Induced Alkalosis and Caffeine Supplementation: Effects on 2,000-m Rowing Performance

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Introduction: The purpose of this investigation was to determine the effect of ingested caffeine, sodium bicarbonate, and their combination on 2,000-m rowing performance, as well as on induced alkalosis (blood and urine pH and blood bicarbonate concentration \([\text{HCO}_3^-]\)), blood lactate concentration \([\text{La}^-]\), gastrointestinal symptoms, and rating of perceived exertion (RPE).

Methods: In a double-blind, crossover study, 8 well-trained rowers performed 2 baseline tests and 4 × 2,000-m rowing-ergometer tests after ingesting 6 mg/kg caffeine, 0.3 g/kg body mass (BM) sodium bicarbonate, both supplements combined, or a placebo. Capillary blood samples were collected at preingestion, pretest, and posttest time points. Pairwise comparisons were made between protocols, and differences were interpreted in relation to the likelihood of exceeding the smallest-worthwhile-change thresholds for each variable. A likelihood of >75% was considered a substantial change.

Results: Caffeine supplementation elicited a substantial improvement in 2,000-m mean power, with mean (± SD) values of 354 ± 67 W vs. placebo with 346 ± 61 W. Pretest \([\text{HCO}_3^-]\) reached 29.2 ± 2.9 mmol/L with caffeine + bicarbonate and 29.1 ± 1.9 mmol/L with bicarbonate. There were substantial increases in pretest \([\text{HCO}_3^-]\) and pH and posttest urine pH after bicarbonate and caffeine + bicarbonate supplementation compared with placebo, but unclear performance effects.

Conclusions: Rowers’ performance in 2,000-m efforts can improve by ~2% with 6 mg/kg BM caffeine supplementation. When caffeine is combined with sodium bicarbonate, gastrointestinal symptoms may prevent performance enhancement, so further investigation of ingestion protocols that minimize side effects is required.

Keywords: blood pH, buffering, blood lactate, competition

A 2,000-m rowing event requires 6- to 8-min efforts at a high percentage of \(\text{VO}_{2\text{max}}\) (Hagerman, Connors, Gault, Hagerman, & Polinski, 1978), and postrace blood lactate concentration \([\text{La}^-]\) can reach 15–17 mmol/L (Hahn, 1989). Given these physiological demands, rowers could benefit from nutritional ergogenic aids that may improve both endurance- and high-intensity-exercise performance.

Sodium bicarbonate loading can improve performance in high-intensity anaerobic exercise of <10 min duration (Burke & Pyne, 2007; Matson & Tran, 1993; McNaughton, Siegler, & Midgley, 2008; Requena, Zabala, Padial, & Feriche, 2005). Preexercise sodium bicarbonate ingestion increases blood bicarbonate concentration \([\text{HCO}_3^-]\) and pH (Matson & Tran, 1993), and it has been suggested that induced alkalosis before exercise can offset fatigue when pH decrement during exercise is delayed (Gledhill, 1984). Investigations of sodium bicarbonate supplementation’s effects on rowing performance have yielded equivocal results. McNaughton and Cedaro (1991) reported that in a 6-min rowing-ergometer test that simulated the demands of on-water racing, significantly greater distance was covered after ingestion of 0.3 g/kg body mass (BM) sodium bicarbonate. Conversely, with a similar bicarbonate dose and 6-min ergometer test, Brien and McKenzie (1989) found no significant differences in work outputs with bicarbonate compared with placebo.

Caffeine supplementation can improve short-term (5–10 min) endurance performance (Jackman, Wendling, Friars, & Graham, 1996; Wiles, Bird, & Hopkins, 1992) via enhanced voluntary muscle activation (Ferré, 2008; Kalmar, 2005), reduced rating of perceived exertion (RPE) and pain perception during exercise (Ganio, Klau, Casa, Armstrong, & Maresh, 2009; Tarnopolsky, 2008), and antagonism of adenosine receptors (Graham, Battram, Dela, El-Sohemy, & Thong, 2008; Keisler & Armsey, 2006; McCartney, Heigenhauser, & Jones, 1983). Performance enhancement with caffeine can also reduce postexercise RPE (Doherty & Smith, 2005) and increase posttest blood \([\text{La}^-]\) (Anselme, Collomp, Mercier, Ahmaldi, & Prefaut, 1992; Bell, Jacobs, & Zamecnik, 1998). There have been conflicting outcomes to investigations of ingestion of 6 mg/kg caffeine and rowing performance. Previously, 1–2% improvements in well-trained male and female rowers were demonstrated.
(Anderson et al., 2000), but more recently only trivial performance differences between caffeine and placebo trials (Skinner, Jenkins, Coombes, Taaffe, & Leveritt, 2010) were found.

Given the potential for improved rowing performance with caffeine and sodium bicarbonate supplementation, combining the two ergogenic aids may provide an additive benefit. In the only investigation combining these two agents, no significant differences in simulated 200-m swim races were found between placebo and caffeine, sodium bicarbonate, and their combination (Pruscinato, Ross, Gregory, Savage, & Planagan, 2008). Further investigation of the combination of caffeine and sodium bicarbonate using a different sport-specific test (2,000-m rowing efforts) is warranted, because athletes do combine the two ergogenic aids for use in competition (Burke, 2008) and effects on rowing efforts separated by 48 hr (as required in a regatta) have not been investigated in this context. Furthermore, there is disagreement in the published literature as to the effects on rowing performance of sodium bicarbonate (Brien & McKenzie, 1989; McNaughton & Cedaro, 1991) and caffeine (Anderson et al., 2000; Bruce et al., 2000; Skinner et al., 2010).

Therefore, the primary purpose of this investigation was to determine the performance effects of sodium bicarbonate, caffeine, and their combination on 2,000-m rowing efforts. The secondary purpose was to investigate induced alkalosis and fatigue development through the measurement of blood [HCO₃⁻], [La⁻], and pH and RPE. Specifically, we hypothesized that (a) mean power in 2,000-m rowing-ergometer efforts would substantially improve with 6 mg/kg BM caffeine and 0.3 g/kg BM sodium bicarbonate and when both agents were combined (b) blood [HCO₃⁻] and pH after supplementation in the bicarbonate and caffeine + bicarbonate conditions would be substantially greater than in either the caffeine or placebo condition.

Methods

Subjects

Eight well-trained rowers participated in this study (6 men and 2 women, with M ± SD personal-best 2,000-m ergometer times of 6:24.6 min:± 12.9 s for men and 6:57.0 ± 2.1 s for women and body mass 82.2 ± 12.2 kg for men and 77.5 ± 6.4 kg for women). All subjects had previously competed at the Australian Rowing Championships, and 6 were scholarship holders at the Western Australian Institute of Sport. All were experienced at performing 2,000-m rowing-ergometer tests. Written informed consent was obtained from each participant, and prior approval for the protocol was granted by the University of Western Australia ethics committee.

Experimental Overview

Subjects completed 6 × 2,000-m rowing-ergometer tests including two baseline and four experimental trials (sodium bicarbonate, caffeine, sodium bicarbonate + caffeine, and placebo) over a 3-week period. A crossover design was employed, and double-blinded treatments were administered in a semicounterbalanced fashion. Testing was completed in two cohorts, the first cohort (n = 6) at the Canning Bridge Rowing Centre, Perth, Western Australia, and the second cohort (n = 2) at the Australian National University, Canberra, Australian Capital Territory. Testing was conducted over a 20-day period; the first baseline test commenced on Day 1, and two experimental trials were subsequently performed, with 48 hr between trials to replicate the timing and physical demands of consecutive races in a rowing regatta, as has been done in several recent investigations (Slater, Rice, Sharp, Jenkins, & Hahn, 2007; Slater et al., 2005; Slater, Rice, Tanner, Sharpe, Gore, et al., 2006; Slater, Rice, Tanner, Sharpe, Jenkins, & Hahn, 2006). Participants then trained normally and testing recommenced on Day 15, with baseline and experimental tests again separated by 48 hr. The two baseline tests (on Days 1 and 15) were performed to quantify the performance effects of differences in training status that may have occurred throughout the 20-day testing period.

Dietary Standardization and Training

Subjects recorded all food and fluid consumed (including details of the volume, type, and mass) and all training (type, duration, and intensity of each session) performed for the 24 hr before their first baseline test, and they replicated their dietary intake and training pattern before each subsequent test. Subjects abstained from caffeine for the 48 hr before each test and were provided with a comprehensive list of caffeine-containing foods, beverages, and medicines, all of which they needed to avoid maintaining caffeine abstinence.

Supplement Ingestion

Subjects arrived at each testing session after an overnight fast. For all experimental conditions (sodium bicarbonate, caffeine, sodium bicarbonate + caffeine, and placebo) participants were issued two supplement doses. The first dose was ingested 90 min before the performance test (at ~90 min) and was either 0.3 g/kg BM sodium bicarbonate powder encased in gelatin capsules (PPCA, NSW, Australia) or an equal number of placebo capsules containing corn flour (White Wings foods, NSW, Australia). The second dose was ingested 30 min before the performance test (at ~30 min) and was either 6 mg/kg caffeine (No-Doz, Key Pharmaceuticals Pty. Ltd., NSW, Australia) in gelatin capsules or an equal number of placebo capsules containing glucose (Glucodin, NSW, Australia). In the sodium bicarbonate condition, sodium bicarbonate was taken at ~90 min and then placebo at ~30 min, for the caffeine condition participants ingested placebo at ~90 min and caffeine at ~30 min, in the caffeine + sodium bicarbonate condition sodium bicarbonate was taken at ~90 min and then caffeine at ~30 min, and placebo was
ingested at –90 min and –30 min in the placebo condition. All capsules were taken with 600 ml water.

**Experimental Trials**

An overview of testing sessions is shown in Figure 1. All sessions commenced at 6 a.m., and subjects performed each test on the same type of rowing ergometer (Concept IID, Concept, Vermont, USA), at the same time as at least 1 other subject to simulate racing conditions. Drag factor on the ergometer was set according to the Rowing Australia standards for subjects’ sex, age, and lightweight or heavyweight classification. Subjects completed a 7-min standardized warm-up adapted from a previously published protocol (Slater et al., 2005; 4 min at 70% of maximal power output, followed by a 3-min period that included passive rest and $2 \times 10$ maximal strokes) before they commenced the 2,000-m test. Stroke rate, mean power, and time elapsed for each 500-m split were recorded. Immediately after completing each performance test, subjects indicated on a scale of 6 to 20 (Borg, 1970) their RPE for the test.

**Capillary Blood Sampling and Analysis**

Capillary blood samples were taken before supplement ingestion, before warm-up, and 2 min after completion of the performance test. Before capillary blood sampling, we applied a hyperemic ointment (Finalgon, Boehringer Ingelheim, NSW, Australia) to the fingertip to increase blood flow. The ointment was then removed and the fingertip was pierced with a sterile 2.0-mm retractable lancet (Medlance, Ozorkow, Poland). The first drop of blood was removed and then 100 μl blood was collected in a glass capillary tube (Radiometer, Copenhagen, Denmark). For the first cohort, samples were stored on ice and then analyzed for [HCO$_3$-], [La–], and pH using a blood-gas analyzer (Radiometer ABL 725, Copenhagen, Denmark). For the second cohort, blood samples were immediately analyzed using a portable blood-gas analyzer (iSTAT, Abbott, IL, USA) for pH and bicarbonate concentration, and a second, 20-μl sample was collected and immediately analyzed at the pretest and posttest time points using a portable blood lactate analyzer (Lactate Pro, Arkray, Kyoto, Japan).

**Urine pH**

Subjects collected a urine sample immediately after waking (after an overnight fast and before eating or drinking) and as soon as possible after completing each 2,000-m test. Samples were analyzed using a pH meter (CyberScan pH1500, Eutech Instruments, Singapore).

**Posttest Questionnaire**

After each performance test, experimenters recorded verbal responses when subjects were asked which treatment they thought they had received, reasons for their guess, details of any side effects, and when symptoms were experienced (before, during, or after the 2,000-m test).

**Statistical Analysis**

A power analysis was performed to determine the sample size necessary for adequate precision with 90% confidence limits based on the smallest worthwhile change in performance (Hopkins, Marshall, Batterham, & Hanin, 2009) and indicated that 7 subjects would be required. Similar investigations have used 8–10 subjects (Anderson et al., 2000; Bruce et al., 2000; Skinner et al., 2010). Blood [HCO$_3$-], pH, and [La–] at the preingestion, pretest, and posttest time points; performance data; and RPE values were entered into a spreadsheet: http://www.sportsci.org/resource/stats/xPostOnlyCrossover.xls. To eliminate confounding effects of differences in training status across a 20-day period, change scores from baseline (the mean of the baseline tests conducted on Days 1 and 15) were used when making comparisons between conditions for performance data. After this baseline adjustment for all four conditions, comparisons were made between placebo and sodium bicarbonate, placebo and caffeine, and placebo and caffeine + sodium bicarbonate. Absolute values were used for physiological variables and RPE. Pairwise comparisons were made between conditions to determine the probability of differences greater than the smallest worthwhile change for each variable. The likelihoods were set as <1%—almost certainly not; <5%—very unlikely; <25%—unlikely, probably not; 25–75%—possibly, possibly not; >75%—likely, probably; >95%—very likely; and >99%—almost
certainly. A probability of >75% was interpreted as a substantial difference. Results were deemed unclear if the likelihoods of small positive and negative effects were both <75%.

Results

Performance

Performance test results are summarized in Table 1. There was a substantial increase in average power change scores with caffeine supplementation in comparison with placebo. There was also a 74% probability of differences between caffeine and placebo for the performance time change scores, which is very close to the substantial-change threshold of 75%. There were unclear differences between placebo and the bicarbonate and caffeine + bicarbonate conditions. The greatest power output was observed in the first 500 m in the caffeine condition (391 ± 72 W), which was substantially greater than placebo for the corresponding section (367 ± 65 W) of the 2,000-m effort (Figure 2).

Table 1 Rowing-Ergometer 2,000-m Performance (M ± SD, N = 8)

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Sodium bicarbonate + caffeine</th>
<th>Sodium bicarbonate</th>
<th>Caffeine</th>
<th>Placebo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average power output (W)</td>
<td>344 ± 59</td>
<td>352 ± 63</td>
<td>348 ± 67</td>
<td>354 ± 67</td>
<td>346 ± 61</td>
</tr>
<tr>
<td>Time (min:s)</td>
<td>6:43.2 ± 20.9</td>
<td>6:42.6 ± 21.6</td>
<td>6:44.4 ± 23.4</td>
<td>6:40.8 ± 22.5</td>
<td>6:43.8 ± 23.4</td>
</tr>
<tr>
<td>Average stroke rate (per minute)</td>
<td>31 ± 2</td>
<td>32 ± 1</td>
<td>32 ± 1</td>
<td>31 ± 1</td>
<td>32 ± 1</td>
</tr>
<tr>
<td>Peak heart rate (beats/min)</td>
<td>189 ± 5</td>
<td>190 ± 10</td>
<td>187 ± 9</td>
<td>185 ± 9</td>
<td>188 ± 9</td>
</tr>
<tr>
<td>Posttest blood lactate concentration</td>
<td>14.1 ± 2.0</td>
<td>18.7 ± 3.2</td>
<td>16.2 ± 3.3</td>
<td>15.6 ± 3.5</td>
<td>14.6 ± 3.2</td>
</tr>
<tr>
<td>Rating of perceived exertion (6–20)</td>
<td>18 ± 2</td>
<td>17 ± 2</td>
<td>18 ± 2</td>
<td>18 ± 2</td>
<td>18 ± 2</td>
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Perceived Exertion

There was a substantial 1-unit reduction in RPE after caffeine and bicarbonate supplementation in comparison with placebo. Differences between all other treatment conditions and placebo were unclear (Table 1).

Induced Alkalosis

There were substantial increases in blood [HCO₃⁻] after caffeine and bicarbonate supplementation (29.2 ± 2.9 mmol/L) and bicarbonate loading (29.1 ± 1.9 mmol/L) in comparison with placebo (24.4 ± 1.1 mmol/L). Similarly, the peak postsupplementation pH values observed in the caffeine + bicarbonate (7.48 ± 0.02) and bicarbonate (7.46 ± 0.02) conditions were both substantially higher than with placebo (7.40 ± 0.03; Figure 3).

Blood [La⁻]

Posttest blood [La⁻] in the caffeine + bicarbonate condition was 4.2 ± 2.7 mmol/L higher than in the placebo condition (Table 1). There were unclear differences

Figure 2 — Ergometer power output (M ± SD) for each 500-m section of the 2,000-m time trials (N = 8).
Discussion

This is the first systematic investigation of the effects of caffeine, sodium bicarbonate, and their combination on performance in a simulated rowing regatta and the associated acid-base disturbance indicated by blood [HCO$_3^-$], [La$^-$], and pH. We found a substantial improvement in 2,000-m performance after 6 mg/kg caffeine administration. Despite substantial pretest alkalosis in the bicarbonate and caffeine + bicarbonate conditions, there were unclear performance effects in both conditions.

A performance enhancement of ~2% after 6 mg/kg BM caffeine is consistent with previous reports on rowing performance with competitive male (Bruce et al., 2000) and female rowers (Anderson et al., 2000) but contrasts with the recent report of no significant differences in 2,000-m rowing performance after caffeine and placebo (Skinner et al., 2010), which could be explained by compromised caffeine absorption caused by coinestion of a pretest meal (Skinner et al., 2010). In the current study and earlier investigations (Anderson et al., 2000; Bruce et al., 2000) subjects completed each trial after an overnight fast. The timing of coinestioned meals could be detrimental to caffeine absorption (Skinner et al., 2010), but for some athletes preevent meals are an important part of competition preparation (Burke, 2008), and racing under fasted conditions could hinder performance. To increase the external validity of future studies, effects of standardized pretest meals on caffeine absorption and subsequent performance should be systematically investigated.

The ergogenic effect of caffeine demonstrated in the current investigation and subjective data collected from our subjects provide some support for documented effects of caffeine on the central nervous system. Caffeine ingestion can increase perceptions of wakefulness and alertness (Ferré, 2008; Kalmar, 2005; Tarnopolsky, 2008). Subjects in this study reported feeling more alert, hyperactive, and on edge after caffeine ingestion, responses that are consistent with the perception of increased wakefulness. Furthermore, 6 of our 8 subjects correctly noted when they had been assigned the caffeine condition, suggesting that they experienced noticeable changes after supplementation. Although increased alertness with caffeine ingestion is not a direct mechanism for performance enhancement (Graham et al., 2008; Tarnopolsky, 2008), observed effects in our subjects do provide evidence of central nervous system stimulation, which can more directly enhance performance via other means such as reduced pain perception and RPE (Ganio et al., 2009; Tarnopolsky, 2008). Performance in our subjects after caffeine ingestion substantially improved in comparison with placebo, but RPE scores for the two conditions were very similar. Therefore, if equal power outputs were attained for caffeine and placebo, RPE in the caffeine condition would be lower, and this could be beneficial in actual race efforts.

There was no clear performance benefit in the current investigation after ingestion of a combination of 6 mg/kg BM bicarbonate and caffeine, and 6 mg/kg BM caffeine.
caffeine and 0.3 g/kg sodium bicarbonate. This finding is consistent with the only other investigation of performance effects with the same supplement combination (Pruscino et al., 2008). Substantial blood alkalosis was induced with both studies, and in the current investigation postsupplementation [HCO₃⁻] and pH preexercise values reached 29.2 ± 2.9 and 7.48 ± 0.02 mmol/L, respectively. Furthermore, there was a substantial elevation in posttest urine pH compared with placebo in this condition, consistent with previous results (Ibanez, Pullinen, Gorostiaga, Postigo, & Mero, 1995; McKenzie, 1988; Wilkes, Gledhill, & Smyth, 1983). The lack of a performance enhancement in 2,000-m rowing time trials and repeated 200-m freestyle sprints (Pruscino et al., 2008) suggests that despite the demonstrated induced alkalosis, the increased buffering potential may have been inadequate. It has been reported that posttest blood [La⁻] can be higher than with placebo after both sodium bicarbonate (Cameron, McLay-Cooke, Brown, Gray, & Fairbairn, 2010; McNaughton & Cedaro, 1991; Wilkes et al., 1983) and caffeine administration (Anselme et al., 1992; Bell et al., 1998; Wiles et al., 1992), and in this investigation we also observed the highest posttest blood [La⁻] after caffeine + bicarbonate supplementation. The interpretation of our [La⁻] data is limited because our measurements were only taken at one posttest time point, but it is possible that intracellular acidosis during exercise could be substantially increased with caffeine + bicarbonate supplementation in comparison with the other experimental conditions and placebo. One potential explanation is that the proposed extracellular buffering action of HCO₃⁻ (Gledhill, 1984; Requena et al., 2005) could be insufficient to counteract the inhibitory effect of increased acidosis on glycolysis and muscle contraction (Johnson & Black, 1953; Sutton, Jones, & Toews, 1981). However, it has been suggested that pH decreases are not the only explanation for the onset of muscle fatigue (Cairns, 2006). Therefore, mechanisms other than the delayed onset of intramuscular acidosis have been proposed to explain enhanced performance via increased blood [HCO₃⁻], including improved K⁺ regulation, preservation of muscle-membrane excitability (Sostaric et al., 2006), and even reduction of central fatigue (Cairns, 2006).

The high incidence of side effects experienced by our subjects may explain the lack of performance enhancement after bicarbonate in isolation and when combined with caffeine. All subjects in our investigation reported gastrointestinal side effects (including nausea, vomiting, and stomach pain). Potentially, experiencing gastrointestinal symptoms negates or confounds the ergogenic effect of sodium bicarbonate (Cameron et al., 2010), especially if side effects are experienced before or during a maximal effort, as was the case with participants in this investigation. Side effects associated with bicarbonate ingestion may be reduced or alleviated by the use of different supplementation protocols. Previously, work in our own laboratory has demonstrated that the incidence of gastrointestinal symptoms experienced with sodium bicarbonate supplementation is substantially reduced when the ingestion protocol incorporates a preevent meal (Carr, Slater, Gore, Dawson, & Burke, 2011). Although the aforementioned investigation examined ingestion protocols with no subsequent performance test, future investigations should investigate pretest meals coingested with bicarbonate and effects on gastrointestinal symptoms in the context of a performance study. Several investigations have documented side effects after bicarbonate supplementation (Cameron et al., 2010; Stephens, McKenzie, Canny, Snow, & McConnel, 2002; Van Montfoort, Van Dieren, Hopkins, & Shearman, 2004), and future investigations should quantify specific symptoms so that the impact of gastrointestinal symptoms on performance can be quantified.

Conclusion

Performance in well-trained rowers can improve by ~2% with 6 mg/kg caffeine supplementation. However, when caffeine is combined with sodium bicarbonate supplements, gastrointestinal symptoms during exercise may prevent an enhancement in 2,000-m rowing performance, despite enhanced blood buffering potential via induced alkalosis. Alterations to both the caffeine and sodium bicarbonate ingestion protocols in future investigations could elucidate supplementation strategies that alleviate deleterious side effects and facilitate enhancements in rowing performance.

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