Rehydration After Exercise Dehydration in Heat: Effects of Caffeine Intake

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Context: Dieticians, physiologists, athletic trainers, and physicians have recommended refraining from caffeine intake when exercising because of possible fluid-electrolyte imbalances and dehydration. Objective: To assess how 16-hour rehydration is affected by caffeine ingestion. Design: Dose–response. Setting: Environmental chamber. Participants: 59 college-age men. Intervention: Subjects consumed a chronic caffeine dose of 0 (placebo), 3, or 6 mg · kg⁻¹ · day⁻¹ and performed an exercise heat-tolerance test (EHT) consisting of 90 minutes of walking on a treadmill (5.6 km/h) in the heat (37.7 °C). Outcome Measures: Fluid-electrolyte measures. Results: There were no between-group differences immediately after and 16 hours after EHT in total plasma protein, hematocrit, urine osmolality, specific gravity, color, and volume. Body weights after EHT and the following day (16 hours) were not different between groups (P > .05). Conclusion: Hydration status 16 hours after EHT did not change with chronic caffeine ingestion. Key Words: electrolyte, osmolality, specific gravity, plasma protein

Because of the diuretic effect of caffeine ingestion at rest, the medical, exercise-physiology, and nutrition communities recommend refraining from caffeine intake before or during exercise.¹ For example, the American College of Sports Medicine guidelines for exercise testing and prescription² state that individuals should drink ample fluid and avoid caffeine for 3 hours before physical-fitness testing. Despite this recommendation, caffeine, or 1,3,7-trimethylxanthine, is widely used by athletes as an ergogenic aid. The pharmacological effects of caffeine affect the cardiovascular, metabolic, renal, and nervous systems. Caffeine reportedly increases heart rate, blood pressure, resting metabolic rate, lipolysis, and arousal and decreases peripheral vascular resistance.³,⁴ Little is known, however, regarding the influence of chronic caffeine intake on fluid or electrolyte balance.

During exercise in the heat, thermal balance is achieved through redistribution of cardiac output, increased skin blood flow, and increased sweat secretion.⁵ Diuresis can amplify the usual decreases in plasma volume, stroke volume, and cardiac output that occur. Although restoration of body water is accomplished by fluid and food ingestion during the hours following exercise,⁶ the possible diuretic effect of caffeine might affect hydration the next day.

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Individuals habituated to caffeine can develop tolerance, because prolonged stimulation could result in decreased responsiveness, and it might depend on different doses. In addition, caffeine withdrawal after a period of use might result in a different response. Therefore, the objective was to verify whether different chronic doses of caffeine affect rehydration status 16 hours after exercise in the heat.

Methods

Design

After an initial equilibration phase of 6 days consuming capsules containing 3 mg/kg of caffeine, which brought all subjects to the same caffeine intake, subjects were randomly assigned to 1 of 3 groups in a double-blind process. On days 7–12, they consumed 1 of 3 caffeine doses (0, 3, or 6 mg · kg⁻¹ · day⁻¹ in groups G0, G3, and G6, respectively). Subjects performed an exercise heat tolerance test (EHT) on day 12. No consumption of caffeine in daily food or fluids was permitted during the entire study. On the morning of day 13, after laboratory measurements, the subjects were allowed to consume caffeine ad libitum.

Participants

Fifty-nine college-age men took part in the study. The subjects’ mean (± SD) characteristics were age 21.6 ± 6.9 years, height 177.9 ± 6.1 cm, body mass 75.4 ± 7.7 kg, and percent body fat 11.1% ± 5.4%. Subjects completed a medical-history questionnaire to rule out any contraindications to participation; these included a history of cardiovascular, metabolic, or respiratory disease or a history of heat illness. A dietary-caffeine questionnaire was completed, and individuals who consumed excessive caffeine (≥600 mg/day) were excluded. The University of Connecticut’s institutional review board approved all procedures, and participants provided written informed consent.

Intervention

Subjects recalled their physical activity history (1 month) and did not change it throughout the study. They recorded all food and fluid consumed 2 days before and during the 13 days of the study; only the results of the final day are reported here. Diet records were analyzed for energy, nutrient composition, sodium, potassium, and fluid intake using Nutritionist Pro software (Version 1.2, N-Squared Computing, Salem, Ore). On the mornings of days 1–12, subjects ingested half of their daily caffeine dose (between 7 and 9 AM), observed by an investigator. The other half of the caffeine-dose ingestion occurred between noon and 2 PM and was confirmed by phone.

On day 12, subjects reported at 7 AM to receive their morning caffeine, at which time a blood sample was obtained. They provided a urine sample and were weighed (platform scale, Ohaus DS44L, Florham Park, NJ). They returned between noon and 2 PM to receive their second half-dose and to perform the EHT.

The standardized 90-minute EHT was conducted in an environmental chamber (Minus Eleven Inc, Model 200, Malden, Mass) in a stable environment condition (dry-bulb temperature 37.7 ± 0.1 °C, wet-bulb temperature 29.8 ± 0.3 °C, relative
humidity 56.3% ± 1.5%). The EHT involved continuous treadmill walking at 5.6 km/h up a 5% incline, which has been used in previous research. Subjects stopped exercise at subjective exhaustion, after 90 minutes of walking, or when their rectal temperature reached 39.5 °C. Measurements of body weight, blood, and urine were obtained before and after EHT.

On the morning of day 13, subjects returned for final weighing and to provide urine and blood samples.

**Measurements**

Body fat was assessed from 3-site skinfold thicknesses and calculated via the Brozek equation using a caliper (Harpenden Skinfold, UK).

**Blood Analyses.** Hematocrit was measured in triplicate after microcentrifugation. Total plasma protein was determined with a refractometer (Atago A 300CL, Japan).

**Urine Analyses.** Urine osmolality was determined via freezing-point depression with an osmometer (Model 3DII, Advanced Digimatic, Mass). Urine specific gravity was determined by using a refractometer (Atago A 300CL). Urine color was defined using a validated urine-color chart.

**Statistical Analysis**

Volunteers were described by common descriptive statistics for measure of height, weight, age, and body composition. One-way analysis of variance was used to evaluate day 12 diet differences between groups (from morning of day 12 to morning of day 13). One-way analysis of covariance, using day 12 or pre-EHT measures as covariates, evaluated day 13 urine and hydration indices and post-EHT between-group differences. All statistics evaluated significance between groups at the $P < .05$ level, using SPSS Base 10.0 software (SPSS Inc, Chicago, Ill). Data are expressed as means ± SD.

**Results**

Dietary composition and fluid ingestion on day 12 (Table 1) were similar in all groups.

Body-weight loss after EHT was similar in all groups: 0.7 ± 0.7, 1.0 ± 0.6, and 0.6 ± 0.6 kg in G0, G3, and G6, respectively. In addition, hematocrit (45.2% ± 2.6%, 45.1% ± 2.7%, and 45.3% ± 2.9%) and total plasma protein (8.5% ± 0.5%, 8.5% ± 0.4%, and 8.2% ± 0.4%) were similar after EHT ($P > .05$) in all groups, even when measures before EHT were used as covariates.

Table 2 presents hydration indices, and Table 3 presents urine indices measured on the mornings of days 12 and 13. No between-group differences were detected on day 13, even when day 12 data were used as covariates.

On day 13, for the first time, subjects voluntarily consumed caffeine in forms other than capsules. The groups ingested in 1 day 0.55 ± 1.4, 1.26 ± 1.94, and 0.67 ± 1.03 mg/kg in G0, G3, and G6, respectively. These levels were not significantly different (ANOVA).
Table 1  Day 12 Dietary Contents (24 hours), Mean ± SD*

<table>
<thead>
<tr>
<th>Group</th>
<th>Protein (%)</th>
<th>Carbohydrate (%)</th>
<th>Fat (%)</th>
<th>Na⁺ (mg)</th>
<th>K⁺ (mg)</th>
<th>Fluid (ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>G0</td>
<td>18.0 ± 4.9</td>
<td>49.9 ± 8.6</td>
<td>32.1 ± 8.0</td>
<td>4370 ± 2350</td>
<td>2504 ± 1390</td>
<td>2380 ± 750</td>
</tr>
<tr>
<td>G3</td>
<td>18.0 ± 6.3</td>
<td>49.8 ± 13.0</td>
<td>32.2 ± 7.2</td>
<td>4750 ± 2120</td>
<td>2840 ± 1550</td>
<td>3280 ± 1810</td>
</tr>
<tr>
<td>G6</td>
<td>15.5 ± 4.1</td>
<td>50.7 ± 8.5</td>
<td>33.8 ± 7.0</td>
<td>4360 ± 1840</td>
<td>2560 ± 1483</td>
<td>2600 ± 910</td>
</tr>
</tbody>
</table>

*No statistical difference between groups (P > .05). One-way analysis of variance.
Table 2  Hydration Indices on the Morning of Days 12 and 13, Mean ± SD*

<table>
<thead>
<tr>
<th>Day</th>
<th>Group</th>
<th>n</th>
<th>Body weight (kg)</th>
<th>Hematocrit (%)</th>
<th>Total plasma protein (mg/dl)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>G0</td>
<td>20</td>
<td>75.4 ± 7.8</td>
<td>44.6 ± 2.7</td>
<td>7.6 ± 0.5</td>
</tr>
<tr>
<td></td>
<td>G3</td>
<td>20</td>
<td>74.9 ± 7.9</td>
<td>44.2 ± 2.1</td>
<td>7.5 ± 0.4</td>
</tr>
<tr>
<td></td>
<td>G6</td>
<td>19</td>
<td>74.8 ± 8.4</td>
<td>44.4 ± 3.5</td>
<td>7.5 ± 0.4</td>
</tr>
<tr>
<td>13</td>
<td>G0</td>
<td>20</td>
<td>75.0 ± 7.6</td>
<td>44.4 ± 2.5</td>
<td>7.6 ± 0.5</td>
</tr>
<tr>
<td></td>
<td>G3</td>
<td>20</td>
<td>74.5 ± 8.0</td>
<td>44.0 ± 2.3</td>
<td>7.6 ± 0.4</td>
</tr>
<tr>
<td></td>
<td>G6</td>
<td>19</td>
<td>74.4 ± 8.1</td>
<td>43.3 ± 2.6</td>
<td>7.4 ± 0.4</td>
</tr>
</tbody>
</table>

*No statistical difference between groups (P > .05) in day 13. One-way analysis of covariance (day 12 data as covariate). No adjusted means are presented.

Table 3  Urine Indices on the Morning of Days 12 and 13, Mean ± SD*

<table>
<thead>
<tr>
<th>Day</th>
<th>Group</th>
<th>Urine specific gravity</th>
<th>Urine osmolality (mOsm/kg)</th>
<th>Urine color</th>
<th>Urine volume (ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>G0</td>
<td>1.019 ± 0.005</td>
<td>690 ± 208</td>
<td>4+/–1</td>
<td>1390 ± 440</td>
</tr>
<tr>
<td></td>
<td>G3</td>
<td>1.020 ± 0.007</td>
<td>764 ± 304</td>
<td>4+/–2</td>
<td>1360 ± 630</td>
</tr>
<tr>
<td></td>
<td>G6</td>
<td>1.021 ± 0.009</td>
<td>679 ± 254</td>
<td>5+/–1</td>
<td>1210 ± 250</td>
</tr>
<tr>
<td>13</td>
<td>G0</td>
<td>1.017 ± 0.006</td>
<td>648 ± 225</td>
<td>5+/–2</td>
<td>1430 ± 700</td>
</tr>
<tr>
<td></td>
<td>G3</td>
<td>1.019 ± 0.006</td>
<td>662 ± 281</td>
<td>4+/–1</td>
<td>1220 ± 670</td>
</tr>
<tr>
<td></td>
<td>G6</td>
<td>1.020 ± 0.010</td>
<td>621 ± 258</td>
<td>5+/–2</td>
<td>1270 ± 450</td>
</tr>
</tbody>
</table>

*No statistical difference between groups (P > .05) in day 13. One-way analysis of covariance (day 12 data as covariate). No adjusted means are presented. Urine volume represents 24-hour collection ending the morning of day 14.

Comments

The objective of this investigation was to evaluate whether caffeine use alters body-fluid status during the 16 hours after exercising in the heat by comparing the effects of 2 caffeine-intake levels, mild and moderate (3 and 6 mg · kg⁻¹ · day⁻¹) with placebo. The scientific and medical literatures contain a limited number of studies regarding the effects of beverages, in particular of caffeine-containing beverages, on fluid balance. The present results demonstrated that chronic ingestion of 3 and 6 mg · kg⁻¹ · day⁻¹ did not significantly alter fluid balance during the 16 hours after exercise-heat exposure. This dosage (3 and 6 mg · kg⁻¹ · day⁻¹) would represent 225 and 450 mg, respectively, of caffeine a day for the average subject.
in the study (75 kg). A can of cola contains 35 mg and a regular cup of coffee 100 mg of caffeine.

G3 had the same caffeine dose during the equilibration and treatment phases (12 days, 3 mg · kg\(^{-1}\) · day\(^{-1}\)). G3 ended the EHT with the same level of dehydration and the same 16-hour fluid restoration (fluid loss replaced) as placebo and 6 mg · kg\(^{-1}\) · day\(^{-1}\), demonstrating that the caffeine did not alter rehydration state, in agreement with the results of Fiala et al.\(^{14}\) Habitual caffeine consumption might result in tolerance\(^{15}\) caused by adenosine-receptor upregulation\(^{16}\) or as a result of fatigue of the receptors in affected organs, because prolonged stimulation decreases responsiveness. This can include renal responsiveness. Robertson et al\(^{19}\) determined that nearly complete tolerance developed during the first 4 days of caffeine ingestion, and no humoral and hemodynamic effects were found by the seventh day of caffeine ingestion. The between-group similarities of hydration indices demonstrated that the body’s fluid-regulatory mechanisms (ie, hormonal and neural effects on urine) were able to maintain homeostasis at these mild and moderate levels of caffeine consumption. In support of this concept, Maughan and Griffin\(^{17}\) reported that the large interindividual variability of physiological responses to caffeine suggests that small differences in dose are unlikely to effect measurable differences.

G0 had no caffeine after a 6-day (3 mg · kg\(^{-1}\) · day\(^{-1}\)) equilibration phase and ended the EHT with the same level of dehydration and the same 16-hour fluid restoration as G3 and G6. For Fisher et al,\(^{10}\) only 4 days of abstinence were needed for subjects to become caffeine naive. Therefore, we interpret our findings to mean that 6 days in the placebo group (0 mg · kg\(^{-1}\) · day\(^{-1}\)) washed out the 6 previous days of 3 mg · kg\(^{-1}\) · day\(^{-1}\).

We expected a high caffeine intake when subjects were allowed to eat and drink whatever they wanted after 13 days of consuming capsules. Instead, most ingested little caffeine (G0, 0.55 ± 1.40; G3, 1.26 ± 1.94; and G6, 0.67 ± 1.03 mg/kg). This suggests that subjects might have become accustomed to eating no caffeine in daily food and fluids, and this deserves future research.

Caffeine is the most commonly consumed drug in the world, and athletes use it as an ergogenic aid\(^{15}\) in doses of 1.5 to 10 mg/kg.\(^{17,20}\) Thus, the present findings are relevant to active populations and provide no evidence to support recommendations to avoid moderate levels of caffeine on the grounds of their diuretic effect. These data suggest that individuals who become tolerant of a specific level of caffeine (ie, 3 mg · kg\(^{-1}\) · day\(^{-1}\)) can change their daily intake (ie, to 0 or 6 mg · kg\(^{-1}\) · day\(^{-1}\)) without a significant change in fluid balance. Also, caffeine withdrawal after 3 mg · kg\(^{-1}\) · day\(^{-1}\) for 6 days might cause no fluid imbalance.

In conclusion, caffeine ingestion (3 and 6 mg · kg\(^{-1}\) · day\(^{-1}\)) did not alter body-fluid status after 16 hours following exercise in a hot environment compared with placebo (0 mg · kg\(^{-1}\) · day\(^{-1}\)).

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References


