<td>Osmolality, mOsm/kg</td>
<td>6.5</td>
<td>382.5</td>
</tr>
<tr>
<td>[Na(^+)], mmol/L</td>
<td>3.1</td>
<td>166.9</td>
</tr>
<tr>
<td>[K(^+)], mmol/L</td>
<td>0.0</td>
<td>6.9</td>
</tr>
<tr>
<td>[Ca(^{2+})], mmol/L</td>
<td>0.0</td>
<td>2.9</td>
</tr>
<tr>
<td>Total carbohydrate, g/L</td>
<td>0.0</td>
<td>46.5</td>
</tr>
<tr>
<td>Simple sugar, g/L</td>
<td>0.0</td>
<td>1.5</td>
</tr>
<tr>
<td>Total fat, g/L</td>
<td>0.0</td>
<td>7.0</td>
</tr>
<tr>
<td>Total protein, g/L</td>
<td>0.0</td>
<td>15.0</td>
</tr>
</tbody>
</table>

*Note.* Osmolality of soup determined on liquid fraction. Electrolyte and nutrient content for soup determined by homogenization. Water = commercially available bottled water; soup = chicken noodle soup; [Na\(^+\)], [K\(^+\)], and [Ca\(^{2+}\)] = sodium, potassium, and calcium concentration, respectively.
computer screen on a black background written in a color that does not match the color of the word (for example, red written in green letters). Participants were asked to indicate the color of the letters (not the word itself) by pressing a computer key, thus setting up decision making in which the more automatic response must be inhibited. Participants were instructed to “complete the task as quickly and accurately as possible” and completed as many trials as they could in 45 s. For consistency, participants always used their dominant hand and, during exercise, the computer was set on a cart level with their dominant arm with the palm of their hand resting on the computer. To reduce the variability associated with learning, all participants were given one complete 45-s test before data collection.

**Biochemical Analyses**

Blood samples were analyzed in triplicate for hemoglobin concentration using the cyanmethemoglobin spectrophotometric assay (Stanbio, Boerne, TX) and for hematocrit by microcapillary centrifugation. Hematocrit values were corrected for trapped plasma volume between red blood cells (0.96) and venous-to-total-body hematocrit ratio (0.91; Chaplin & Mollison, 1952; Chaplin, Mollison, & Vetter, 1953). Percent plasma volume change was calculated by the equations of Dill and Costill (1974) using the within-treatment baseline measurement as a reference. Total urine volume was measured three times: before the start of exercise, at the end of steady-state exercise, and after completion of the time trial. Plasma and urinary osmolality were measured by vapor-pressure osmometry (Westcor, Inc., Logan, UT), and electrolyte concentrations, by selective ion electrodes (Medica, Bedford, MA). Plasma glucose concentration was measured by enzymatic spectrophotometric assay (Stanbio Laboratory, Boerne, TX), and urine specific gravity, by spectral refractometry (Leica Microsystems, Inc., NY). All plasma and urine measurements were performed in duplicate.

**Calculations**

Fluid balance (g) was calculated as the difference between baseline body mass and body mass after steady-state exercise. As described in the experimental protocol, the body-mass measurement was preceded by total urine volume collection.

The effectiveness of preexercise beverages to reduce urinary water loss independent of water intake during rest and exercise was determined by calculating the percent water retention as shown in the following equation:

\[
\text{% water retention} = \left[ \frac{\text{total fluid ingested (g)} - \text{U}_{\text{tot}} (g)}{\text{total fluid ingested (g)}} \right] \times 100
\]

In this equation, total fluid ingested is the sum of the mass of the experimental beverage and water intake during steady-state exercise (g) and \(U_{\text{tot}}\) is the estimated urine mass (urine volume \(\times\) specific gravity; g) produced during rest and steady-state exercise. Percent dehydration after steady-state exercise was calculated as the percent change in body mass during 90 min of exercise. Percent dehydration expresses fluid balance normalized to body mass.

Osmonic (\(C_{\text{OSM}}\)) and free-water (\(C_{\text{H2O}}\)) clearance rates were calculated as shown in the following equations to determine the rate of solute and water clearance from the plasma to urine (Wesson & Anslow, 1952):

\[
C_{\text{OSM}} (\text{ml/min}) = \frac{V \times U_{\text{OSM}}}{P_{\text{OSM}}}
\]

\[
C_{\text{H2O}} (\text{ml/min}) = V - C_{\text{OSM}}
\]

In these equations, average rate of urine accumulation (V; ml/min) during steady-state exercise was determined by dividing urine volume by time spent in steady-state exercise (90 min). Average plasma osmolality (\(P_{\text{OSM}}\)) was used due to multiple measurements during steady-state exercise. Because urine was collected after steady-state exercise, post-steady-state-exercise urine osmolality represents the average during steady-state exercise (\(U_{\text{OSM}}\)).

Total evaporative water losses during steady-state exercise, including sweat and respiratory losses, were calculated by adding the total ad libitum volume of water ingested to the total body mass lost during the 90 min of steady-state exercise. Evaporative losses were corrected for body surface area (m\(^2\)) estimated by the DuBois equation (DuBois & DuBois, 1916) and expressed as grams of body water loss per meter squared per hour.

**Statistical Analyses**

All statistics were calculated using JMP 8.0 statistical software (SAS, Cary, NC). Baseline body mass, plasma osmolality, and urine specific gravity were compared using paired \(t\) tests to determine the effectiveness of pretrial dietary and physical activity control. Mean steady-state exercise VO\(_2\) (L/min) was analyzed using paired \(t\) tests to ensure consistent exercise intensity between trials. Chamber WBGT was calculated from temperature and humidity and compared across trials using paired \(t\) tests to ensure equal thermal stress between trials. Primary outcome variables including fluid balance, percent dehydration, percent water retention, ad libitum water intake during steady-state exercise, and evaporative water losses were evaluated using paired \(t\) tests. Secondary outcomes including urine variables (total urine volume and sodium, potassium, and chloride concentrations) and performance time (min; \(n = 8\)) during the time trial were analyzed using paired \(t\) tests. Other secondary outcomes including blood plasma variables (percent plasma volume change; glucose, sodium, potassium, and chloride concentrations; and osmolality), urine variables (osmolality and specific gravity), cognitive function by Stroop color–word test (mean reaction time, number of correct answers, and number of errors), and ratings of perceived thirst were subjected to two-way (Treatment \(\times\) Time) repeated-measures analysis of variance (RM-ANOVA). One individual was unable to finish the performance trial, and another was unable to urinate after steady-state exercise, so analy-
ses were only run with those who had complete data for those variables (n = 8). Significant treatment (preexercise beverage), time, and interaction effects were evaluated using Tukey’s honestly-significant-difference post hoc analyses where appropriate. Data are reported as M ± SD, and statistical differences were declared if p < .05.

Results

Study Control

Baseline body weight (75.1 ± 6.7 vs. 75.0 ± 6.8 kg; p = .53), urine specific gravity (1.017 ± 0.007 vs. 1.018 ± 0.005; p = .35), and plasma osmolality (280.9 ± 6.4 vs. 281.1 ± 4.3 mOsm/kg; p = .96) were similar between the WATER and SOUP trials, respectively. Mean percent VO2peak during steady-state exercise was similar for both treatments (72.5% ± 10.7% vs. 79.1% ± 13.8% for WATER and SOUP, respectively; p = .16). While the mean intensity is above the 50% VO2peak prescribed in this study, the heat stress contributed to the rate of increase in VO2 (percent of maximal) during steady-state exercise (66.2% ± 13.8%, 76.4% ± 12.2%, 84.8% ± 15.6%; time effect p < .001). Mean WBGT was 25.9 ± 0.4 °C and was similar in both treatments (p = .35).

Fluid Balance

Total ad libitum water intake after SOUP (1,795 ± 672 g) was greater than after WATER (1,465 ± 562 g; p = .01). Total water intake was higher due to an increase in ad libitum water intake during the 90 min of steady-state exercise after SOUP (1,435 ± 593 g) compared with WATER (1,163 ± 427 g; p < .03). Water intake during the time trial was similar for WATER and SOUP (302 ± 236 vs. 360 ± 260 g, respectively, p = .14). Although water intake differed between WATER and SOUP, ratings of perceived thirst were similar across treatment group (p = .74), time point (p = .30), and treatment-by-time interaction (p = .39).

Total urine volume was similar between treatment groups (353 ± 246 and 229 ± 196 ml for WATER and SOUP, respectively, p = .13). Water retention (%) tended to be higher with SOUP than with WATER (87.7% ± 7.6% vs. 74.9% ± 21.7%, respectively, p = .09), and free-water clearance tended to be lower in SOUP than with WATER (–0.3 ± 1.2 vs. 0.5 ± 1.1 ml/min, respectively, p = .07). Osmotic clearance was not different by treatment (1.8 ± 1.3 vs. 1.4 ± 0.6 ml/min, respectively, p = .41). Urine osmolality was lower in WATER than with SOUP immediately before steady-state exercise (1.013 ± 0.009 vs. 1.019 ± 0.008, respectively, p < .05) and after 90 min of exercise (1.009 ± 0.008 vs. 1.015 ± 0.007, respectively, p < .05) and dropped significantly after 90 min of exercise in WATER compared with pretrial levels (p < .05; n = 8). While urine-specific-gravity responses had a pattern similar to that of urine osmolality, the differences did not reach statistical significance (interaction p = .12). Total urinary sodium, potassium, and chloride outputs were similar in both trials (p = .51, .39, and .45, respectively). Calculated evaporative losses (respiratory + sweat losses) through 90 min of steady-state exercise were similar in both groups (536 ± 89 and 536 ± 106 g · m–2 · h–1 for WATER and SOUP, respectively, p = .81).

Fluid balance tended to be greater after SOUP ingestion (~106 ± 603 g) than with WATER (~478 ± 594 g; p = .05). Similar results were observed for percent dehydration, with a trend for improved hydration status in SOUP (~0.1% ± 0.8%) compared with WATER (~0.6% ± 0.8%; p = .06). However, within-group changes suggest that fluid balance and percent dehydration were different from baseline after WATER (95% CI = −916 to −39 g and −1.2% to −0.0%, respectively; not overlapping zero) and similar to baseline after SOUP (95% CI = −544–333 g and −0.7 to 0.5%, respectively; overlapping zero).

Plasma Constituents

Plasma osmolality increased during exercise (time effect p = .02) similarly for both trials, with greater plasma osmolality after 30 min of exercise compared with before beverage ingestion despite a greater intake of electrolytes and macronutrients in SOUP than with WATER (interaction effect p = .44; Figure 2[A]). Figure 2(B–D) also shows plasma electrolyte concentrations during rest and 90 min of steady-state exercise. Plasma sodium responses were unchanged throughout rest and exercise (time effect p = .21), and responses were similar for SOUP and WATER trials (interaction effect p = .60). Plasma potassium responses were similar for both trials, with a marked increased immediately before exercise and during exercise compared with before beverage intake and exercise (time effect p < .001). Plasma chloride concentrations were greater after the first 60 min of exercise than before beverage intake and after 30 min of exercise compared with immediately before exercise (p < .001); however, SOUP and WATER had similar responses (interaction effect p = .60). Plasma volume decreased significantly during exercise compared with rest (time effect p < .001) and tended to be higher after SOUP than with WATER (p = .06) before and throughout exercise (Figure 3). Plasma glucose responses were similar for both trials, with a gradual decrease during exercise (time effect p < .04).

Physical and Cognitive Performance

The average work the participants were required to complete in 10 min during the time trial was 155.6 ± 22.1 kJ (n = 8). The time to complete the prescribed amount of work was independent of preexercise beverage, and, therefore, water intake during exercise (13.9 ± 2.1 and 14.0 ± 2.4 min for WATER and SOUP, respectively, p = .77).

Mean reaction times in the Stroop color–word test were similar between trials (0.7 ± 0.1 and 0.7 ± 0.2 s for WATER and SOUP, respectively, treatment effect p = .84) and decreased significantly during exercise and after the time trial compared with rest (time effect p < .001). While on average the number of correct answers
was similar across trials (63 ± 7 and 66 ± 14 for WATER and SOUP, respectively, treatment effect $p = .47$), overall, the number of errors committed in the SOUP trial was less than in the WATER trial (3 ± 2 and 2 ± 2 for WATER and SOUP, respectively, treatment effect $p = .04$). The number of errors increased late in exercise compared with baseline and after the conclusion of the time trial (time effect $p = .002$); however, the error responses were similar (interaction effect $p = .98$).

**Discussion**

Chicken noodle soup ingested 45 min before exercise increased ad libitum water intake during 90 min of steady-state exercise compared with an equal volume of water without concurrently raising total urine output. Ad libitum water intake during exercise replaces approximately 70% of total water losses (Greenleaf & Sargent, 1965; Hubbard et al., 1984). In this study, participants replaced ~90% of their total water losses with chicken noodle soup compared with ~70% after water ingestion. The rates of body-water replacement observed in this study are higher than expected and higher than those we recently reported.

---

**Figure 2** — Plasma (A) osmolality, (B) sodium, (C) potassium, and (D) chloride responses ($M \pm SD$) during rest and 90 min of steady-state exercise after ingesting either commercially available bottled water or chicken noodle soup. Treatment-by-time interaction was not significant for any of the variables. *Time effect, $p < .05$.

**Figure 3** — Percent change in plasma volume ($M \pm SD$) during rest and 90 min of steady-state exercise after ingesting either commercially available bottled water or chicken noodle soup. Plasma volume response tended to be lower with water than with soup (treatment effect, $p = .06$). *Time effect, $p < .05$.
Fluid intake during and after exercise is regulated by beverage temperature, flavor, and electrolyte content (Hubbard et al., 1984; Nose, Mack, Shi, & Nadel, 1988; Wemple, Morocco, & Mack, 1997). While few studies have examined the effect of preexercise beverage composition on water intake during exercise, it appears that similar mechanisms exist with beverages containing relatively higher concentrations of electrolytes (chicken noodle soup) or carbohydrates and lower sodium content (carbohydrate–electrolyte beverage) promoting greater ad libitum water intake (Johannsen et al., 2009). Evidence also suggests that high-electrolyte-containing meals or beverages, especially those containing high amounts of sodium, result in greater water retention (Johannsen et al., 2009; Nose et al., 1988; Ray et al., 1998; Shirreffs & Maughan, 1998; Sims et al., 2007). In the current study, we observed a significant increase in ad libitum water intake without a subsequent increase in urine output with soup before exercise. However, we only observed trends for a change in water retention and free-water clearance, suggesting a change in kidney function as a possible mechanism. Future studies will need to be conducted to confirm these trends in our data.

We expected plasma osmolality to increase to a greater extent after ingestion of chicken noodle soup during the 45-min preexercise resting period than with water, as we have previously observed (Johannsen et al., 2009). In our previous study, plasma osmolality increased during the rest period and remained higher during steady-state exercise after ingesting chicken noodle soup compared with water in a study design similar to that of the current investigation. A closer examination of Figure 2(A) shows trends after SOUP (small increase) and WATER (small decrease) trials similar to those in our previous investigation (mean difference 3.0 vs. 3.1 mOsm/kg, heat vs. room temperature; Johannsen et al., 2009). Further calculations show a moderate effect size (ES) for the difference in plasma-omolality responses during the resting phase in this study (ES = 0.52) that is similar to our previous observations (ES = 0.50 in Johannsen et al., 2009). Our initial research used more than double the number of subjects (n = 19), and while it is likely that statistical significance could have been achieved with a larger sample size, the lack of power to detect differences does not negate the potential meaningfulness of the change in plasma osmolality. An increase in plasma osmolality has been tied to thirst, kidney function, and other central nervous system mechanisms involved with body-fluid homeostasis (Maresh et al., 2004; Montain, Laird, Latzka, & Sawka, 1997). The increases in plasma osmolality observed in the first preexercise study, independent of plasma sodium content, were later replicated in a resting chicken-noodle-soup-feeding study investigating plasma constituent changes (Johannsen, 2007). In that study, participants ingested 355 ml of either water, chicken noodle soup (167 mmol/L Na+), or water plus sodium chloride (167 mmol/L Na+) before 2 hr of rest. Chicken noodle soup and salt water induced similar increases in plasma osmolality that persisted throughout the 2 hr of rest. The inclusion of macronutrients and other electrolytes in the chicken noodle soup induced changes in plasma osmolality more quickly than salt water alone (15 min vs. 60 min). The independent effect of plasma osmolality on water intake during exercise could be investigated by adding an osmotic agent other than sodium to an experimental beverage during an additional trial.

Ingestion of soup before exercise prevented the persistent reduction in plasma volume observed at rest and throughout exercise in the WATER trial. It is likely that after soup ingestion, electrolytes and macronutrients were taken up into the blood plasma and allowed more of the ingested water to remain in the vasculature. This isotonic plasma volume expansion is supported by the greater plasma volume and negligible increase in plasma sodium and osmolality during exercise. Water intake, on the other hand, may have resulted in a migration of water out of intravascular stores, as evidenced by a reduction in plasma volume before and throughout exercise compared with SOUP. The observed plasma volume responses in this study were not observed in our previous study (Johannsen et al., 2009) or by other researchers (Gisolfi, Summers, Lambert, & Xia, 1998; Shi et al., 1994) and will need to be studied mechanistically.

We expected the heat stress to result in higher sweat rates and percent dehydration, leading to physical and cognitive performance decrements. However, evaporative water losses in this study were fairly low (~1 L/hr) compared with previous research showing sweat rates of 1.0–3.0 L/hr (Costill, 1977; Montain & Coyle, 1992; Rehner, 2001), and percent dehydration was mild (~0.6%) in the WATER trial. This level of dehydration was not sufficient to induce physiologic decrements, but we did observe an increase in the number of errors in the Stroop color–word task. An increase in the number of error trials in the 45-s test with a similar number of correct trials and similar reaction times in the correct trials indicates that the poor decisions were made quickly, impulsively. Cognitive performance in the hypohydrated state seems to be dependent on the type of task (Cian et al., 2001; Gopinathan et al., 1988; Grego et al., 2005), with significant effects observed with as little as 2% dehydration (Gopinathan et al., 1988). However, most of the cognitive tasks in previous research were memory- or arithmetic-based and did not require higher level cognitive processing. The fact that we found cognitive deficits with even
mild dehydration suggests that tasks that require higher level cognitive activity such as speeded selective attention (Carter et al., 1995) in which impulsive decisions must be inhibited may be especially sensitive to dehydration. Although we suspect that the differences in cognitive performance were related to the improved hydration status of the participants after soup intake, we cannot ignore the possible confounding influence of the small amount of carbohydrates, fats, and protein consumed before exercise in the SOUP trial.

Despite the important contribution of this study to determine mechanisms underlying preexercise hyperhydration and fluid balance with soup ingestion, minor limitations need to be addressed. First, our sample size was not large enough to detect significant differences in plasma osmolality as observed in our previous research (Johannsen et al., 2009). Our sample-size calculations were conducted on change in fluid balance and ad libitum water intake after soup ingestion compared with water before exercise based on our initial study. However, we did see a moderate effect size (0.52) for change in plasma osmolality during the 45-min rest period, suggesting a similar mechanism for changes in drinking behavior in this study compared with our previous research. Second, the beverages were served at different temperatures, possibly confounding the results of this study. To our knowledge, the effect of preexercise-beverage temperature on fluid balance has not been evaluated systematically. While we recognize this as a potential limitation, we feel justified in serving the beverages at a temperature at which they are normally consumed to create a “real-world” simulation of meal- and beverage-ingestion behavior. Although these limitations are important to consider, we feel they do not detract from the main results of the study.

In conclusion, chicken noodle soup ingested 45 min before exercise increased ad libitum water intake throughout 90 min of steady-state exercise at ~70%VO2peak in the heat. Likewise, chicken noodle soup before exercise tended to reduce kidney water loss and therefore increase water retention and overall fluid balance. While these changes resulted in no observable decrements in physical performance, there was evidence for a positive effect on rapid, accurate cognitive processing.

Acknowledgments

This research was funded in part by Campbell Soup Company. The authors would like to thank the participants and all of the graduate and undergraduate students who contributed to data collection.

References


